The design of a haptic exercise for post-stroke arm rehabilitation

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ABSTRACT

In this paper we present an application based on an immersive workbench and a haptic device, designed to motivate stroke patients in their rehabilitation of their arm. The work presented in this paper is the result of a six-month project, based on evaluation with stroke patients and on informal interviews with medical doctors, physiotherapists and occupational therapists. Our application called "The Labyrinth" has been used for studies with stroke patients and we have seen that arm rehabilitation using Virtual Environments and haptics can be very encouraging and motivating. These factors are crucial to improve the rehabilitation process.

1. INTRODUCTION

For a stroke patient the main concern is to improve. Rehabilitation is often crucial for recovery and has to be performed on a daily basis (Carr and Shephard 2003). Every individual has different needs and preferences so it is important to have a wide range of exercises to choose from. One of the most common symptoms after a stroke is impaired arm movement and haptic devices can potentially be used in the rehabilitation process as an alternative to ordinary rehabilitation exercises.

According to research by Andersson et al. (2003) the patient normally makes good progress during the beginning of the rehabilitation program when there are regular meetings and practice sessions with the physiotherapist/ occupational therapist (PT/OT). The problems often begin when the patient is supposed to continue their rehabilitation at home and on their own. Lack of motivation due to boredom and lack of support from family and friends can make the rehabilitation progress slow down. According to Broeren (2002) the use of meaningful and rewarding activities has been shown to improve the patient's motivation to practice.

According to Andersson et al. (2003), a new system needs to be implemented to rehabilitate stroke. This is particularly urgent as a consequence of the reduction in hospital funding and the increasing queues for healthcare. They suggest moving more of the rehabilitation to the patient's home. To do this, the home rehabilitation exercises need to be introduced at the rehabilitation clinic, so that the patient can get used to and understand the exercises. The problem in this case is that rehabilitation at home is not as efficient as rehabilitation in a clinic working under the expertise of nursing staff, primarily because the rehabilitation at home is irregular and not undertaken frequently enough. This is mainly because patients find the exercises boring and not stimulating, and also because the feedback from the clinic is unsatisfactory and not frequent enough. If it was easier for patients to see their progress immediately then they would be more motivated to keep on doing their exercises.

According to Carr and Shephard (2003) computer games are likely to be increasingly used in training for various aspects of upper-limb movement. They state that the use of a game focuses attention on the outcome of the movement as opposed to the movement itself. The motivating effects of being an active participant on an interesting task may be powerful facilitators in the rehabilitative process.

During the work progress we visited a rehabilitation clinic in Sweden. We tried most of the current rehabilitation exercises ourselves. There were exercises such as baking a cake, building a jigsaw, planting seeds but also games like Othello as well as sports like dart, swimming and tennis. The overall feeling we got from performing the exercises was that they were boring, repetitive and gave us a feeling of being back at pre-school. We also talked to some of the patients and they had similar opinions. One patient said that she felt the exercises sometime were only to tell her that she was worse than before the stroke, worse than average, and left her with a feeling of being worthless. Another patient said that she didn't do her best, because the exercises were not motivating enough. These two statements summarise the problem with the traditional exercises quite well. If the exercises leave the patients feeling worthless, it's quite obvious they will not feel motivated to do their best. If the patients are not doing their best, they will not receive the best possible rehabilitation.

The use of computer enhanced environments in combination with haptic devices for post-stroke rehabilitation has the possibility to address these problems and it is one of the reasons why it has become a popular area of research. Here we present some of them:

An advanced home rehabilitation systems incorporating both virtual reality and haptics (PHANTOM Omni) was proposed by Rydmark et al. (2005). In this system the patient's home-based workstation is connected to a rehabilitation unit with a game server with rehabilitation exercises, a patient database and a patient management system. Through the database system PT/OT can access information concerning motion capture data (movement of the haptic device). Using both data visualization and text output it is possible to analyze the work done by the patient while playing the game. The PT/OT can then evaluate the progress of the patient's rehabilitation and adjust the parameters of the game using the relevant patient data. System updates (game updates, new games, etc.) are carried out by the system developers when necessary. The benefit of this system is that new games may frequently be added and the PT/OT receives instant feedback on the patient's progress. It is used for rehabilitation of hemiplega (paralysis) in both the left and right upper-body. It also includes examples of games that are as yet very basic in nature. The same research team presented an initial study in 2002 (Broeren et al. (2002)) which shows promising results in the recovering process.

