VIRTUAL REALITY GAMING FOR REHABILITATION: AN EVALUATION STUDY WITH PHYSIO- AND OCCUPATIONAL THERAPISTS

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Abstract

The number of stroke patients in Hong Kong continues to increase and the ages of the stroke patients are getting younger. The benefits of introducing virtual reality (VR) technology to enhance the rehabilitation services of post stroke patients are studied. A VR walking game for patients recovering from strokes was developed. Twenty physiotherapists, occupational therapists, and prosthetic-orthotic therapists were invited to evaluate the benefits of the games through questionnaires and interviews. Eighty percents of the therapists agreed or strongly agreed that the introduction of the VR walking game could help them to care for more post-stroke patients. The first prototype used a head-mounted display (HMD) to present the VR simulation and 12 therapists reported that the quality of HMD would cause potential disorientations in elderly patients. A second prototype with three panel-mounted displays was developed and results of further evaluation confirmed that the potential benefits of VR games in clinical management of patients recovering from strokes. Specific technical recommendations concerning an ideal VR game for rehabilitation are reported.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

Keywords: rehabilitation, assistive technology, VR games

1. Introduction

On average, more than 20,000 stroke (including haemorrhage, infarction, and non-specified stroke) patients are treated and discharged in Hong Kong every year (Hospital Authority, 2011). After an operation, a stroke patient's motivation and persistence in gait practicing is of vital importance towards a full recovery (Connor *et al.*, 2002). Very often, there is a limited time window for patients to practice their gaits in order to achieve a desirable level of recovery. While the full attention of a therapist will definitely encourage a patient to practice his or her gait, the cost of one-on-one service is high. A study was carried out to develop and evaluate VR game prototypes as an assistive technology to encourage and motivate stroke patients to practice their gaits.

This prototype was designed to enable a nursing assistant to help a patient to practice their motor skill under the remote supervision of a therapist. It was hoped that a VR gaming environment would be more engaging for stroke patients to practice their gaits. With these goals in mind, the design team developed two turn-key prototype systems for testing and verification.

The objective of this study was to evaluate the level of acceptance among medical practitioners and to identify and generic concerns. The benefits of using VR technology for rehabilitation has been the subject of many studies (Edmans *et al.*, 2004; Jung *et al.*, 2006; Kiryu and So, 2007; Saposnik *et al.*, 2010; and Stewart *et al.*, 2006; Sveistrup, 2004). In particular, Saposnik and his colleagues reported a randomized trial using Wii games for rehabilitation with 20 stroke patients. Encouraging results were found. As part of the outcomes of the EU project entitled 'PLAYMANCER', Lam *et al.* (2009) reviewed the use of VR games for rehabilitations and reported promising therapy results (Lam *et al.,* 2009). The focus of current study is to obtain critical opinions from medical practitioners such as physiotherapists, occupational therapists, and prosthetic-orthotic therapists. This study was approved by the Human Subject Committee of the Hong Kong University of Science and Technology. .

Figure 1. *A street of Hong Kong.*

2. The Virtual Reality Gaming Hardware

The main theme of the game was to encourage patients to walk through virtual streets of Hong Kong on a passive treadmill and collect points that would lead to some kind of real world rewards. The use of urban areas instead of country side was recommended by the physiotherapists whose aims were to train the stroke patients to be able to coupe with daily living in a city. Figure 1 shows a snapshot of a street in Hong Kong. Streets of Hong Kong were drawn in 3D Studio Max^{TM} (Figure 2) and were animated into a gaming environment using the RenderwareTM programming platform (Figure 3). To increase the realism, computer-animated characters were placed on the streets and audio recordings of real surrounds were used.

While the game content and the VR graphics work towards the enhancement of the level of enjoyment for patients, correct gait postures had to be encouraged and monitored. Consequently, goniometers (measuring angles of the knee and ankle joints), in-sole pressure pads, and customized software were developed to monitor and measure the gait postures of the patients. Since this paper focuses on the evaluation aspects of the study, details of the technical designs and implementations are not presented here. At certain levels of the game prototype, a proper move was only registered when a correct gait posture and sequence was measured (Whittle, 1991). Depending on the level of difficulty in the game, the program had different requirements on the correctness of the gaits. In addition to the pressure pads and the goniometers, a digital camera was used to record pictures of the gait cycles. Information was stored in a database and therapists could then study and assess the progress of individual patients remotely via their mobile devices such as ipadTM or iPhoneTM (Figure 4).

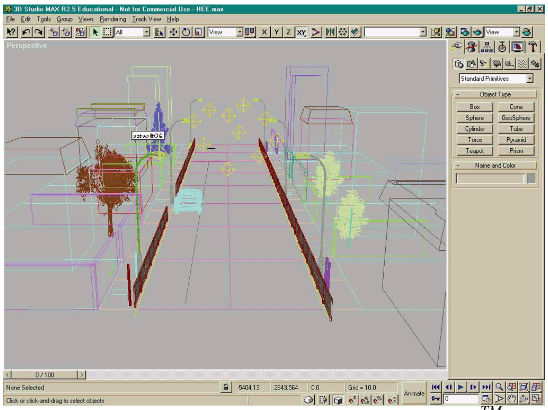

Figure 2. *A street of Hong Kong in 3D Studio Max^{TM}*.

