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The Effects of Visual Feedback in Therapeutic Exergaming on Motor Task Accuracy

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Abstract—**Poor exercise technique and lack of adherence during home exercise are implicated in preventing a full recovery to peak physical function during rehabilitation. It is widely believed that therapeutic exergaming has the potential to solve these issues. However, the field is still young and there is little empirical evidence supporting, in particular, its effectiveness in helping the patient to maintain correct technique. In this paper we present preliminary results from a study to examine the effects that visual feedback during exergaming has on a person's accuracy in performing a motor task. Our study showed that interacting with a game incorporating simple visual feedback results in improved accuracy compared to performing exercise from memory or with limited feedback in the form of an instructional video demonstration. These results provide early evidence that exergaming can be used to enhance technique during exercise performance.**

I. Introduction

Exergaming, the combination of exercise therapy and gaming to promote physical activity, has seen a recent surge in interest and popularity, mainly due to the success of the Nintendo Wii console and more recently the Microsoft Kinect platform, both of which have revolutionised gaming by focusing on the fundamentals of game play and thus appealing to a much wider population than traditional video games. Therapeutic exergaming involves the use of exergaming technology, combined with human motion capture, as part of a prescribed rehabilitation program for movement impairment disorders [1]. These systems are also sometimes referred to as virtual rehabilitation systems. Exercise intervention is a critical component in the treatment of musculoskeletal conditions with patients typically undergoing both clinical and home-based treatment [2]. When treatment moves to the home, a return to full physical function may be hampered by a lack of adherence to the rehabilitation programme [3], [4] and/or poor performance of the exercise technique.

Exergaming technology should be tailored to a patient's personal rehabilitation needs. Furthermore, the technology should ensure that patients are performing correct and useful therapy motions [5] and therapists should be able to objectively measure and monitor this. Integrating sensor technology as input into therapeutic exergaming provides a measure of objective feedback for both the therapist and the patient. Making rehabilitation engaging or fun can increase a patient's motivation to adhere to their exercise programme at home and it is widely believed that a gaming environment can provide this fun, motivating context [6], [7], [8].

In fact, much research into rehabilitation through technology stresses the importance of feedback to motivate the rehabilitation process [5], [9]. There is much less discussion on the equally important topic of whether such technology can ensure maintenance of correct technique when exercising. If a patient is not executing their exercise accurately they may not gain the full benefit of the exercise. With certain complex exercises, inaccuracy can potentially cause further injury. However, therapeutic exergames have the potential to provide feedback on quality of movement, allowing the patient to adjust their movements to the correct position during rehabilitation, without the need for a physiotherapist to be present. As such, the focus of this paper is to examine whether an exergaming environment is more beneficial in helping a patient maintain correct movement form than other typical forms of rehabilitation, including exercising alone without feedback, or exercising having first viewed a video demonstration.

II. The Therapeutic Exergaming System

The exergaming application being examined in this study is designed to support physiotherapy rehabilitation in the home. With regard to our design strategy for the therapeutic exergame, we had the following initial requirements:

- The system should be general enough that it can support a wide range of both upper and lower limb rehabilitation exercises.
- Interaction should be hands free to remove interaction complexity and allow the user to focus on their exercise movement.
- The number of sensors should be minimised to avoid a lengthy set-up procedure, which could have negative effects on adherence.
- The initial prototype should have a simple form of real time feedback that will provide the patient with information on their accuracy in performing the exercise, allowing them to correct their movements in real time, if necessary.
- It should be easy to add or remove feedback components from the system interface to suit a wide range of user preferences.

An iPhone strapped to the body acts as the single sensor input to the game. The 3-axis accelerometer in the iPhone is

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used the measure the angle of the phone with respect to gravity. A custom built application on the iPhone is run when the patient is playing the game in order to send accelerometer readings to a central server. The exergaming application has both physiotherapist and patient interfaces that are presented in flash applications and are hosted on the central server and displayed to the patient in a web browser. When interacting with the game, the patient controls the input by moving the iPhone. The iPhone sends the accelerometer readings to the server and the Flash application uses the accelerometer readings to adjust the current game state.