Another method used for post-stroke rehabilitation is "The Rutgers ankle" (Boian et al. (2002)).This involves controlling a computer game with a haptic device strapped to the foot. By moving the ankle, an airplane or boat is guided on-screen and the built-in-resistance helps rehabilitate the control mechanism of both the foot and the lower leg muscles. It is also worth noting that efforts have been made to create more engaging games by using force-feedback. For example, when the airplane bumps into something, as part of the game previously mentioned, the device gives the user haptic feedback.

An example of yet another device used for rehabilitation is the CyberGlove (Adamovich et al (2005)). It exercises various finger movements and increases strength. The exercises they use also seem to be quite simple of nature.

In this present project we have been trying to enhance our knowledge of the rehabilitative process through the exercises available today and creating a novel forms of exercise using virtual environments and haptics. It is not our intention to provide a substitute for those exercises already in use. We hope our application can complement them. The main reason for introducing virtual environments in combination with the rehabilitation process is the possibility of providing a number of alternative exercises that are engaging, stimulating and fun. In the research mentioned above, all exercises and games are quite basic and appear not being engaging enough. To fulfil the needs of a stroke patient, the exercises require careful design. In this paper we present an aid in the process of creating successful VR exercises in this context.

2. FUNDAMENTAL DESIGN CONSIDERATIONS

To make an exercise encouraging, stimulating, engaging and playable for a stroke patient several design aspects have to be considered. These aspects are the result of literature studies, informal interviews with medical doctors, physiotherapists, occupational therapists and a study with stroke patients. There are many design aspects and questions that arise when designing these exercises. In this paper we have decided to focus on the most important ones:

- *Reward system:* With an efficient reward system the chance of keeping the patients interest increases dramatically. Using a scoring system also gives the user instant feedback about the progress. By creating an exercise where the stroke patient can get a feel of achievement and encouragement, consequently the rehabilitation process will become more interesting. By incorporating the exercise in a VE it allows many possibilities of encouragement apart from just scoring systems, for example, a combined visual and sounding applause, cheerful animations and tunes, happy faces etc.
- *Difficulty:* The degree of disability after a stroke varies for different patients; hence the level of difficulty must be set individually. The patient's engagement needs to be maintained; too easy, no challenge; too hard, they are likely to give up. It is important to remember exercises that suit a smaller

range of patients should be considered as well. For example, specially designed exercises for patients in the first stages of the rehabilitation process where the patients may have particular needs.

- *Multimodal feedback:* It is important for the user to get real time task-specific feedback when interacting with the interface.
- *Environment design:* Textures and structures that resemble pleasant environments are effectively used to create suitable environments.
- *Intuitive task:* An exercise that would require long explanations and a long time of use to get used to might risk losing the patients interest in the initial stages. More advanced exercises could be motivated in the sense of increasing the challenge and make it more engaging, but must be designed carefully.
- *New possibilities:* In a virtual environment almost anything is possible. This allows us to listen to what stroke patients want and prefer, and create exercises based upon these criteria. There are many game ideas that stroke patients would find interesting, such as *The Labyrinth*, but also consider real-life situations that might be impossible to do with an impaired arm, for example playing an instrument, play sports, gardening etc. that are possible in a VE.

3. OUR APPLICATION

For our application we use an immersive workbench and a PHANTOM Omni from Sensable Technologies as a haptic input and output device to control the game. It is a mechanical arm that has 5 joints, enabling the user to interact with objects in the virtual environment. There is a 'pen' attached to the end of the mechanical arm and the user holds it with the hand to interact with virtual objects by moving their arm. The PHANTOM Omni is connected to a computer and the movement of the physical pen corresponds to the movement of the virtual stylus on screen (Figure 1).

As a development environment we chose to work with the H3D API from SenseGraphics AB. It is based on a scene graph structure and provides the developer with both haptic and graphical rendering. It runs on top of Open Haptics that is used for developing low level applications in C++. H3D is, on the other hand, a fairly easy and intuitive environment that enables a rapid development process. H3D API uses X3D for the scene graph and scripts are written in Python. The H3D API is open source and all updates are available freely on the Internet.

In the application we have built called "The Labyrinth" (Figure 1) the view for the user is as if the user was looking through a window into a room. Five outer walls make up the room and inside there are a number of smaller walls creating a maze.

