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Development and Evaluation of Low Cost Game-Based Balance Rehabilitation Tool Using the Microsoft Kinect Sensor

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Abstract— The use of the commercial video games as rehabilitation tools, such as the Nintendo WiiFit, has recently gained much interest in the physical therapy arena. Motion tracking controllers such as the Nintendo Wiimote are not sensitive enough to accurately measure performance in all components of balance. Additionally, users can figure out how to "cheat" inaccurate trackers by performing minimal movement (e.g. wrist twisting a Wiimote instead of a full arm swing). Physical rehabilitation requires accurate and appropriate tracking and feedback of performance. To this end, we are developing applications that leverage recent advances in commercial video game technology to provide full-body control of animated virtual characters. A key component of our approach is the use of newly available low cost depth sensing camera technology that provides markerless full-body tracking on a conventional PC. The aim of this research was to develop and assess an interactive game-based rehabilitation tool for balance training of adults with neurological injury.

I. INTRODUCTION

THE primary goal of rehabilitation following spinal cord injury (SCI) and traumatic brain injury (TBI) is to promote a maximal level of recovery of function while pushing the confines of physical, emotional, and cognitive impairments. Full reintegration into the community and vocation are the ultimate goals. Individuals with access to intensive multidisciplinary rehabilitation programs demonstrate earlier and faster functional gains on functional independence measures and shorter hospital stays [1,2]. Given the vast array of impairments associated with Stroke, SCI and TBI, the rehabilitation community is challenged with providing high quality evaluations, and interventions at a reasonably affordable price.

The estimated number of people in the United States with SCI is 300,000 with approximately 12,000 new cases each year [3,4]. The average estimated lifetime costs directly attributable to SCI vary between 3-7 million, depending on severity of injury. Of the three million Americans who suffer nonfatal TBIs each year, it is estimated that 90,000 will be left with lasting disability [2,5]. The CDC estimates that at least 5.3 million Americans currently have a long-term or lifelong need for help to perform activities of daily living as a result of a TBI [4,6]. Direct medical costs and indirect costs such as lost productivity are estimated at 60 billion in the United States and the lifetime costs for one person surviving a severe TBI can reach 4 million [4,7].

Stroke incidence, new or recurrent, is approximately 800,000 every year [8]. As the population ages this number is expected to rise. The neurological impairments that can result from a stroke include hemiparesis, coordination difficulties, apraxia, and impairments in postural control [9]. All of these, especially impairments in postural control, can affect a person's balance and mobility in everyday activities. For community dwelling adults with stroke, incidence of falls range from 23 to 50% [10]. Immediately following discharge from rehabilitation services, this rate is much higher [11].

The most effective means to improve neuroplasticity and subsequent recovery of motor function following injury or disease to the nervous system is through intense skillful practice [12,13]. Unfortunately, the level of intensity required to induce neuroplastic changes is far more than any one therapist could direct. With increasing medical costs, reduction in paid benefits, longer waiting periods, and a shortage of rehabilitation specialists, individuals with SCI and TBI are in need of low-cost quality home-based sensorimotor rehabilitation. Substitutes and adjuncts to contemporary therapies are being developed that incorporate Virtual Reality (VR) and video games for rehabilitation. These games can uniquely address a wide range of clinical topics of concern and research questions. Virtual Reality technology can assess and augment motor rehabilitation under a range of stimulus conditions that are objective and well controlled. Whereas, real world objective, reliable and valid measures of these conditions is often difficult.

The use of the commercial video games as rehabilitation tools, such as the Nintendo WiiFit, has recently gained much interest in the physical therapy arena. Whilst anecdotal evidence suggests that games have the potential to be powerful motivators for engaging in physical activity, limited published research exists on the feasibility and effectiveness of leveraging the motion sensing capabilities of commercially available gaming systems for rehabilitation [12,13,14,15,16]. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation following stroke and spinal cord injury [14,15,16,17]. However, currently available commercial games may not be suitable for the controlled, focused

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exercise required for therapy. Usability studies have found that some commercially available games provide negative auditory and visual feedback during therapy tasks [13,18]. These observations demonstrate the importance designing games specifically for rehabilitation, a design approach that has been investigated by several recent researchers [18,19,20]. However, the limitations of the commercial video game motion sensing technology have been a challenge to achieving this goal. Motion tracking controllers such as the Nintendo Wiimote are not sensitive enough to accurately measure performance in all components of balance. Additionally, users can figure out how to "cheat" inaccurate trackers by performing minimal movement (e.g. wrist twisting a Wiimote instead of a full arm swing). Physical rehabilitation requires accurate and appropriate tracking and feedback of performance. To this end, we are developing applications that leverage recent advances in commercial video game technology to provide full-body control of animated virtual characters. A key component of our approach is the use of newly available low cost depth sensing camera technology that provides markerless full-body tracking on a conventional PC. This allows the user to puppet a virtual character on screen that directly represents their movements and pose in the real world. Using low cost depth sensing cameras and a flexible software framework, individuals can interact with game-based rehabilitation tools that are tailored to their individual therapy goals. Not only does our approach sense full-body motion without markers, our application allows the individual and clinician to make choices about the experience and record more meaningful performance data.

