Designing a Game-based Solution for In-home Rehabilitation

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Abstract: This paper presents initial concepts and formative evaluation results from a research (REHAB@HOME) investigating the patient-centred design of game environments aimed at raising patients' motivation and compliance with motor-cognitive rehabilitation programs. During the initial phase of the project five games were deployed through main gaming platforms and interaction devices (Kinect, LeapMotion, Sifteo Cubes). A pilot study involving six patients from two different rehabilitation centres (one in Italy and one in Austria) was conducted to assess usability and motivational factors implied in the initial usage of the solutions proposed. From the pilot study results we derive indications to inform the future design of game solutions for raising patients' compliance with upper body rehabilitation programs.

1 INTRODUCTION

Stroke is the second most common cause of death in Europe (EU Cardiovascular Disease statistics 2012) and it affects about 15 million people worldwide each year. Stroke survivors experience a broad range of problems that can impact their cognitive and motor systems, leading to chronic disability (e.g., hemiparesis) more often affecting the upper body (i.e., arms, Dobkin, 2005). The goal of rehabilitation is to help survivors become as independent as possible and to attain the best possible quality of life. For over half of stroke patients, rehabilitation will be a long-term process requiring work supervised by therapists, supported by specialized equipment, lasting several months. However, increasing cost pressure on the healthcare system is leading to shorter periods of intensive rehabilitation at specialized facilities. Therefore the adoption of suitable technologies for in home rehabilitation, together with a proper training about the execution of a personalized program of exercises, can help reduce the patient's stay at the hospital, as well as the need and cost of reaching the rehabilitation facilities. In this work, we present early results from the REHAB@HOME European project where game solutions for rehabilitation of the upper body were designed and tested in a pilot study conducted at two different rehabilitation centers, one in Italy and one in Austria.

2 RELATED WORK

In the area of rehabilitation research and practice, there have been previous attempts to leverage on low cost gaming platforms, such as Wii (Deutsch et al., 2008) and Playstation 2 EyeToy (Flynn et al., 2007), to support post-stroke therapy. However, these solutions are difficult to deploy with patients in earlier stages of recovery when they have only limited range of motion. For this type of patients other more specific game-based solutions have been recently proposed. Huber et al. (2008) and Jack et al. (2001) developed haptic glove based games in which users scare away butterflies, play the piano, and squeeze virtual pistons to improve the player's finger flexion and extension. Burke et al. (2009) built two webcam color tracked games similar to whack-a mole. In addition, they created a physics-

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based orange catching game and a whack-a-mouse game, both controlled with magnetic sensors and a vibraphone game, using a Wii remote as a pointing device. Game concepts and solutions more related to everyday tasks and activities of daily living have been explored to increase patients' motivation to play, by providing more meaningful settings (Sanchez et al., 2006; Burke et al., 2009). Flores et al. (2008) identified game design criteria that stem from stroke rehabilitation and elderly entertainment. Vandermaesen et al. (2013) developed the Liftacube prototype for training of the upper extremities and tested it with four patients (affected by cerebrovascular accident or paraplegia) finding encouraging results and benefits regarding patients' motivation.

In our work, instead of focusing on developing games for specific ranges of disability we aim to realize solutions that can be adapted for use by patients at different levels of recovery (a similar approach was proposed in Alankus, 2011). By informing our design with requirements from therapists and patients, we aim to realize a rehabilitation platform enabling therapists to select and tailor games for individual patients' programs.

3 GAME DESIGN FOR MOTOR REHABILITATION

During the first year of the REHAB@HOME project we conducted a patient centered design process to realize a set of rehabilitation games targeting post-stroke and multiple sclerosis patients in need of upper body motor rehabilitation. The design process also involved requirements collected by interviewing a number of therapists at Fondazione Don Gnocchi (Italy) and Neurological Therapeutic Centre Gmundnerberg (Austria). We ended up developing four games, three of which could be played with the Kinect gaming platform, one with the SifteoCubes platform. We also decided to include in the experimentation an available game for the novel LeapMotion device (a sensor controller that supports hand and finger motions as input, analogous to a mouse, but requiring no hand contact or touching).

The criteria for inclusion and development of these 5 games, was to assess their benefits for deployment in the context of arm/hand motor rehabilitation sessions. The specific movements required by the games were the following: shoulder abduction, adduction, flexion, extension, wrist flexion, extension, supination, opening/closing of hand, reaching movements and finger movements of precision.