The goal of the exercise is to navigate the virtual stylus through the maze (Figure 1), using the Phantom, from one panel to the other, without touching any of the walls. Touching the walls will give you minus five points but you are rewarded with plus fifty every time you touch the panels. After going back and forth two times a new set of walls are loaded, the next level. Every exercise consists of four levels, then you get a final score and a high score list based on previous games.

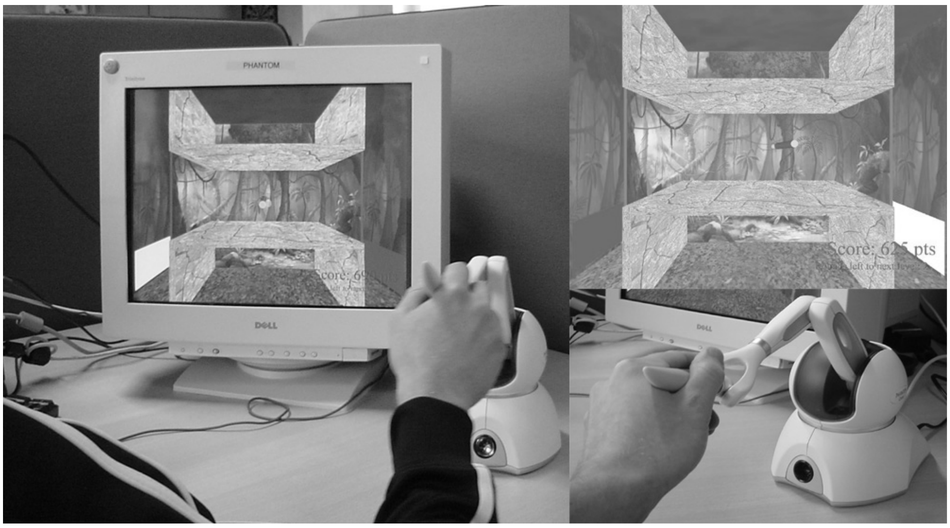

Figure 1. *The PHANTOM Omni and The Labyrinth.*

3.1 The design

The Labyrinth was created during an iterative design process and was informed by medical doctors, physiotherapists and occupational therapists. It was also finally tested with a group of stroke patients and after testing it was further refined. Here, we give some examples of how we have applied the fundamental design considerations in our application:

3.1.1 Reward System: The stroke patient gets rewarded and feedback on their progress by achieving a score that is displayed both during and at the end of a completed exercise. The top score from the five best games are displayed in a list. Ideally the patient feels motivated to set a higher score every time a new game is played and thereby wanting to improve. All of the scores are stored in a text-file making it possible for a PT/OT to monitor the patient's progress. This is the standard scoring method used in many computer games and works well for stroke exercises as well.

3.1.2 Difficulty: With The Labyrinth it is possible to set the difficulty by creating different mazes. It requires little effort and no programming to make new levels. This gives the PT/OT easy control over the level designs. In Figure 2 we present screen shots of four different levels of the game showing increasing difficulty.

It is the various movements e.g. avoiding the walls and going through the maze, that provides the training. A small maze with a few walls will make it possible for the user to go quickly through the maze using large arm movements, giving one type of training. Alternatively, the maze may have many walls and the user is forced to use smaller and more controlled movements thereby achieving another type of training.

Another way to set the degree of training is to use force fields. A force field is a static force applied in a specified direction and of a certain magnitude working on the haptic pen independent of its position. Initially, there is no force-feedback applied to the stylus, as it has no resistance. The task of going through the maze can then be made more difficult by applying resistance with a force field in, for example, the opposite direction of the patient's movement. Alternatively, a gravity force can be used to give the stylus a larger mass so it has to be lifted over the walls or balanced in between. There can also be objects that the user can pick up and carry to the other side of the labyrinth to gain bonus points. These objects can be of different size and weight to give a variety of training.

The Labyrinth is designed to be playable by a wide range of patients; both in the initial stages of rehabilitation and in their later stages.