The physiotherapist interface supports the collection of the patient's accelerometer data in a clinical setting, including their baseline repetition of the exercise being prescribed, recorded using the iPhone. It also allows the physiotherapist to create the patient's home exercise programme, by selecting the number of repetitions they should perform in each session and setting the difficulty level of the exercise. The patient interface supports the user in interacting with the chosen game. In terms of inputs from the user, they must switch on the laptop and open the exergaming application from the desktop. This launches their personalised rehabilitation programme. The iPhone application also needs to be opened, which then requires a single button press to connect the iPhone to the main application. This allows the main application to wirelessly access accelerometer data from the iPhone. All further interactions with the system are hands-free.

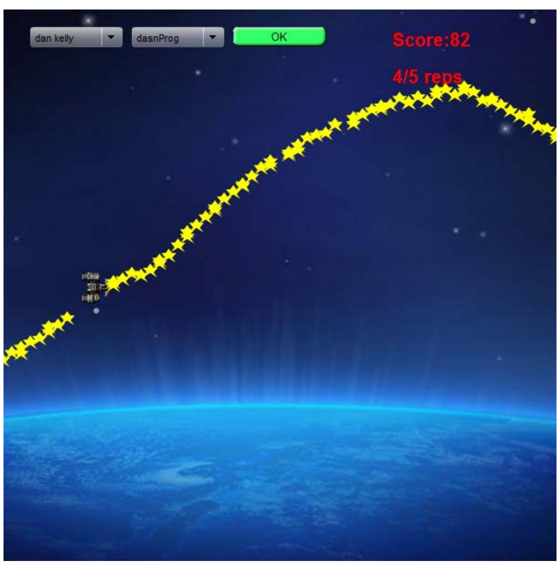

Fig. 1. The game used in the study required the user to maintain a spaceship on the correct path with their movement. The shape of the path is determined by the user's baseline repetition of the exercise

A number of games are currently available on the application, and each can control a large number of both upper and lower body rehabilitation exercises. The premise behind the game used in our study is that the patient is presented with a moving spaceship on screen, which they control with their exercise (Figure 1). The patient's goal is to move the spaceship along a certain trajectory, which represents their baseline repetition recorded under clinical supervision, so that it follows a sequence of stars. If the patient's movement is in line with their baseline movement, the spaceship clears the stars. If the patient makes an incorrect movement, such as not maintaining a regular pace or not achieving the correct angle of movement, one or more stars will not be cleared. This prompts the patient to correct their movement, to return the spaceship to its correct trajectory. At the end of the exercise session, the user receives an accuracy score as a percentage. Thus, in addition to real time feedback to support technique correction, the game aims to provide a level of increased enjoyment over exercising alone, in addition to promoting a sense of increased confidence that the user is performing the exercise correctly. Movement data is uploaded to a remote server once the user's exercise session is complete. The physiotherapist can then view this data.

III. EVALUATION METHODOLOGY

A. *Study Design*

The aim of this study was to examine any differences in levels of accuracy when performing a motor task under three different levels of feedback:

- **Control** – no feedback.
- **Video** – limited feedback in the form of a demonstration video shown prior to the participant performing their exercise task.
- **Exergame** – visual feedback (i.e. the exergame) that provides real time feedback on the participant's accuracy in performing the task.

A total of 8 healthy participants (3F, 5M; mean age 28) took part in the study. The experiment took place over two days in a research laboratory. Study equipment/apparatus consisted of a single iPhone 3GS attached to the participant's thigh and a laptop that provided the visual feedback. A double leg squat exercise was chosen as the test motor task in this study as it is a relatively simple exercise yet one that is frequently performed incorrectly in terms of depth of squat and rhythm of repetitions.

B. *Methodology*

On the first day of the experiment, participants signed consent, filled in a demographic questionnaire and then moved onto the training and recording phase. The iPhone application was launched to begin streaming orientation data to the laptop. The phone was then secured to the anterior aspect of the participant's thigh using a Velcro strap. A physiotherapist demonstrated 2 lower limb exercises to the participant, the lunge and the squat (to counter learning effects). Accurate performance of exercise technique is difficult to rate objectively and different therapists may differ in the precise details of the exercise technique that they impart to a patient. However, this was not a critical issue in this study as our goal was to ascertain whether the exergaming application could be used to replicate exercise performance as prescribed by a specific therapist.

