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Therapeutic Exergaming

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Abstract- Exercise therapy is prescribed by physiotherapists and rehabilitation practitioners as part of the treatment programme for many movement impairment disorders. Poor adherence and inadequate exercise technique often result in poor outcomes for these patients and delays their return to full physical function. Therapeutic exergaming, which is the use of computer games and body-worn motion tracking sensors to teach therapeutic exercise programmes to patients, may offer solutions to these problems. In this paper we describe one such system, known as FlyFit, which offers a sensor-driven flight game environment that allows physiotherapists to intuitively design game levels that will induce patients to correctly carry out their exercises programme. A four-week pilot study to investigate the training effect of the system compared to a conventional exercise training approach is described. Results suggest these exergaming systems may induce improvements in balance and strength similar to the conventional programme along with increased levels of intrinsic motivation but further research is warranted.

I. INTRODUCTION

Recent developments in the area of human motion tracking, such as inertial-based sensors, have improved the accuracy and portability of motion capture technology. This has allowed researchers to take motion capture outside laboratory setting and into people's homes and workplaces. Using these body-worn sensors to monitor body movements has facilitated the development of novel system designs aimed at improving our health and wellbeing. Therapeutic exergaming, which combines together the three fields of human motion capture, computer games and exercise therapy, may be beneficial to patients who must complete exercise programmes as prescribed by their physiotherapist or by other rehabilitation professionals.

Musculoskeletal disorders such as knee pain are highly prevalent health problems today and exercise therapy is an essential intervention in the treatment and management of these conditions [1]. Exercise therapy involves a patient completing treatment-focused exercises to improve motor control, strength and endurance of muscles aimed at increasing dynamic joint stability. If patients are to achieve adequate rehabilitation outcomes and regain normal physical function they must repeatedly perform their individually prescribed exercise programmes in the clinic, at

home or at their workplace. Two major problems encountered with these exercise programmes are inadequate adherence levels [2] and poor performance of the exercise technique. As most exercise therapy is completed as part of a home exercise programme there is a need to investigate novel strategies to instruct, monitor and improve enjoyment during these programmes.

Exergaming systems, combining large body movements into game-play, have recently experienced an exponential increase in popularity especially with the advent of Nintendo's revolutionary Wii console. The Wii has demonstrated how the use of motion sensing technologies can allow players to participate in game-play in a much more natural way, by simply performing the appropriate actions, whether swinging a bat, bowling a ball, or steering a car, as they play. Where other manufacturers have focused on attaining new levels of graphical realism, Nintendo has instead focused on the fundamentals of game-play.

Therapeutic exergaming systems are effectively exergaming systems designed specifically for rehabilitation purposes. These systems are also referred to as virtual rehabilitation system and were recently described by Burdea and colleagues as "the combination of computers, special interfaces, and simulation exercises used to train patients in an engaging and motivating way" [3]. The idea is that the patient will perform his/her exercises by playing a computer game, using sensor-based control, such that playing the game well corresponds to performing the prescribed exercise correctly. Therapeutic exergaming and virtual rehabilitation systems are being utilized for motor control training in neurological impairment and vestibular disorders, and to a lesser extent with musculoskeletal conditions [4,5]. Recent research has begun to demonstrate the clinical benefits of using systems with patient groups in the areas of stroke rehabilitation, acquired brain injury, Parkinson's disease, orthopedic rehabilitation, wheelchair mobility training and functional activities of daily living training [5].

The work in this paper will focus on the design and initial evaluation of such a system to teach a lower limb rehabilitation exercise. The next section will describe the components and operation of the FlyFit system, focusing on the sensor technology that has been used in this prototype

and the various components and modes of operation. We will pay particular attention to the novel way in which the physiotherapist can use the system to intuitively create the right sequence of game-play for a given exercise. Section 3 will outline the Methodology of an initial pilot study to evaluate the effects exercising with the FlyFit system with Results included in Section 4. Section 5 provides a Discussion of the findings and a Conclusion in Section 6.

II. FLYFIT SYSTEM

The prototype FlyFit system is comprised primarily of a motion tracking interface, the physiotherapist's software to create and monitor the exercise programme, and the patient's software to allow them to complete the programme effectively. The Windows-based system has been developed in C++ and is currently designed around a specific game-template, namely a 3D flying game in which the player must control their flight-path within a 3D world as they navigate through a variety of milestones. A unique feature of this system is the functionality to tailor the movement pattern of the exercise to the needs of each individual user.

