Therapy-led Design of Home-Based Virtual Rehabilitation

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ABSTRACT

Virtual Reality is emerging as a useful tool to facilitate rehabilitation, and has potential to support home-based exercise programmes to maintain progress and improve long-term outcomes. A number of commercial systems have emerged with games that promote increased physical activity. However, the current off-the-shelf games are not well suited to support therapeutic goals, but the alternative is expensive bespoke applications. In this paper we summarise the background of virtual rehabilitation and discuss the challenges in bringing it into a domestic setting. We propose a therapy-led design approach which can result in solutions which not only suit rehabilitation goals, but also can be used for more generalised game-based exercise. We illustrate the approach using a case study for shoulder therapy.

Keywords: Virtual Reality; Rehabilitation; Therapy-Led Design

Index Terms: H.1.2 [Models and Principles]: Human Factors; H.5.1 [Information Interfaces and Presentation]: Artificial, augmented, and virtual realities

1 INTRODUCTION

A wide variety of health conditions are correlated with pain and generalised motor dysfunction [11], with associated reduction in work and leisure activities, and increasing disability [9]. Conventional rehabilitation strategies are generally centred on physical therapy [7], which may involve physical manipulation of tissues and structures, coupled with passive and active exercise programs. The best outcomes are achieved if patients are able to continue self-administered therapy beyond the end of the limited supervised sessions offered by most health-care providers [7]. However, this step in patient recovery can often become the weak link, as patient compliance with home exercise programs can be poor and ineffectual [8, 26].

In recent years, VR has been emerging as a useful tool of both physical and psychological rehabilitation [22]. As well as offering precise, repeatable control in a safe environment [15, 22, 23], it also provides a more engaging therapeutic experience [3, 22, 25], which may be able to address some of the problems with adherence to conventional therapeutic programmes.

2 VIRTUAL REHABILITATION

Three key benefits of VR have been identified which may offer particular benefits to physical rehabilitation. These are engagement or enjoyment of therapy, reduced perception of pain, and improved movement.

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2.1 VR and Patient Engagement

It is likely that patients will engage more with therapy if it is more enjoyable. Furthermore, it has been suggested that the interactivity of Virtual Reality may be able to distract patients by focusing on the visual engagement of the task [22]. There are a number of successful studies that have used this technique to enhance enjoyment of physical therapy.

For example, VR was evaluated for use in children with Cerebral Palsy (CP) [3]. This study compared interactive VR with conventional exercise for ankle mobility. CP children are often non-compliant with the physical therapy required to reduce spasticity, and it was found that children with CP reported more fun and greater interest, performed more repetitions of the exercise, and generated more ankle dorsiflexion when using the VR game in comparison to standalone exercise. This supports the suggestion that greater enjoyment leads to more engagement with the therapy.

Similarly, a study of 27 adults with Traumatic Brain Injury participated in 6 weeks of either activity-based or VR-based balance training, followed by focus group debriefing. Whilst both programmes demonstrated improvements in balance, the improvements were greater in the VR group and, in addition, this group expressed greater enjoyment than the activity-based group [25].

Although only a small number of studies have directly measured engagement in virtual rehabilitation, the evidence to date suggests that VR may offer an enjoyable and engaging experience, which could increase adherence to therapeutic programmes, even in the absence of a supervising therapist.

2.2 VR and Reduced Pain Perception

Pain competes for finite attentional resources [5, 9], and the use of distraction techniques can reduce the perception of pain [9, 14]. The immersive properties of VR have been recognised for their ability to distract from attention to pain, and a number of research groups are now systematically studying this phenomenon [6, 13].

Furthermore, there has been found to be a significant reduction in activity in the pain-related areas in the brain during interaction with VR, suggesting that the pain-reducing properties seen with VR are unlikely to be due to distraction alone [13]. There is compelling evidence that VR can contribute significantly to reduced pain perception, and this effect may be usefully exploited in virtual rehabilitation.

2.3 VR and Improved Movement

The goal of rehabilitation is to recover lost function, and with respect to motor rehabilitation this means improvements in endurance, speed and quality of movement, particularly with respect to ADL (activities of daily living). Therefore, if VR is to prove of benefit in rehabilitation, beyond the ability to increase engagement and reduce pain, then it must demonstrate the potential to facilitate improvements in motor function, and these improvements should be transferable to daily activities.

An early review of VR for motor rehabilitation noted that although most of the studies discussed are small case studies, and often have no control condition, there was sufficient evidence to suggest that VR has a potential contribution to make in rehabilitation, and that the improvements achieved in VR may be transferable to ADL [23].

More recent larger studies on stroke patients [17] and children with cerebral palsy [3] have demonstrated that VR therapy is not only effective, but may offer greater benefits than conventional therapy alone.

Although the evidence indicates that Virtual Reality (VR) can provide an engaging and effective environment for physical therapy, historically VR rehabilitation systems have been lab based or in large specialised clinics, requiring expensive hardware and software. They are generally one-off designs to suit a very specific patient group or therapeutic task [1, 4]. Such systems are neither practical nor economically viable for long term or patient-directed therapy, but the current best alternative is to leverage commercial off-the-shelf (COTS) systems and adapt them for therapeutic use [21, 24]. However, at best the use of such systems does not cater for most therapeutic requirements, and can even be detrimental to patient recovery.