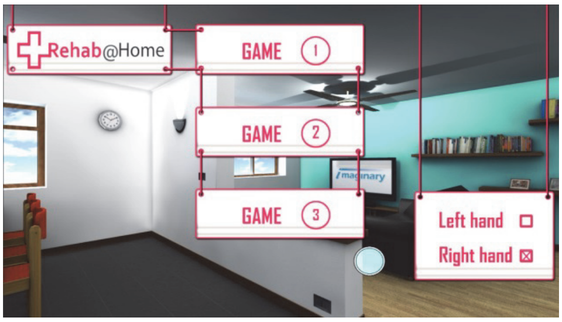

Figure 1: Screenshot of the menu to select the Kinect games.

In the following we briefly describe the games considered for our initial pilot testing (Fig.1 shows the menu screen for selecting the Kinect games developed): 1) Bombs&Flowers minigame [Kinect]: the patient interacts in a living room environment where s/he has to touch flowers items and avoid bombs, s/he is required to use both hands and is provided instructions, visual feedback, and total score achieved during the session. 2) Can minigame [Kinect]: the patient needs to move cans from a central table to the correct shelf, by matching corresponding colors which change position during the game; s/he can use just one hand per session and get instructions, visual feedback and overall score achieved. 3) Blackboard minigame [Kinect]: the patient needs to move different shapes from the left side to colored spots on the right side, by following a random path. Random pairings are proposed (e.g. star-blue, square-red) on the top of the screen, red dots appear along the path, which should be collected; instructions, visual feedback and overall score are also provided. 4) Caterpillar game [LeapMotion]: the patient needs to guide a caterpillar around the screen with one finger to collect numbers in a sequential order, achieve levels and eventually become a butterfly; instructions, visual and auditory feedback are provided. 5) Simon game [Sifteo Cubes, Fig.2]: 3 (1.7 inch) cubes are provided in fixed positions on a table which display colours randomly assigned by the system; the patient is asked to tilt a fourth cube to select a colour on its display and put the cube in contact with the corresponding cube (same colour) in the fixed positions; visual, auditory feedback, number of sessions played and score are provided through the cubes displays; typically the patient plays by using one hand for 3 consecutive sessions.

Figure 2: Simon game played with Sifteo Cubes.

3.1 The Pilot Study

To preliminary assess the level of usability and engagement of the games and devices described above, we conducted a pilot study involving 6 post-stroke and multiple sclerosis patients (age range 54-74, Mean: 66) with motor impairments of the upper body, enrolled in rehabilitation programs (since at least a month before) at the two rehabilitation centers in Italy and Austria (Table 1). The test sessions were run in dedicated rooms at each center (where the devices and games had been previously set up) and demonstrated to patients by a member of the research team. Each patient was asked to try at least one session with each device/game available and then to provide feedback and ratings on their user experience, perceived usefulness, motivation to use of the device/games experienced in a final semi-structured interview. Example of the questions used in the interviews: "How useful would you rate the **devices\games** used to support the rehabilitation program at home?" on a Likert scale from 1 to 7. The overall session lasted about 1 hour. The sessions were video recorded for subsequent analysis, the input devices and games were presented randomly to avoid order effects. The contents of the video recordings were analysed independently by 3 human factors specialists to extract relevant usability and user experience indicators regarding ease-of-use, learnability, level of engagement, effectiveness, satisfaction, error frequency and prevention. The individual reports of the 3 specialists were then discussed in a meeting and results summarized in a final document shared with the developers' team. The post session interview data were analysed to identify the main points of strength and weakness of the solutions tested and inspire our next development phases.

Table 1: Patients demographics and clinical characteristics.