A. Motion Capture Engine

The current FlyFit prototype has been developed to work with the MTx motion tracker (Xsens Technologies BV, The Netherlands). The MTx sensor (Figure 1) is a small, light, robust sensor that is capable of sensing its orientation in 3D space. The small size and light-weight (30g) of the sensor means that it can be easily (and comfortably) strapped to a limb segment or a joint. These sensors are comprised of 3D accelerometers, magnetometers, and gyroscopes. The accelerometer is used to measure acceleration due to gravity and, therefore, the inclination of the sensor. The magnetometer measures the strength of the earth's magnetic field and can therefore measure the yaw of the sensor, relative to magnetic north. And the gyroscope measures the angular velocity, or rate of turn, of the sensor. These outputs are integrated by the MTx to deliver an accurate sensor orientation in real-time that can be communicated to a PC via a serial USB cable.

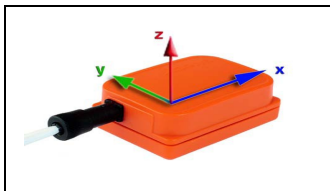


Figure 1. Mtx Inertial Sensor

The raw sensor data can then be used as the basis for computer-game control by using the MTx interface code provided with the Xsens MT Software Development Kit (SDK). The SDK provides the Game Engine with a range of methods for accessing and manipulating the basic sensor data. This includes functions for extracting the pitch, roll,

and yaw of the sensor. The FlyFit game was developed using OpenGL and is designed to interface directly with the sensor data by calculating the pitch, roll, and yaw matrices in order to manipulate the OpenGL viewing matrix, which controls the player's game-world view port.

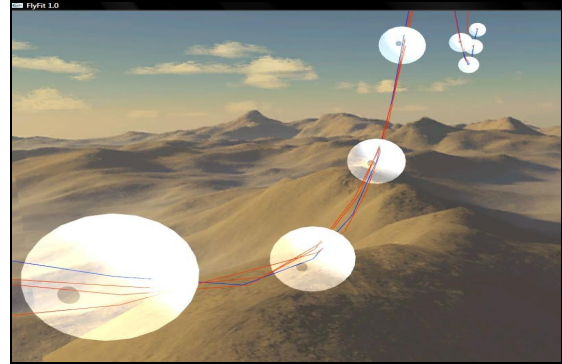


Figure 2. Review of the paths taken by the user at home (red), and the path taken when under supervision of a physiotherapist in the clinic (blue).

B. Physiotherapist's Interface

The software of the FlyFit system is designed to allow a physiotherapist to create a particular sequence of game-play. The game-play sequence is designed to guide the patient to reliably perform a particular sequence of body movements, which correspond to a prescribed therapy. To do this FlyFit provides the therapist with a simple GUI (Figure 3) where they can set certain game parameters, including the software mode (create or review tracks) exercise choice, difficulty, as well as adjusting the gaming environment itself (e.g., by selection a particular virtual world). This interface also allows the physiotherapist to configure how the sensor will respond to movement, which will very much depend on the type of exercise that is being designed; for example the physiotherapist can choose how each sensor axis relates to a particular game-control.

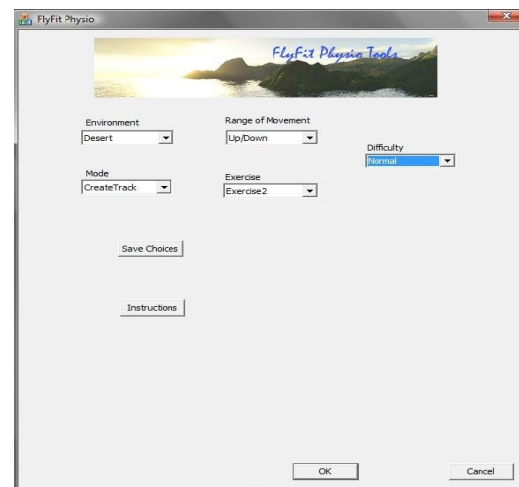


Figure 3. Physiotherapist's Options GUI

To create the desired game-play sequence the physiotherapist instructs the patient to perform the desired exercise while the patient is wearing the Xsens sensor (Figure 5). The result is that the FlyFit Game Play Generator (GPG) will record the sequence of movements made during the exercise.

