Music and Motion-Detection: A Game Prototype for Rehabilitation and Strengthening in the Elderly

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***Abstract*—Traditional physical therapy methods require significant time from trained medical staff, which is costly for clinics and hospitals, and often leave patients bored and unmotivated to complete their exercises. We offer a prototype for a motion-detection and music game to inspire greater engagement and adherence from patients undergoing physical therapy exercises for rehabilitation or strengthening. The game is customizable based on the patient's needs, dynamically reacts to the patient's performance in real-time, and may be used with or without the guidance of a medical professional.**

***Index Terms*—rehabilitation; music; motion-capture; motion detection; physical therapy; preventive medicine; gaming**

I. Introduction

Stroke is the number one cause of disability in adults in the US [1]. Incidence of stroke ranges from approximately 100-300 out of 100,000 people in most countries [2], and in those with ageing populations, such as Singapore, the incidence of stroke is expected to rise dramatically [3]. Stroke often results in motor impairments with postural control, coordination, and apraxia [4] that lead to difficulties performing everyday activities, and high rates of falls [5]. Caring for this population places a large burden on healthcare institutions, and despite the help of dedicated staff, compliance with prescribed physical therapy is often low, with patients describing exercises as boring and tedious [6]. In light of this global situation, there is an increasing need for self- and tele-rehabilitation systems, especially those which may be employed not only alongside, but *after* traditional rehabilitation services [7].

Technology can provide a cost-effective tool for motor rehabilitation, and motion capture-based systems can be especially efficacious for guiding exercises and tracking patients' progress. The Microsoft Kinect sensor, for example, has been used in a variety of medical applications to support motor function [8, 9, 10]. In this type of approach, it is important to note that existing (popular) video games are not ideal for motor rehabilitation; rather, games should be designed with patients' limitations and specific needs in mind for maximum therapeutic benefit [11]. Further, because motion capture systems that offer rehabilitation exercises often focus on regaining balance and strengthening of muscles, these exercises can be useful for strengthening as preventive medicine for the elderly [12]. This is useful given the ageing population of many countries [13].

Technology utilising a *music therapeutic approach* can provide an effective means of treating and supporting the well-being of patients. Moving in time (physiological entrainment) to music has been shown to aid several different disorders and conditions (e.g., Parkinson's Disease), and music therapy can be helpful for motor rehabilitation in stroke patients (especially, balance, range of motion, reaching movements) and strengthening in the elderly [14, 15, 7]. To this end, a new music and motion-detection system is described below.

In this paper, we first provide a brief overview of existing systems for motor rehabilitation that implement motion sensors (Section II), before describing our music-based prototype (Section III). We then discuss the target populations for this technology, as well as our proposed build-in evaluation methods for testing the efficacy of the game intervention (Section IV), before drawing conclusions (Section V).

II. Existing Motion based systems for rehabilitation

In recent years, motion detection sensors have become adopted by the general public. This has resulted in a handful of studies that use existing video games with sensors such as Nintendo Wii [16, 17, 18], the virtual reality device EyeToy for Sony PlayStation 2 [19], and Leap-motion [20] for physical exercises in clinical settings. These systems use *existing games*, however, and therefore cannot offer a controlled environment for therapeutic exercises. In this paper, we focus on a dedicated game, developed specifically for motor rehabilitation and strengthening.

For this project, we opted to work with the Kinect motion sensor[1], which has a depth sensor, colour camera, and four-microphones. The Microsoft SDK[2] for Kinect allows software to tap into its capabilities to provide functions such as full-body 3D motion capture with skeleton tracking and facial recognition [21]. The Kinect sensor may be a useful tool in clinical settings for evaluating movements and postural control; for example, in a study by Clark et al. [22], the Kinect system was able to reach reliability comparable to a multi-camera 3D motion system for several movements (e.g., forward and lateral reach), using tailored measurements such as "Trunc flexion angle in the sagittal/coronal plane."