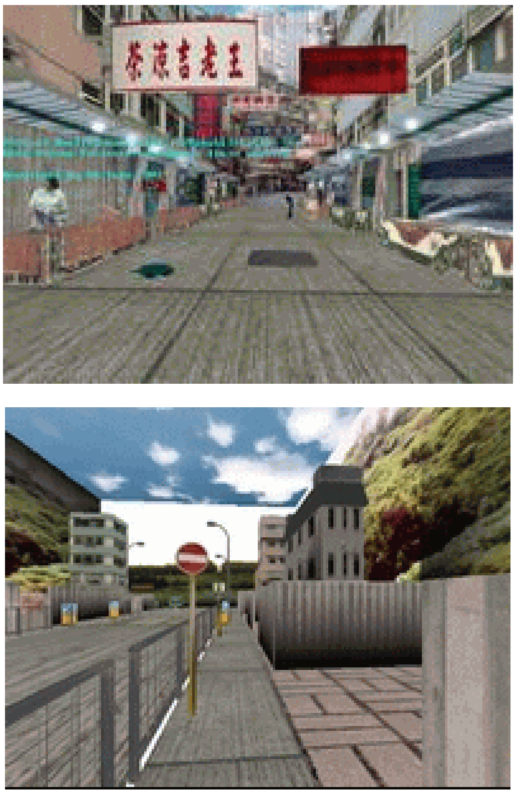

Figure 3. *Computer-animated streets of Hong Kong in Renderware^{TM}*.

All the hardware components in the system were powered by four AA-size batteries and data connections to computers were optically isolated to prevent electric shocks to the patients. A safety harness was installed to support the patient. Figure 5 illustrates the finished Mark I prototype. This prototype used a binocular head-mounted display (HMD, io-glassTM with outside view blocked) and viewers could turn their heads to get panoramic stereoscopic views of the VR game environment.

3. The Game

The objective of the game was to encourage stroke patients to walk on the streets of Hong Kong in the presence of traffic and with proper gait patterns. These objectives were developed through consultation with physiotherapists and occupational therapists at the Rehabilitation Engineering Center of the Hong Kong Polytechnic University. Users were invited to walk along the virtual pavements from location A to location B through animated VR scenes of the city of Hong Kong. Their progress was rewarded by points proportional to the meters that they have walked and these points could be transferred to real incentives such as supermarket coupons. The game has three levels. At the first level, gait parameters (knee angles, ankle angles, and in-sole pressures) were only measured and were not feedback to the patients. At the next levels, therapists could set different constraint and requirements on the gait measurements so that patients need to exercise a pre-determined gait cycle pattern before the gaming consoles would register a successful step forward on the virtual pavement. At the highest levels, different distractions like traffic noise, car horns, road blocks, street noise could be added by the therapists as appropriate. Through out the gaming experience, audio and visual feedbacks were played interactively to the users through speakers and displays (HMD in Mark I and panoramic displays in Mark II).

The authors would like to stress that the games were only means to an end in this study. While every possible attempt were spent to make the games perfect, the real objective of the study was to solicit and evaluate the responses of practicing therapists on the appropriateness of such gaming interventions to the in-hospital rehabilitation of patients recovering from strokes.

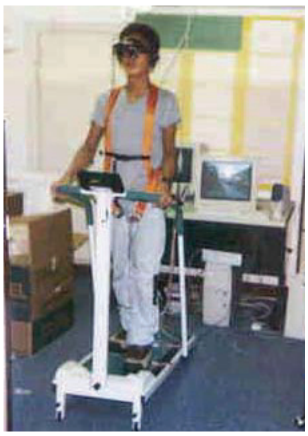

Figure 5. *The Mark I prototype system.*

4. The Evaluation

The Mark I prototype was delivered to the rehabilitation centre at the Hong Kong Polytechnic University for testing and verification. Twenty-six physiotherapists, occupational therapists, prosthetic-orthotic therapists and rehabilitation engineers were invited and twenty participated in the evaluation study. They were 10 physiotherapists, 6 occupational therapists, 2 prosthetic-orthotic therapists and 2 rehabilitation engineers. After the evaluation trials, they were asked to complete a questionnaire about the potential benefits of the prototype. They were also de-briefed so that we could obtain suggestions for improvement. Eleven and five therapists agreed and strongly agreed, respectively, that the introduction of the VR walking game could help them to better manage the rehabilitation of post-stroke patients. In particular, the use of VR game could increase the motivation of the post-stroke patients to exercise during the critical period after their respective operations. The remaining four therapists expressed concerns about the competency of a nursing assistant to oversee the procedure and the quality of the HMD. Indeed, twelve therapists expressed concerns over the quality of the HMD both in its delayed responses to head movements and the optical distortion. In particular, therapists were concerned about possible visual stress that patients might experience in order to for their eyes to verge to form a stereoscopic view of the 3D streets. The Mark I prototype presented head-steered stereoscopic views of the computer-generated 3D streets on a commercially available HMD. A review of literatures confirmed that the mismatch between accommodation demands and vergence requirement and visually induced motion sickness (VIMS) are potential problems with the use of HMDs (e.g., Chang et al., 2007; Lo and So, 2001). So et al. (1999) reported that about one-third of the Hong Kong Chinese population is susceptible to motion sickness. Previous studies have shown that viewing rotating or translating scene motion displayed on a HMD can cause significant increases in symptoms of motion sickness such as nausea and eye fatigue (e.g., Lo and So, 2001; So et al., 2001). In addition, delayed responses of images to head movements could also cause degradation to perceived difficulty of a task (So and Chung, 2002; So and Griffin, 2000). Consequently, a second prototype, the Mark II prototype, with three panel-mounted displays was developed. This prototype replaced the HMD with three displays mounted side-by-side. Results of further evaluation indicated that concerns for visual stress were completely eliminated. During the de-briefing, patient safety was singled out as the most important consideration when the games were to be introduced into the clinic setting. When asked whether the use of hanging harness was enough, 16 out of 20 therapists agreed that it should be enough.