The recorded movements are translated in to a particular route, or flight-path through the game-world so that when the patient plays the game he/she will see the route rendered on-screen. For example, at the moment, FlyFit is designed to render the route in the form of a sequence of “portals” which the player must fly-through. In this way movements in the real world are replicated in-game. For instance, in the lunge exercise (Figure 4), which we will discuss during the pilot study later, as the patient dips their body into the position of the lunge, the flight path also dips downwards. On returning to the upright position, the flight path is returned to level flight.



Figure 4. Track Creation Under Supervision of Physiotherapist

By adjusting the difficulty of the game, during design, the physiotherapist effectively controls the diameter of these portals, so that greater difficult implies smaller portals, which require the patient to perform their exercise routine more precisely. Typically the therapist will work with the patient to create a number of different exercises, with differing durations and difficulty levels, each carefully customized according to the patient’s injury and physical characteristics. In this way the physiotherapist has the ability to create a highly personalized exercise programme for an individual patient.

The FlyFit systems can also be used to provide the physiotherapist with feedback about how well the patient has been performing the prescribed exercises. For example, the FlyFit system can generate a comprehensive set of reports to document the patient’s progress day by day, week by week, and exercise by exercise. The therapist can even review individual exercise traces in order to better understand how well the patient is recovering and how the prescribed exercise programme may need to be adapted. For example, Figure 2 shows an example of the particular game-trace in which the patient’s progress is represented as a red line while the original exercise is represented as a blue line.

C. Patient Interface

In this mode the patient is presented with a preferences GUI similar to the physiotherapist's, in which they select the exercise to perform, which movements the sensor will be configured for, and login that will dictate where the personal feedback will be saved for the physiotherapist to analyse. The patient is then directed to attach their sensor and starts playing the appropriate game using a standard PC or laptop as shown in Figure 5. During each game the patient is presented with a sequence of checkpoints to navigate through and their progress is communicated as a game score, based on how accurately they have reproduced the original exercise route. Each game record is saved for later review by the physiotherapist and as the patient progresses they have the opportunity to move on to new game levels and progressively more challenging exercises, or alternative exercises that are more appropriate to late-stage recovery.

The next section will outline the pilot study conducted to evaluate the benefits of using the system during a 4-week exercise programme as compared to conventional methods.



Figure 5. Patient Using the System at Home

III. METHODOLOGY

Ten healthy subjects (8 male, 2 female) from the local university undergraduate population volunteered to participate in this research study. Participants were randomly allocated into an exergaming group (4 male, 1 female, with average age, height and mass of 20.8 ± 0.74 years, 175.6 ± 5.03 cm, 67.3 ± 17.4 kg) and a conventional group (4 male, 1 female, average age, height and mass of 21.2 ± 0.74 years, 181.1 ± 9.60 cm, 74 ± 8.36 kg).

A. Evaluation Procedure

Balance and strength measures were completed prior to and following the 4-week exercise programme. Intrinsic motivation was evaluated following the exercise programme to assess the subjective experiences experienced by both groups.

1) Star Excursion Balance Test

The star excursion balance test (SEBT) has been established as a highly reliable and valid procedure for

assessing dynamic postural control [6]. It is a functional dynamic balance test that involves the subject having to maintain a base of support on one leg while maximally reaching in set different directions with the opposite leg, without compromising the base of support of the stance leg. Reach directions were set as Anterior, Posterolateral and Posteromedial in this investigation.

2) Isokinetic Dynamometry

Isokinetic dynamometry (Biodex System 3) was used to measure knee flexion and extension concentric strength and endurance. Five repetitions at a speed of 30°/Sec was used to measure subject's strength and 20 repetitions at a speed of 180°/Sec was used to measure endurance.

3) Intrinsic Motivation Inventory

The intrinsic motivation inventory (IMI) is a questionnaire used to measure motivation following a specific task. [7] Five sub categories of the IMI were used to assess subject's perceptions of the exercise programme following completion of the 4 weeks. These categories included interest/enjoyment, perceived competence, effort/importance, pressure/tension and value/usefulness. The IMI was completed by all subjects at the follow up testing session.

B. Exercise Programme

The straight-line lunge was chosen as the exercise in this study. The lunge is often prescribed as part of a rehabilitation exercise programme after lower limb injuries (e.g. knee injuries) to assist in the restoration of the correct movement pattern which may have been compromised due to injury. Performing the lunge involves the subject to stand upright with the legs shoulder-width apart. One leg is extended behind the shoulders with the knee straight while the opposite leg is placed in front and slightly bent (Figure 5 and 6). The body weight is controlled while bending and straightening the front knee and the back always is kept in a vertical position.