Previous research has explored the use of Kinect-based systems in dedicated games and systems for rehabilitation. In

[1] www.xbox.com/en-US/kinect
[2] https://developer.microsoft.com/en-us/windows/kinect

Preprint accepted for publication in the Proceedings of the IEEE International Conference on Orange Technologies (ICOT), Singapore. Dec. 2017

Parry et al. [23]'s research on burn rehabilitation with existing video games, a study with 30 children revealed that maximal shoulder flexion, shoulder abduction, and range of elbow flexion were significantly greater while playing with Kinect rather than Playstation Move. Lange et al. [24] developed a Kinect game specifically for stoke patients to train reaching and weight shift for balance improvement. In their game, the player travels trough a mine and must remember a particular order of gems collected. A study including 20 participants with balance impairments due to stroke shows an overall increase in patients' motivation for the exercises. In a post-study survey, patients describe the system as more "fun and challenging" than traditional physiotherapy exercises. Eight of the participants were not, however, able to use the system due to their specific limit of motion, a problem that we address in the current system by including a calibration phase.

Chang et al. [6] used Kinect in an experiment with two motor impaired teenage patients with insufficient muscle endurance. They investigate whether a Kinect based system could motivate the patients to conduct their exercises. The system allows users to control a singing whale that is more responsive when patients perform movements correctly. In an ABAB study, with 'A' being traditional exercises and 'B' with the system, both patients showed more correct movements when using the Kinect system. In a follow up study, Chang et al. [8] examined one patient with cerebral palsy (including inflexibility of upper and lower limb movements), and another with muscle atrophy. Both had insufficient muscle endurance. The study tested three movements: raising the hand; bringing the hand forward; and moving the hand to the mouth. In an ABAB study, both patients performed considerably better with the aid of the Kinect system: they were more highly motivated and their exercise performance improved (i.e., they performed the full motion rather than quitting prematurely). For a more complete overview of existing rehabilitation systems that use Kinect, the reader is referred to [9].

While the systems described above implement a game-based approach to motivate patients to complete their exercises, there are a few systems that specifically incorporate music. Music is a complex, multi-modal domain that implicates many cognitive resources, and has the added advantage of being able to improve mental health (e.g., reduce anxiety and depression in patients) [25]. The benefits of integrating music have become especially clear in the field of neurologic music therapy (NMT), which includes aspects such as auditory motor synchronization whereby the participant's movements synchronise with a musical rhythm [26]. This has been explored in systems that enable Parkinson's patients to walk more fluidly through music listening [14]. In rehabilitation settings, the approach may be useful to stimulate patients to continue engaging in exercises to the beat of a musical track. van Wijck et al. [7]'s prototype rehabilitation game uses a Wii sensor attached to a patient's arm to let him/her move in sync with the beat, but this system has not yet been evaluated in a clinical setting. The glove developed by Friedman et al. [15] is used with the game Frets on Fire, which allows patients to play music (similar to the popular game 'Guitar hero'). The game is adapted to fit patients' individual abilities, and a study with 10 patients reported a positive effect on motivation for physical exercises.

In this project, we intend to create a dedicated suite of applications that focus on specific exercises for rehabilitation and strengthening. Unlike some existing approaches, the game will be created specifically for this purpose, and include a monitoring component to track the patient's progress across sessions. It will also include a calibration phase so that the difficulty of the exercise is tailored to the individual abilities of the patient, as well as dynamic feedback about the patient's movements. Finally, the game incorporates music to further motivate patients and tap into the healing aspects of music mentioned above.

III. Prototype system description

A. Overview

We present a prototype game that uses music-based tasks to motivate participants to perform particular physical exercises for rehabilitation and strengthening. To ensure the system is suitable for elderly users, the game employs a simple user interface, straight-forward task, and will incorporate appropriate music for this population. In addition to improving engagement and adherence, we also aim to improve upon existing systems by creating games that are customizable (for specific exercises, and calibration for patients with varying motor abilities/constraints), and that are able to provide real-time feedback regarding performance.

In order to make the game customizable to the patient's particular needs and current abilities, the patient or therapist first selects an exercise from a drop-down menu on the screen. Currently, options are available for adduction/abduction and flexion/extension exercises, and more exercise options are being developed. Once a type of exercise is selected, there is a calibration phase, during which the participant is asked to lift his or her arm as high as possible (and then back to a lowered position at their side). Based on the patient's movements, the initial difficulty level (i.e., range of motion) is set. The range of motion of the exercise is displayed on the screen via an upper and lower sphere, which are placed next to the patient-controlled avatar. The user's task, once the music begins playing, is to move his or her arm (without bending the elbow) up and down to the beat of the music, while maintaining an upright posture (stroke patients often make compensatory movements that are not productive for rehabilitation). On each beat, one of the two spheres becomes alternatingly illuminated to mark musical time, and the outstretched arm should be raised (or lowered, accordingly) to the height of the illuminated sphere. A small horizontal bar moves between the two spheres at the level of the user's hand for ease of viewing and interaction. A screenshot of the game prototype is displayed in Figure 1. Again, the lower sphere is set at the height of the patient's hand at resting position, and the higher sphere is set to the maximum hand position during calibration, in order to customize the system based on the participant's movement capabilities. The patient's overall

Fig. 1. Screenshot of game prototype while feedback is being provided in real time.

score is reported at the top of the screen, and when a beat is missed, the sphere turns red and the user's score decreases (this is displayed as a running percentage of correct movements to the beat).