Therefore, reflecting current norms in clinical practice, we relied upon the clinical expertise and judgment of the therapist to determine whether the participant was performing the exercise with a correct biomechanical technique. The therapist in this study used 5 key points to explain the exercise technique and judge participant performance. Participants practiced both exercises and had a chance to ask for clarification. We then recorded a baseline repetition of each exercise for each participant under the supervision of the physiotherapist, using the physiotherapist software interface. Orientation data from the iPhone during exercise performance was used to set the participant's personal parameters in the exergaming condition. At this point, the participant had not seen the game interface.

On day two of the experiment, each participant returned to the research laboratory and applied the iPhone, with continuous streaming of orientation data, to their thigh in the same manner as previously. They were then asked to perform a series of squats under the three different feedback conditions outlined above, the order of which was counterbalanced across participants. Prior to the participants performing the Exergame condition, the evaluator demonstrated the use of the game. The participant was then allowed up to two practice attempts before their data was recorded under that condition. Each participant performed five repetitions of the squat under each condition.

Sagital plane thigh orientation was analyzed from the iPhone data output in each condition. MATLAB 2009b (Natick, Massachusetts) was used to create algorithms to extract the desired features from each test. The depth of squat, in degrees, and the time taken to complete each squat, in seconds, were calculated for the baseline squat on day one and all subsequent conditions on day two.

C. *Hypotheses*

We hypothesised that participants would perform most accurately under the Exergame condition. More specifically, we hypothesised that:

1. The depth reached in squatting under the Exergame condition would be closer to the depth reached in the baseline repetition, than the Control or Video conditions.
2. The time taken to complete an individual repetition in the Exergame condition would be closer to the time taken to perform the baseline repetition than in the Control or Video conditions.
3. The Video condition would result in better accuracy (in terms of both depth and timing) than the Control condition, but not as good accuracy as the Exergame condition.

Our results are outlined in the following section.

IV. RESULTS

In terms of accuracy of performing the motor task, we examine two measures:

- Comparing the depth of the participant's squat under each feedback condition to their baseline repetition, in terms of difference in angular orientation of the thigh compared to the baseline repetition recorded on day 1. From here on we refer to this as **Angle Difference**.
- Comparing the length of time taken to perform a repetition under each feedback condition to the time taken to perform the baseline repetition. From here on we refer to this as **Timing Difference**.

These measures are visually explained in Figure 2.

A. *Angle Difference*

The average angular orientation of the thigh at the deepest part of the squat was calculated across the participant's middle three repetitions for each condition. This was then subtracted from the baseline angle measurement to calculate angle difference. Results can be seen in Figure 3. A single factor ANOVA analysis of angle difference across the three conditions reveals a significant difference (F=3.86, Fcrit=3.5, p=0.037). Looking more closely at comparisons between the conditions, we can see that for 7 of the 8 participants, the angular orientation of the thigh at the bottom of the squat under the Exergame condition was more similar to the baseline condition than the Control condition (i.e. there is a smaller difference in the former). A paired 2 samples t-test reveals this result is significant (p=0.017, df=7). The same is true for all 8 participants under the Exergame condition when compared to the Video condition (p=0.008, df=7). A significant difference was also observed between the Control condition and the Video condition (p=0.04, df=7), with 6 of the 8 participants performing better in the Control condition than in the Video condition (Figure 3).

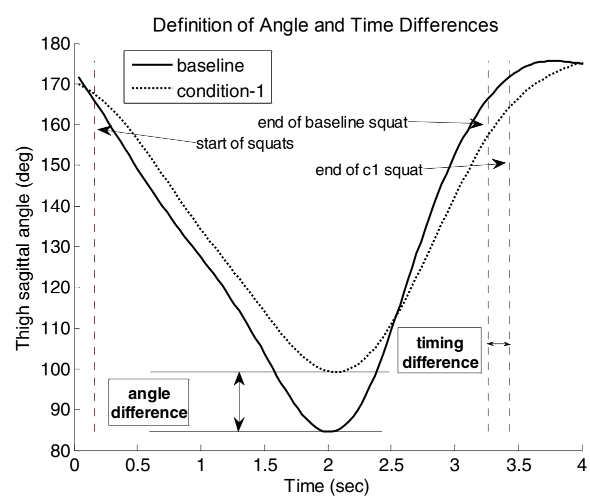

Fig. 2. Visualisation of the angle difference and timing difference in squatting data