The lunge exercise was completed three times per week for four weeks by all subjects in each group. Subjects performed three sets of 10 lunges on each leg during each exercise session. The exercise was progressed on a weekly basis by increasing the lunge distances from week one to week four (50, 60, 70, and 80cm respectively) as well as reducing the amount of time allowed to complete the exercise (10, 8, 7, and 6 seconds respectively) and by adding in resistance using different dumbbell weights held in each hand (0, 1, 2, and 2.5 kg).

Subjects assigned to the exergaming group were instructed to wear a knee brace on the right leg with the Xsens MT sensor secured to the outside of the leg slightly below the knee (Figure 6). The output of this sensor was used to control the subjects' interaction with the FlyFit game during exercise performance to provide real time feedback regarding exercise performance. By performing

the lunge exercise correctly the subject followed the desired track through the FlyFit checkpoints that were recorded by the therapist at the outset of the exercise programme. Subjects in the conventional group performed the lunge exercises as instructed by an exercise handout.



Figure 6. Xsens Sensor Secured to the Patients Knee

IV. RESULTS

All 10 subjects completed the 12 exercise sessions. Changes in group mean SEBT scores and changes in group mean isokinetic scores following the programme are reported in tables 1 and 2 respectively. During data analysis we identified technical problems with the isokinetic test results from one subject in each group. Therefore, the results for the remaining 4 subjects in each group were used during data analysis. IMI scores following the programme are reported in figure 7.

TABLE I. CHANGES IN MEAN SEBT SCORES

Direction	Leg	Exergaming	Conventional
Anterior	ND	7	6
	D	8	5
Posteromedial	ND	1	9
	D	8	5
Posterolateral	ND	3	5
	D	3	3

ND, Non-dominant; D, Dominant. SEBT scores are reported in reach distance in centimeters as a percentage of leg length

TABLE II. CHANGES IN MEAN PEAK TORQUE ISOKINETIC SCORES

Direction	Speed	Exergaming	Conventional
Extension	30°/Sec	5.58	-8.48
Flexion	30°/Sec	5.58	1.22
Extension	180°/Sec	0.74	-1.08
Flexion	180°/Sec	5.34	5.36

Peak torque scores are reported in Newton meters..

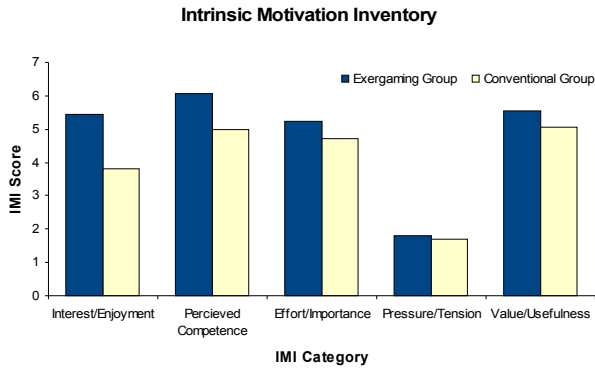


Figure 7. Intrinsic Motivation Scores

V. DISCUSSION

This pilot study has demonstrated the utility of using body-worn sensors to interface patients with therapeutic exergaming systems. Due to the small sample size results must be interpreted with caution but results show similar changes in physical function between exergaming and conventional groups. The study however does indicate a greater level of interest and enjoyment in the exergaming group compared to the conventional group.

This increase in levels of interest and enjoyment may provide the motivational stimulus to a patient that prompts them to carry out and complete their prescribed rehabilitation course. By providing a means of making the monotonous repetition of movements somewhat more enjoyable, we can aid physiotherapists and patients in combating the problem of poor adherence. If improved adherence to home exercise programmes can be achieved with these systems it may result in improved outcomes for patients.

In future work the creation of a system involving a small network of sensors worn on different key points would permit a greater level of discretion in analyzing 'player' performance in more complex motor tasks and therefore would increase the utility of this approach to rehabilitation. The challenge for researchers is to trade off the simplicity that single sensor systems offer the user versus the fine motor training discretion that the use of sensor networks could provide.

VI. CONCLUSION

This paper has described how a single body-worn sensor can be used to provide the input for a novel therapeutic exergaming system and as such is a useful starting point in the field. The results of this pilot study show a similar pattern of balance or strength changes following the 4-week exercise programme but the IMI indicates an increased level of intrinsic motivation in the exergaming group.

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