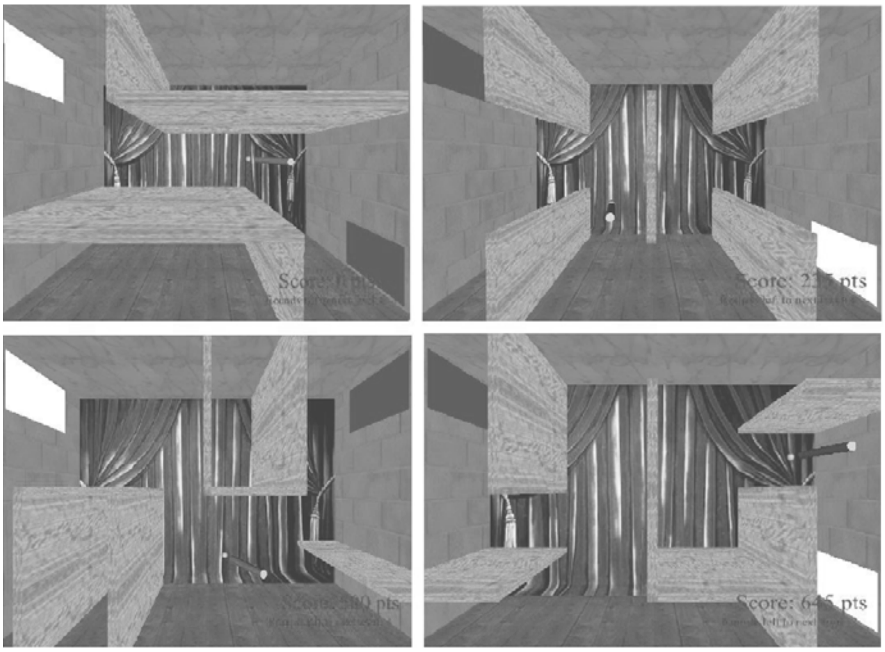

Figure 2. *Suggestion of level design with different difficulty.*

3.1.3 Multimodal Feedback. The PHANTOM Omni provides force feedback making it impossible to go through the walls. This forces the patient to stay inside of the maze and the user can feel when they are touching a wall. The user gets visual feedback every time one of the walls is touched by highlighting them in a different colour. Audio feedback is provided by using 'approving', harmonic sounds for the panels and 'disapproving', dissonant sounds for the walls. By using the force feedback as well as the audio and visual possibilities of the virtual environment, the communication with the stroke patient is very effective. The three different ways of showing the user when they have done something wrong makes the task more understandable. What we observed in our study (Dreifaldt and Lövquist 2006) was that patients want clear instructions before the exercise and instant feedback during the exercise, something that traditional exercises often lack.

3.1.4 Environment Design. In our case we have used three different types of environment to place the maze: jungle, theatre and mountains. Figure 2 shows the theatre design. Our goal is to find neutral but interesting environments.

3.1.5 Intuitive Task. With "The Labyrinth" the aim is to provide an exercise that is as intuitive as possible. It does not require more than a minute of explanation and then the patient can use it without hesitation.

4. STUDY

The initial prototype application design was based on literature reviews and informal interviews with medical doctors, physiotherapists and occupational therapists. To evaluate the application and to confirm our designs with end-users we did evaluation sessions with the "thinking aloud"-method (Lewis 1982) and additional discussions with three stroke patients. All of them enjoyed using "The Labyrinth" and they all showed increasing motivation when playing the game.

5.1 The Experimental setup

The final testing of the application was carried out during a one day qualitative study at a rehabilitation clinic in Sweden. The setup was the SenseGraphics 3D-IW Semi-immersive workbench and stereoscopical eyeglasses. The observations were both visual and auditory and the sessions were video recorded. The system was tested with three stroke patients. They all had 30 minutes each to use the system and another 30 minutes for an interview at the end of the session.

The users received the following instructions while watching the investigator playing the first level: Use the "Labyrinth" exercise. Start with level one, then move on to level two and finally level three. Start the game by pressing the "Start" button. The user should now move from one panel to the other and try not to touch any of the walls. The next panel to touch will light up (white) when touched and that panel then goes back to the "normal" colour and the other one lights up. Every time the users touch a panel they get plus 50 points and every time they touch a wall they get minus 5 points. When the level is finished the total score and a high-score list will be presented.

5.2 Users

The users are:

- *Patient A* was in her late 40's and had a stroke two months ago. She had good movement in her arm but was still confined to a wheelchair. She had good computer knowledge and a positive attitude to computers even though she did think that computer games were mostly for children.
- *Patient B* was also in her late 40's, she had her first stroke two years ago and was almost totally rehabilitated when she had a second stroke only a month before trying our system. She was the only one of the patients that was walking without a problem and also had the best movement in her arm. She didn't have much computer knowledge and admitted she was hesitant of computers.
- *Patient C* was in his late 50's and had a stroke only two weeks ago. Nevertheless he had a good movement in the arm. He told us he was very motivated to get better as soon as possible as he wanted to get back to his work as a surgeon. He was used to used to computers on a daily basis for writing patient's journals, and he was open and interested to new technology in the medical field.