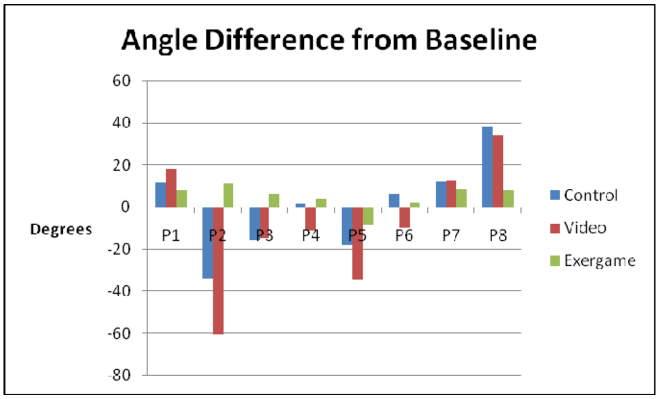

Fig. 3. Angle difference from each participant's baseline data

B. Timing Difference

In terms of timing data, we were interested in evaluating how well the exergame helped participants to maintain a steady pace, as determined by the pace of their baseline repetition. The results can be seen in Figure 4. A single factor ANOVA analysis of timing difference across the three conditions reveals no significant difference (F=3.1, Fcrit=3.5, p=0.07). Comparing the conditions more closely, we can see from Figure 4 that for 6 of the 8 subjects, there was a smaller difference from the baseline in the time taken to complete, on average, a repetition in the Exergame condition compared to the Control condition. This result is significant (p=0.014, df=7). The same is true for 6 of the 8 participants in the Exergame condition when compared to the Video condition (p=0.014, df=7). There were no significant differences observed between the Control condition and the Video condition (p=0.26, df=7). Thus, overall participants were more accurate in terms of both angle and timing when performing the squatting exercise under the Exergame condition.

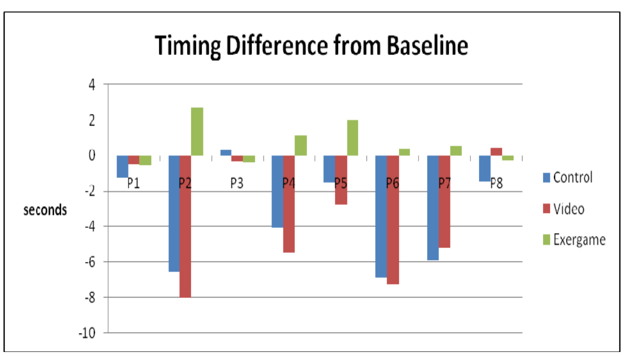

Fig. 4 Timing difference from each participant's baseline data

V. DISCUSSION

The principal finding in this investigation was that a simple feedback interface based on orientation sensor input used to track limb motion improves the quality of lower limb exercise technique. This has potentially important clinical implications as it demonstrates that exergaming can improve accuracy during exercise performance as prescribed by a rehabilitation professional. Whilst there is no direct evidence that accurate exercise technique is definitively associated with improved rehabilitation outcomes, this is generally accepted to be the case in exercise science.

Therapeutic exergaming has the potential to address a patient's rehabilitation needs while increasing motivation to adhere to an exercise programme. While there is a significant amount of literature regarding the issue of adherence, there has been much less focus on the clinical benefits that home-based therapeutic exergaming can provide. It has been shown that exergames provide similar benefit, in terms of physical function, as typical methods of exercise training [10], [7]. However, given the potential for the engaging nature of visual feedback in therapeutic exergaming environments to distract the patient from their primary (motor) task, we felt it necessary to determine whether exergaming can improve the quality of movement over traditional methods of rehabilitation.