3 Using Commercial Games for Rehabilitation

Most commercial off-the-shelf (COTS) games are designed for the gaming community, with their primary goals being engagement and entertainment. More recently there has been acknowledgement of the need to increase general levels of physical activity, resulting in a number of games consoles designed to support more active gaming ("exergames") (e.g. Microsoft Kinect, Nintendo Wii, Playstation Move). However, although such systems may have rehabilitation potential, at best they are designed to promote general exercise in a healthy population, and cannot account for the diverse and complex needs of rehabilitation. Furthermore, even within normal populations these systems can have adverse physical consequences, including musculoskeletal injury [2].

The goals of the game may not support the type and quality of movements required for therapy, and may even conflict directly with the therapeutic objectives. Rehabilitation generally requires slow and controlled movements at moderate intensity, but exergames are often designed to elicit high intensity rapid activity with large amplitude motions, which can either cause or exacerbate musculoskeletal injuries. Indeed, "Wii-itis" is a well known phenomenon amongst physical therapists [2]. Furthermore, the activities or sports portrayed in such games generally simply provide a narrative framework for game play, and it is relatively easy for players to circumvent the designers intentions and to "cheat" using alternative simpler or easier movements to achieve the game objectives (e.g. flicking with the wrist in Wii tennis rather than using the full arm motion), further undermining any potential therapeutic benefit.

Currently, therapists have limited options for prescribing virtual rehabilitation for their patients. They are restricted to either using expensive supervised specialist centres, or unsuitable COTS games which, whilst they can be used at home, are unlikely to properly support the therapeutic goals. Furthermore, the limitations and risks of the current COTS systems are not restricted to patients requiring rehabilitation, but indeed pose similar problems for normal healthy users, and solutions which suit rehabilitation goals may well also improve interaction experiences for other users.

With the phenomenal increase in availability of low-cost VR devices such as Oculus Rift, Leap Motion and Virtuix Omni, there has never been a better time to bring virtual rehabilitation out of the lab and into the home. The goal therefore is to deliver home based solutions which are affordable, easily customised for individual users, and take into account specific disabilities or therapeutic goals, whilst minimising the risk of incorrect use or harm. In order to achieve this, a different approach to design is needed. We propose a therapy-centred design approach.

4 Therapy-Led Design of Rehabilitation Games

In common with many other design tasks, in order to design well we must understand the needs of the user. However, in the case of exergames, the game elements are often considered the primary goal, with non-specific physical activity a secondary goal. However, for therapeutic applications, performance of specific movements is generally the primary goal, and the users for these applications may have many constraints to normal interaction. The core steps towards effective design include:

1. Identification of patient population(s)
2. Identification of therapeutic goals and actions
3. Identification of any limitations to movement or cognition
4. Design of a solution to address the interaction requirements
5. Adaptation of software or hardware to address specific therapeutic constraints
6. Generalisation of the solution for other applications.

Whilst it is beyond the scope of this paper to address the potential physical constraints or needs of all users, we will present a case study based on our previous work to illustrate some key components of the process.

4.1 Case Study - VR Rehabilitation for Shoulder Injury

4.1.1 Patient Population

Patients with chronic shoulder pain and restricted movement. Fear of movement or pain is often a limiting factor in regaining shoulder mobility, and therapeutic regimes should encourage patients to work beyond their current limited range of active movement, even though this may be painful [10]. Patients often have associated restriction and pain in head and neck movement..

4.1.2 Therapeutic Goals

The goal is to improve active range of motion (ROM) for shoulder mobility to approach normal passive ROM limitations. Therapeutic actions to be performed are external and internal rotation (5 times each in alternating sequence) [cf. 16]. Flexion, abduction or adduction of the shoulder should be performed in between each rotational movement. The therapist requests an engaging an immersive simulation with a clear goal-oriented meaningful task which allows patients to be sufficiently distracted from the discomfort of the rotation of the shoulder.

The design of the application should not allow users to "cheat" in the movements, but should only give feedback of success after genuine rotational effort.

4.1.3 Limitations to Movement or Cognition

a. Reduced mobility in the shoulder is variable between patients, and therefore the application must be able to be customised to the capacity of individual patients.
b. Restricted ROM of the neck reduces the ability to use conventional head- tracking. Patients should be able to look around the virtual environment without excessive movement of the head or neck

4.1.4 Proposed Solution

The narrative context of the game is apple-picking in a virtual orchard. Trees will contain red or green apples, placed into the peri-personal (reaching) space (Figure 1). An orchard was selected for the application rather than the more common tasks involving balls or balloons for a number of reasons. Placing the apples among the trees allows for a richer engagement involving visual searching, and the shape of the apples supports better depth cues than spherical objects [18]. The use of the apple picking task lends itself to the notion of placing the picked apples in a basket, creating an ecologically valid task which naturally integrates the desired rotational movements, and enables them to be implicit within the game, rather than an explicit focus.