As mentioned in the introduction, while applications of VR technology to rehabilitation is not new (Kiryu and So, 2007), feedback from clinic practitioners such as physiotherapists, occupational therapists, and prosthetic-orthotic therapists could not be found. Besides the reported prevalence of acceptance levels of VR technology, one major contribution of the study is to identify major concerns towards an ideal VR game for successful application to the field of rehabilitation of post stroke patients. After using both gaming prototypes, therapists were asked to rate their concerns on 27 technical aspects of the systems. The 27 aspects can be grouped under 7 headings: (i) the visual environment; (ii) the audio environment; (iii) the user interfaces; (iv) display hardware; (v) the postural measurements; (vi) the treadmill; and (vii) other sensory feedback either than visual and audio. Due to the constraints in resources, only eight out of twenty therapists were able to complete two repeated sessions taken place on different days (test and re-test trials). Results of correlation tests showed that the results of the test and re-test trials are significantly correlated with coefficient of 0.9 ($p<0.001$, Pearson). Using pair-t tests, the aspect that received significantly higher and lower scores (+4: strongly recommend; +2: recommend; 0: neutral; -2: not recommend; -4: strongly not recommend) were identified and are shown in Figure 6. Results of six questions are highlighted. Q1 refers to more realistic graphics; Q2 refers to the addition of more virtual environments (e.g., park, apartment, workplace, beach); Q6 refers to adding more difficulty levels for different stages of patients; Q8 refers to adding other leg exercises such as squatting; Q9 refers to adding game-like voice and music when patients passed their levels; Q25 refers to the reduction of the initial force require to move the passive treadmill.

In addition, therapists were also asked to identify the three aspects that they thought were most important to the success of the game application. The authors were surprised of the spread of opinion. Among the 27 aspects, Q2 referring to the addition of more virtual environments other than the streets was rated as most important by the therapists. Subsequent de-briefing with the therapists indicated that the visual feedback of different environments would be very helpful for patients to re-establish their neural connections. In particular, if environments personalized to individual patients (e.g., streets around their home or even their homes) can be used,

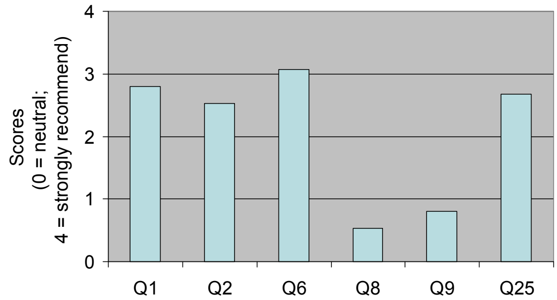

Figure 6. *Mean scores of selected questions that have significantly higher or lower scores within the survey. Details of Q1, 2, 6, 8, 9, and 25 are explained in the main text.*

it would be the best.

5. Conclusions and Limitations

Two virtual reality gait walking rehab gaming systems have been designed and developed (Mark I and II). Both systems allow users to walk on a passive treadmill and receive visual and audio feedback. Evaluation tests were conducted with twenty physiotherapists, occupational therapists, and prosthetic-orthotic therapists. The questionnaires passed the test-and-retest with a correlation coefficient of 0.9 ($p<0.001$, Pearson). Results of the evaluation indicated that 80% of the therapist agreed or strongly agreed that the introduction of a virtual reality game as an assistive tool would help them to manage the rehabilitation of patients recovering from stroke. Specific technical aspects related to an ideal VR game for patient rehabilitation were recommended based on statistical analyses of the survey data. In particular, the use of different virtual environments that are familiar to the patients had been identified as one of the most important features of a successful VR rehabilitation game.

The authors acknowledged that real post stroke patients were not tested in this study. Only therapists were used because of additional liability concerns over the use of stroke patients. However, all the therapists were practitioners and they have ample experience in serving patients in a clinical setting. In the current system, a safety harness was used to prevent users from falling. Further testing on the effectiveness of the harness for fall prevention is desirable before conducting tests on patients.

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