Results from our preliminary investigations demonstrate that accuracy is indeed higher within an exergaming environment, when compared to exercising with no feedback and also with limited video feedback, confirming our first two hypotheses. This has important clinical implications as it means that therapists can have confidence that use of the therapeutic exergaming application does not distract the patient from the specifics of exercise technique. In fact, it enhances the patient's ability to stay within the parameters of the exercise technique as prescribed. We do not know whether the differences in angle and timing replication we have observed during the different conditions are sufficiently large to cause a clinically significant change in the outcome of the exercise over time. However, we do know that the exergaming feedback condition resulted in the most accurate replication of therapist prescription across the 3 conditions so we know that it will help to reproduce therapist instructions. Maintenance of optimal alignment and technique during an exercise is considered by physiotherapists to be a critical factor in determining levels of improvements during rehabilitation. Poor segment alignment or technique can even worsen a condition rather than improve function in some cases. Poor technique during exercise performance can lead to biomechanical malalignment during functional activities, leading to abnormal patterns of forces being applied to bony and soft tissue, with resultant increases in acute or overuse injury risk [11].

An interesting finding from our results was that the participants' performance was less accurate, in terms of angle difference, under the Video condition than the Control condition, rejecting our third hypothesis. Anecdotal evidence suggests that providing a patient with a video demonstration of their exercise programme will assist them in carrying it out correctly, by providing them with a reminder of how the exercise is performed. A possible reason for our result is that the participants were more focused on remembering movements from the video, rather than the instructions they were provided with on the day of training. However, it must be noted that only 24 hours had lapsed since the training session. Another potential factor could be the fact that the video portrays an expert performance and the depth and repetition rate in the squat may not necessarily match what the therapist had demonstrated to the patient at the baseline session. This is a scenario that is likely to be repeated in a clinical setting as each patient has unique exercise needs and it is difficult to match these to a single video record. Further research should look at allowing patient's to see videos of themselves performing the exercise correctly to determine if that could result in higher quality movement.

It is important to recognize the limitations of this investigation. We have assessed accuracy of exercise technique based on orientation of the thigh in a single plane. There are other aspects of technique that must be considered in order to fully evaluate technique of the squat. However, we felt that thigh orientation embodied a good representation of overall technique as it would be difficult to replicate it without staying very close to baseline performance.

While a full usability test of the exergaming application was outside the scope of this particular study, the lead evaluator, with a background in human computer interaction observed all participants interacting with the application and noted any potential usability issues. Ensuring ease of use and intuitiveness are critical factors contributing to both adherence and quality of exercise, as patients are less likely to use an exergaming system if it requires effort. Furthermore, on-screen feedback informing a patient how to correct their technique in real time must be easily and at once understood.

Interaction with the game appeared very intuitive to all participants. Each had a demonstration from the evaluator and a practice session before their interaction was recorded. The only potential problem surrounding interaction involves the iPhone. One participant repeatedly hit the sleep button accidentally, which caused the phone to lose connection, in which case the iPhone application had to be re-launched. The reason this participant experienced this particular problem was because they found it difficult to place the iPhone into the strap that we had designed to hold it. We are examining the addition of a locking feature to the application, which would disable the sleep function when the exergaming application is running on the iPhone but also looking at other ways of attaching the phone to the body that will not be problematic for people with dexterity issues, for example.

Given the importance of feedback within a virtual rehabilitation environment, a significant challenge in our current and future work in designing therapeutic exergames is how to integrate visual (and/or other forms of) feedback that both fosters intrinsic motivation and provides objective feedback regarding quality of movement, without cognitively overloading the patient. External stimuli can have a significant effect on motor function. Visual overload may focus the patient's attention on the screen, rather than on the exercise itself, potentially decreasing accuracy and thus limiting physical benefit. In this application we chose not to provide feedback regarding thigh orientation in the frontal plane – a potential source of error in technique – as we felt it might introduce excessive cognitive load. However, to date there is comparatively little empirical research in this field and thus the relationship between the sensory and motor systems is not well understood. With our research, we are beginning to address this issue by evaluating the effects of different levels of visual feedback on the performance of rehabilitation tasks within therapeutic exergaming applications. Our overall goal is to find the right combination of feedback, whether visual, audio, haptic or a combination of these, for different user groups, to encourage adherence while ensuring no negative effects on accuracy of performance. We also need to extend this work to real patient populations to investigate its capability to address currently unmet clinical needs and identify those patient groups in which it can have the most impact.

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