Virtual baskets are placed behind the patients back at the level of the shoulder and the waist. The patient is required to visually locate the apple, reach and grasp it, and place it into the appropriate basket (green apple → top basket = external rotation, red apple → lower basket = internal rotation). Audible feedback (noise of apple dropping) is given when sufficient rotation to reach the correct basket is achieved.

Figure 1: The virtual orchard

4.1.5 Adapting to Constraints

a. Patients will normally only rotate the arm to the point of pain, but with encouragement can achieve further rotation. An algorithm is incorporated into the software to monitor the rate and trajectory of motion as limit of rotation is reached. A timed delay at this stage before feedback encourages an attempt at further rotation. Feedback of successful delivery of the apple thus is dynamically adjusted according to the capabilities of an individual user.

b. Patients with restricted neck movement increase the range of eye movement, and will tend to direct the eye gaze towards the active hand during target acquisition with minimal movement of the head. Thus conventional head tracking is disabled, and instead a gaze direction vector calculated using the relative positions of shoulder (or head) and hand trackers, and this vector is used to set the direction of the virtual camera (Figure 2). After target acquisition, the camera view is redirected forwards to reflect the normal adjustment of gaze when reaching behind the coronal plane of the body.

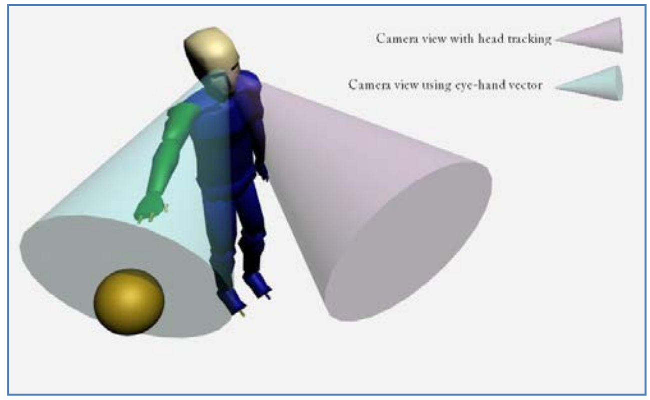

Figure 2: Camera view with eye-hand tracking (left of image) or head tracking (right of image)

4.1.6 Generalisation of Solution

The apple picking task can be easily adapted to give varying levels of difficulty (e.g. limiting the time each apple is visible, varying the position of the target apples, setting a lower limit of rotation for delivery of the apple). The dynamic algorithm for assessing limits of rotation allows users of all abilities to achieve task success only through maximising shoulder rotation.

The minimum tracking requirements for the task are the position of the shoulder and the active hand. The distance between head and shoulder is remarkably consistent between individuals and thus a head tracker can also be used to estimate the shoulder position and vice versa, and can be used for evaluation of shoulder rotations. The benefit of tracking just two points in this system mean that preparation is simplified and reduces the barriers to participation, regardless of ability or motivation.

The shoulder/head tracking point provides a zero point reference from which to evaluate upper limb movement. It should be noted that to accommodate varying heights of users, and both sitting and standing modes of interaction, the shoulder / head tracked point should provide position relative to the floor, in order to input information about the relative eye height to ensure that the viewpoint is calculated correctly. Many systems rely on a rough estimation of viewpoint, but an incorrect horizon and viewing position can increase the issues with distance compression in VR. Furthermore, the shoulder/ head and hand positions can be used to correctly set the target objects within the peripersonal space of an individual user.

Nearly 100 users, both with and without movement restrictions, have used this tracking solution to date, and reported it easy to use and indistinguishable from conventional head tracking, removing any requirement for alternative settings for healthy users and patients, allowing a single application to be used for both patients and their friends and family, facilitating greater engagement, mutual support and compliance with therapy.

It should be noted that the approach described above does not result in a platform-specific solution, but rather a generic design which can be adapted for multiple platforms, including any home-based system which supports basic shoulder or head and hand tracking. Furthermore, whilst being designed to support a particular sub-group of the population, it is equally suitable for use by the general population, requiring no special settings or calibration to identify the capabilities of the user, but instead relying on dynamic adjustments in order to support a range of user abilities and goals. The dynamic evaluation of movement capabilities within the application removes the need for an attending therapist to set the parameters for each training session, making this type of therapy accessible to all patients without the compromises involved in attempting to use standard COTS exergames.

5 Further Considerations

In this paper we have introduced one aspect of the design of home rehabilitation applications. Of course, this can only give a simplified overview, and the challenge and complexity of the task should not be underestimated. The visual elements of the environment itself can impact task performance [18], as can the software and hardware used in the system design [20], and even the choice of audio content [19].

6 Conclusion

Our experience using this therapy-led approach to design drawing on expertise in biomechanics, physical therapy and virtual reality indicates that we do not necessarily need to create bespoke solutions for every potential issue, and indeed it is possible to design therapeutic applications which can appeal to a wide range of potential users and be deployed onto low-cost commercial platforms. The challenges involved in good inclusive design are not trivial, but creating better virtual rehabilitation applications is likely to also create better exergames for the general population.

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