II. METHOD

A. Hardware

This revolutionary game platform uses an infrared depth-sensing camera (produced by an Israeli company, PrimeSense) to capture users' full body movement in 3D space for interaction within game activities. This system does not require the user to hold an interface device or move on a pad as the source of interaction within the game. Instead, the user's body is the game controller operating in 3D space and multiple users can be tracked. The camera connects to PC using USB. The technology behind PrimeSense is used in the commercially available Microsoft Kinect sensor (Fig 1). In the current prototype, the Microsoft Kinect sensor is connected to PC through USB.

Fig 1. Microsoft Kinect sensor

B. Software

Using the Unity3D engine, we developed a game-based rehabilitation task designed to elicit specific therapeutic motions when controlling a virtual avatar in pursuit of the in-game goal. In the early prototype stage of this game, the player travels through a mine, collects gems, and places them in a cart (Fig 2). Following an initial calibration for arm length and limit of stability, the gems are placed at a distance tailored to the player's level of ability (limit of stability), ensuring that achievement of the game goal requires performing motions that are beneficial for rehabilitation. The features of this game-based application also allow the player or clinician to make choices about the task (e.g. gems will light up in different patterns or the player must remember a specific pattern of gems that light up in a row) and about how the patient is represented on the screen (as a full stick figure or as just two hands on the screen).

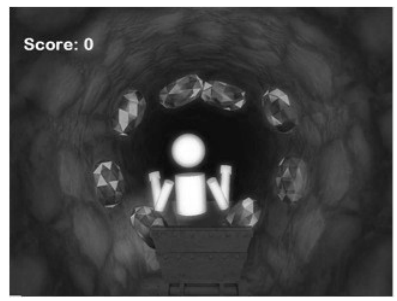

Fig. 2 Screenshot of game

C. Prototype development

The current game-based rehabilitation tool was conceived and developed through a series of stakeholder interviews with clinicians, researchers and key patient populations to explore the need for and key development features of a computer based game for balance exercises. All stakeholder groups supported the concept and provided specific needs/requirements including the option to change the level and tasks for different patients, the ability to record data from the interaction and a motivating and fun game that encourages the appropriate performance of the exercises. Following initial development of the game prototype, preliminary testing took place in an informal setting with a sample of ten people with and without neurological conditions. These participants provided informal feedback about the game prototype. The participants were encouraged to provide feedback about the technical elements of the game (ie. background, objects, game play). The comments and feedback from these informal discussions were compiled and reviewed by the development team. Feedback was incorporated into the design where relevant and appropriate changes were made to the game prototype.

D. Prototype evaluation

To evaluate the preliminary usability of the rehabilitation game, participants who have survived stroke, TBI or SCI were recruited from two Rehabilitation Clinics in California. Participants were asked to perform the balance training exercise. The exercise encourages the participant to perform a game-based task by controlling their virtual avatar using the Microsoft Kinect depth-sensing camera. The researcher observed participants playing the game, taking notes for discussion following the session. Following the interaction, the participant was asked to complete post-study interview questions about their experience. Game performance and researcher observations were analyzed.

III. Results

Twenty participants (17 male, 4 female) with balance issues related to Stroke (n = 10), TBI (n = 3) and SCI (n = 7) were recruited to take part in the study. Ten clinicians (4 male, 6 female) also provided feedback on the application. The majority of participants had limited experience with video games in the clinic or home. Seven participants had previous experience with video games in the clinic and four participants had experience with video games in the home (Playstation, Wii, Wii Fit, Xbox). Three clinicians had experience with video games in the clinic and seven clinicians had some experience with video games in the home setting (Playstation, Wii, Wii Fit, Xbox).

Of the 20 participants recruited into the study, eight of the participants could not perform the position required for the camera to track them. Limitations in range of motion of the impaired upper limb prevented these participants from being able to perform and maintain the required position. The final 12 participants required assistance from a clinician to provide active assisted or passive shoulder flexion, abduction and external rotation of the impaired upper limb in order to perform and maintain the calibration pose.

Participants, both in a wheelchair and in standing, were able to complete the game-based tasks with assistance where required. During game play, participants tended to need more instruction initially at the start of the game. However, following the completion of one to three sets of the jewels, participants appeared to gain sufficient understanding of the task to perform without instructions. Ten of the participants had particular difficulty with perception of the depth of the jewels within the 3D space.