B. Real-time feedback

An important component of the system is that it is able to provide feedback in real-time, making it especially useful for participants who do not have a caregiver or therapist nearby to oversee their activities. Before the game begins, the participant is instructed to lift his/her affected arm without bending the elbow, a common exercise in a rehabilitation settings (see [27], Table 1). If the participant forgets to keep his/her arm straight during the game, a reminder message appears, as shown in Figure 1. Another common problem noted by physical therapists is that patients often use counter-productive compensatory movements post-stroke to accommodate their impairment [1]. For this reason, a feedback message is displayed when the user makes compensatory movements with the non-impaired limb, or when his/her balance shifts (e.g., if the height of one shoulder moves significantly below the height of the other) while attempting the functional task. This kind of dynamic feedback during game play helps to ensure that patients make appropriate movements to aid their recovery or strengthening process.

C. Implementation

The prototype system was implemented in Unity (C♯) with the Kinect SDK interface to control the Kinect v2 for XBox One. In order to obtain the correct timing of beats in each musical piece, beat tracking was performed through Sonic Visualiser [28] with the BeatRoot plugin [29]. Manual corrections were made to obtain more precise results.

For evaluation, we use OpenSIM [30], as described in the next section. A online backend system will track individual patients' scores, movement data, and OpenSIM measurements, a valuable resource for tele-rehabilitation.

IV. Target population and proposed system evaluation

The game described above will be developed primarily for stroke patients suffering upper limb and balance impairments. In the future, we will also test the system's ability to motivate exercise compliance in the elderly, as well as the efficacy of the system for functional improvements in strength, coordinated reaching ability, and motor control in this population.

Most of the systems described in Section II do not include automatic evaluation, although the home-based rehab system called KEHR [10], which is not based on a game, includes the automatic evaluation of three shoulder rehabilitation exercises using Kinect. In an experiment, this system was shown to have an accuracy of 80% when judging the correct execution of an exercise. Here, we plan to test the efficacy of our prototype by using the Kinect sensor in conjunction with openSIM software. Developed by researchers at Stanford University, OpenSIM uses motion capture data to model and evaluate muscle fiber length, tendon length, and much more, which provides a useful quantitative tool for creating simulations models. These types of simulations are widely used by doctors and therapists for planning surgeries, diagnosis, and motion analysis [31]. For our system evaluation, movement data will be collected before and after the participant engages in the music game. In a setup similar to [6] and [8], we will employ an ABA strategy for comparison, where 'A' represents baseline measurements and 'B' represents the musical intervention. OpenSIM will use the data from A sessions to quantify changes in muscle fiber length and range of motion in each patient. We predict that the music game intervention will result in greater muscle fiber length and improved range of motion across participants on average. Further, we plan to compare the results from these experimental participants with muscle fiber length and range of motion results from control participants who are engaged only in traditional physical therapy exercises.

V. Conclusion

Due to the increasing incidence of stroke in Singapore [3] and greater need for engaging, technological approaches to healthcare challenges (to save both manpower and finances), we offer a prototype of a music-based movement game for motor rehabilitation, tele-rehabilitation post patient discharge, and strengthening. The system is customizable based on the patient's particular needs, and provides feedback in real time about whether the patient is correctly performing the exercise and has correct posture during game play. Our system is being developed in consultation with doctors and physical therapists, and will be further developed to fit the needs of patients, the importance of which has been emphasized by Shridhar and Nanayakkara [32]. The entrainment-based movement game described here is meant to be one game in a larger suite of Kinect games currently being developed. In the future, other games for motor and cognitive rehabilitation will be added to this suite. We ultimately plan to deploy the system in hospitals and care centers to help address the unmet needs of stroke patients and the elderly.

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Preprint accepted for publication in the Proceedings of the IEEE International Conference on Orange Technologies (ICOT), Singapore. Dec. 2017