5.3 Observations

We did not experience any problems with their understanding of the stereoscopic display or how to use the PHANTOM; even the patient with the least experience of computers understood that the movement of the mechanical stylus corresponded to the movement of the virtual stylus on screen. After just a couple of minutes of explaining the PHANTOM and the game, they started playing without hesitation. All three were focused on the task and determined to do their best and achieve a good result. None of the patients had any problems understanding the concept of the game or seeing or understanding the virtual environment.

In our experiment we encouraged them throughout the application. All of the three patients were able to complete the exercise, but not too easily. They all agreed that the application had a good mixture of challenge and provided a feeling of accomplishment. In fact, they all said that it was the best exercise they had tried so far.

Even if all three patients seemed to enjoy the system they had different ways of assessing the system. One of them liked it because it felt like a meaningful exercise, another because it was a fun game. It does not seem to matter if the patient considers it a game, exercise or test as long as they engage with it and find it meaningful (Meyer (2001), Kielhofner (1995), Kielhofner (1997)). What we learned was that none of the patients wanted to give up, while two of them complained of sore muscles, but still kept on trying without complaining about the exercise.

Patient C said that he wanted to take the system home to continue training. He saw lots of potential in using it for training his finer motor skills. To him, the encouragement and the playfulness of the system was not as important as the actual training itself. The reward for him was seeing that using the PHANTOM could help him in his recovery. He also said that the points were not that important to him, the important task for him was to avoid the walls and not, as we had thought, to get as a high score as possible. For him it would have been better to get more feedback and encouragement during the game play.

They all found the idea of timing the exercises as something that could be used to increase the level of difficulty. This would be best done in the later stages of the rehabilitation when the patient is used to the exercise, making it more challenging and keep their interest. It was also important to have the possibility of choosing between playing with or without the timing facility. Generally we saw that the more encouragement we used, the better. This would suggest further system implementations incorporating more positive feedback during the game play. For example one could have a voice saying “Good work!” every time a level is completed or adding more possibilities for increasing the score.

The study was carried out in Swedish and below are some quotes freely translated by the investigator.

- *This is much more fun then I thought, I was a bit sceptical before I came here, computer games are mostly for children, but this is fun!* − Patient A.
- *It’s very fun to do this! I think this is the future, will be a great interest for this! If you look at the other inpatients here at the clinic there are of all age groups but a lot of young people. If you look into the future it will be even more young people and even more people used to use computers.* − Patient A.
- *You want it to be easy so you can handle it and gain some self-confidence, but not too easy, then it gets childish. But this is not too easy.* − Patient B.
- *With this one you get it confirmed right away that if you do something wrong, then you feel it and see it, very good!* − Patient B.
- *I think this was very fun; I like to have a system like this at home.* − Patient C.
- *I’m very enthusiastic; actually, this is a perfect tool for therapy.* − Patient C.
- *This is the most fun rehabilitation thing I’ve tried and moreover you practice fine motor skills and I’m dependent on that in my work, so it makes me very motivated.* − Patient C.

5. CONCLUSIONS AND FUTURE WORK

From our studies with stroke patients we have seen that our system contributes to an overall pleasant and encouraging exercise experience. Our main concern is that patients see this as a complement to the rehabilitation techniques used today and to give them alternative exercises that are encouraging, challenging and fun to help ease their recovery. We have shown that it is possible to create encouraging stroke rehabilitation exercises using virtual environments and we also produced a set of general guidelines that can be used in future designs.

The Labyrinth is an example of a haptic exercise for post-stroke arm rehabilitation. It is not designed to be “the perfect” exercise but an application to show many different design aspects that has to be taken into account. We believe that future work will be creating more exercises giving patients more choice. All patients are individuals and have different needs and preferences, hence there must be a wide range of exercises available.

The current application only uses force fields to make the game play more difficult. It would be desirable to create force fields to aid patients with severe arm disability to make it easier to perform the exercise. By having a force field that the stylus floats upon and repelling walls would make it easier to complete the task.

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