The structured interview questions provided qualitative data about user perceptions of the technology, motivation to use the technology and specific feedback on potential changes to improve the existing system. Participants provided the research team with suggestions for improving the instructions for the game and game play elements (such as scoring and sound effects).

A number of participants suggested more instruction would be helpful, including a tutorial at the beginning of the game and more time to practice and familiarize themselves with the new technology. Seven participants had particular difficulty with the visual representation of the gems lighting up and requested that the gems light up in a more obvious way. The majority of participants were happy with the theme (six participants had no comment or preference on theme), three participants wanted more of a story. Other themes suggested included sporting (soccer, baseball), shooting, shopping, and picking up and moving objects such as fruit.

Overall, participants reported the game to be challenging and fun. Specific comments related to level of challenge and enjoyment were:

"I think it was more exciting than working muscles just in the gym"

"You really made me work hard!"

"I enjoyed it but it made me work really hard to get all those gems"

"I felt like I was really slow at first but once I got the hang of it I had fun"

"It was good. I want to play it again."

"When I was collecting the gems I wasn't thinking about how hard I was working"

Clinicians stated they were excited about the use of this type of technology within the clinical setting. The option to calibrate the system for different individuals, vary the task within the game and change the avatar view from skeleton to hand only, providing less feedback, therefore increasing the level of challenge for the patient appealed to the clinicians. Clinicians also provided a range of ideas for further development of specific tasks and discussed the type and presentation of data they would prefer to collect from the game.

IV. Discussion

The release of the PrimeSense and Microsoft Kinect 3D depth sensing technology provides a low-cost option to capture users' full body movement in 3D space for interaction within game activities without the need for the user to hold an interface device. Whilst this provides developers, researchers and clinicians with access to low-cost tracking technologies that can be more easily implemented within tailor made software programs, accessibility of the system is still limited to people who can actively or passively perform the calibration pose. At this point in time, people with disabilities that limit them from being able to perform the calibration pose, cannot interact with the system.

Calibration is an important piece of tailoring game-based applications for individuals with varying levels of ability. The current OpenNI software technology will track the user only once a calibration pose has been performed. The calibration pose requires the user to stand or sit facing the camera, place the arms out to the side with the shoulder in external rotation and at 90 degrees abduction and the elbow at 90 degrees of flexion (Fig 3). The importance of user-centered design is highlighted when issues such as calibration are exposed earlier in the development process to allow for changes that will make the system more accessible to the key stakeholders that will be using the system.

Despite difficulties with calibration, initial user feedback supported the use of game-based rehabilitation and provided a range of suggestions for system improvement. The suggestions and comments are currently being themed and will be discussed, evaluated and prioritized by the research and development team.

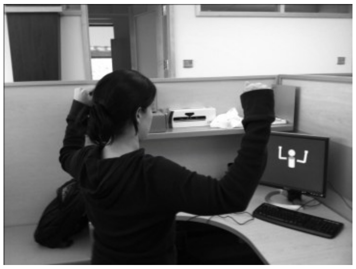

Fig 3. Position required for camera to track user

Feedback from clinicians was supportive of the development of a flexible system that provides the option to tailor the game-based task to the user. Clinicians liked the option to change the avatar view from skeleton to hand only views. Changing the appearance of the avatar, whilst still tracking the skeleton, allows the clinician to remove visual feedback provided to the patient. Removing this external feedback, encourages the patient to rely on internal sensory-perceptual information to control their movement [17]. Providing less visual feedback about the player's movement increases the level of difficulty and this was supported in the participant's unanimous choice of the skeleton avatar as the easiest to understand and use. However, the use of the hands only avatar representation is important progression in therapy guided by motor learning principles [17].

The research team have developed a Flexible Action and Articulated Skeleton Toolkit (FAAST) with a goal to make a general purpose software environment that enables many applications to quickly be modified to use depth sensing technologies projects.ict.usc.edu/mxr/faast/.

V. Limitations

This study provides a preliminary exploration into the usability of a tailored, specific game-based rehabilitation tool. The data presented in this paper was collected as part of an iterative design process of development. Therefore, the data is descriptive and the data collection process did not include quantitative questionnaire data.

VI. Conclusion

A game was developed to specifically train reaching and weight shift to improve balance in patients using the Microsoft Kinect sensor. Initial assessment of the prototype with a sample of clinicians and participants with neurological injury demonstrated that the use of this prototype has potential as a rehabilitation tool. Clinicians and patients provided valuable input and have identified a number of refinements and improvements to the system. Future directions in this research will be more formal usability testing followed by a larger feasibility trial to determine if the use of the game as a training tool improves balance outcomes. Future formal usability evaluations will include a usability/likeability questionnaire and structured interview questions in order to provide both quantitative and qualitative evaluations.

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