Patient (Gender)	Age	Clinical characteristics
P1 (M)	62	Post-stroke, motor impairment of the right upper limb
P2 (M)	71	Post-stroke, motor impairment of the left limb
P3 (F)	54	Multiple Sclerosis, motor impairment of left hand/arm, on a wheelchair
P4 (M)	71	Post-stroke, right hemiplegia
P5 (M)	74	Post-stroke, motor impairments affecting walking, right hand, voice, ataxia
P6 (M)	68	Post-stroke, motor impairment of right upper limb

3.1.1 Main Results

Table 2 below reports patients' ratings on a Likert scale (1-7) about the usefulness of the devices and games experienced during the pilot testing, based on the post-session interview asking each patient how useful each device and game experienced they thought would be for their rehabilitation needs. Overall, the feedback from patients was quite positive. The device scoring less was LeapMotion (Mean=3.6), which was rated lower for some difficulties patients experienced in controlling it. The Kinect device was considered useful, but some improvements to the calibration of the sensor were required to improve interaction. While all the games tested were judged as useful, the Caterpillar and Simon ones were scored higher due to their intuitiveness and facility of play for the patients.

Table 2: Patients perceived usefulness of the devices and games experienced (Likert scale 1=Not useful at all, 7=Extremely useful).

Type of Device / Game	Mean	SD
Kinect device	4.8	2.04
LeapMotion device	3.6	1.14
Sifteo Cubes device	6.3	0.57
Bomb&Flowers minigame	4.8	1.30
Can minigame	4.8	0.75
Blackboard minigame	3.8	1.67
Caterpillar game	5	2.16
Simon game	6.6	0.57

From the analysis of the videos and patients' comments we derived the following needs for improvements of the gaming environments for rehabilitation goals:

a) *Enable games to be easily adapted to patients' different needs and range of movement*: the solutions proposed during the pilot were still too rigid to fit the needs and range of arm/hand movements of most patients. Customization of the solutions should be supported in the future by providing a better calibration module for the Kinect device. In particular, it is very important to clearly define the minimal requirement of the movement abilities of the patients in addition to the limitations of the devices.

b) *Ensure correct execution of the movements, detect compensation:* many patients showed compensatory motion, like rotating/moving their trunk to achieve the game goal as a way of overcoming limitations in their range of motion in the affected limb. In the Simon game (Sifteo Cubes) some patients pushed the cube to be put in contact with the target cube instead of performing precise grasp and release actions. For future sessions we have developed a paper frame and setup where target cubes will be located, thus requiring a patient to raise a cube and move it more precisely to reach the target.

c) *Engage patients by providing more variability and difficulty levels in the games:* we observed that even games that required some effort to be played were able to engage patients with several repetitions performed during a session. However, even within the small group of patients involved, individual differences in needs, preferences and motivation were found that could be better fulfilled by a more comprehensive set of games and within game alternatives provided.

d) *Audio and visual elements should be improved for accessibility and usability:* size and contrast of colors, sounds, animations and other motivational effects available in the game environments were found to require improvements for accessibility and usability. Some of the patients involved had visual impairments (e.g., wore glasses) or had difficulties in reading text, perceiving colors. Accessibility requirements are particularly important to address when considering the target user groups of rehabilitation, to facilitate their adoption.

e) *Motivational elements and incentives should be added:* in the pilot we deployed a limited set of motivational elements, rewards, feedback and incentives, but they played an important role in motivating patients to further engage with the playing setting. Feedback and incentives are fundamental for a patient to keep track of progress made, goals/improvements achieved (Flores et al., 2008), and to avoid over performing or getting tired too soon (with the risk of getting bored) thus jeopardizing the aims of any rehabilitation program in the home setting.

f) *Collaborative forms of play should be added* (Alankus et al., 2010)*:* as many patients reported in the final interviews the possibility of playing some of the games proposed in a collaborative way (e.g., with caregivers, family members) would be important to further raise their motivation and interest in the therapy sessions. We are currently planning to design collaborative forms of play (e.g., with the Sifteo Cubes) to meet this request of the patients.

4 CONCLUSION

This work has presented some initial game concepts for upper body rehabilitation of post-stroke and multiple sclerosis patients, which have been developed for usage through low-cost gaming platforms suitable for home environments. Preliminary results from a pilot study conducted have shown that patients would be willing to use these gaming environments for rehabilitation purposes, provided that professional therapists supervision is also combined with these solutions. We are currently working at implementing a more integrated and improved version of our rehabilitation gaming environment that will include more advanced and complete versions of the games presented. Furthermore the rehabilitation gaming environment will be combined with a professional web client to remotely supervise the training sessions of patients from the rehabilitation centre. A second pilot testing of the integrated solution is planned for Fall 2014 involving a larger number of patients from the two clinics in Italy and Austria.

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