Game-Based Collaborative Training for Arm Rehabilitation of MS Patients: A Proof-of-concept Game

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Abstract

In order to optimise functional performance and quality of life of multiple sclerosis (MS) patients, it is important to provide them with an appropriate rehabilitation program. Especially, during the later stages of the disease, exercising the upper limb is needed to maximise functionality in daily life. In order to provide patients with an individual training program, adapted to their possibilities and to assess their progress, we have been investigating the feasibility of using force feedback in combination with a virtual environment. However, the training tasks given to patients must be motivating for them to continue the rehabilitation program for a longer period. To increase this motivation, we have developed a collaborative rehabilitation game. In this game, the patient has to make training-specific movements in order to successfully complete the game. This game can, however, not be played alone. In fact, only through collaboration of the patient, using the HapticMaster, and the co-player, using a WiiMote or a force-feedback device, they can successfully play the game.

COLLABORATIVE GAMING, REHABILITATION, VIRTUAL ENVIRONMENTS, FORCE FEEDBACK, SERIOUS GAMES

Introduction

Multiple Sclerosis (MS) is a chronic progressive disease of the central nervous system. Depending on the distribution of lesions within the brain, MS may clinically present with impairments of strength, muscle tone, sensation, co-ordination, balance, bladder and bowel function, as well as visual and cognitive deficits, often leading to severe limitations of functioning in daily life. Studies of exercise therapy, focused on balance and walking outcome parameters, have shown a beneficial effect regarding muscle strength, exercise tolerance level, functional mobility and quality of life, while no important deleterious effects were reported (Dalgas et al., 2008). Very few studies have properly investigated the therapeutic potential of arm training in persons with MS. Because training duration and training intensity are considered to be key factors for a successful neurological rehabilitation (Kwakkel et al., 2004), rehabilitation robotics are introduced to provide additional exercises that can be performed independently of the therapist. Crucially, the patient has to be motivated, and keep being motivated to continue the training regime. We are investigating the value of force-feedback assisted rehabilitation of the upper extremities in persons with MS (Feys et al, 2009) and how such technologies can be applied in a self-motivating way. More concretely, a virtual environment (VE) has been realized, which provides the patients with training tasks to be carried out and monitors their progress and success rate (Coninx et al., 2008). Until now the training environments are, however, single-user environments: patients work on their own on the tasks performed in the virtual environment.

As it is important in a rehabilitation setting to keep the patients engaged with the training program in order to achieve beneficial training effects, we are currently investigating how motivational aspects can enhance the training. One important aspect is to involve social interaction to support collaboration and/or competition, which we will discuss in this paper. There is no doubt that gaming concepts have a stimulating effect on engagement in tasks, and that social factors incorporated in many games have added effects on people's enjoyment of playing digital games. In this paper, we focus on engagement in rehabilitation tasks, and, more specifically, on using social interaction as a motivating factor. We first discuss the feasibility, and effectiveness of using force-feedback systems in the domain of rehabilitation training, and will then present a way of increasing patients' motivation to continue such training regimes by opening up the possibility of social play.

Objectives

The overall aim of our investigation is to assess, and where possible increase, the potential of the force-feedback devices for training in the context of rehabilitation of MS patients with upper limb dysfunction. Besides measuring the effect of a force-feedback assisted training approach (Do some quantifiable parameters such as muscle strength and arm function improve after repeated training?), we want to judge some usability issues such as acceptance of this kind of training program by MS and also CVA (stroke) patients.

In order to estimate the effect of the repeated force-feedback assisted tasks, it is important to design appropriate movement tasks. For instance, difficulty levels allow for effect measurements and tasks are designed to allow for as much carry over to actions in daily life as possible. Therefore, the team consists both of rehabilitation and computer scientists, working in a close cooperation with MS patients and clinical therapists of rehabilitation centres. During the design and realization of the training tasks, it is important to pay attention to the possibility of measuring the patient's behaviour, e.g. by means of data logging with respect to movements with the device. The applied training concept also includes to "steer" the patient's behaviour when performing the task by facilitating or obstructing the user's movements through the generation of appropriate forces by the force-feedback device. This allows for personalization depending on the present capabilities of the patient and to change the training level.

Rehabilitation training

Figure 1 Training tasks

In a first phase, we tested the feasibility of force-feedback for rehabilitation purposes. To reach the above-mentioned objectives, a virtual environment was created, consisting of three training applications. Taking into account that some MS patients have reduced cognitive abilities and to minimise initial learning effects, the tasks have to be simple and easy to learn. We have chosen a trajectory task, an object manipulation task, and a speeded-tapping task (see Figure 1) to address different types of motor function. A Phantom 1.5 was used as force-feedback device.

In the first task, the patient had to steer a virtual car over a preset trajectory. The patient was aided in this task by restricting the movements of the force-feedback device to a 2D plane in which the road was located. An adjustable force was applied attracting the car to the centre of the road. This spring force could be set in 3 levels, ranging from small to medium to large, each changing the spring stiffness with a factor of 10. The actual spring constants were empirically determined during several pre-tests.

For the second task, users had to pick up a (virtual) book lying on a table and had to place it in a bookcase. The applied forces simulated the gravity and inertia of the book. According to the patient's capabilities, the weight of the book (force-feedback setting) could be adjusted in 3 levels between 0.5, 1.0 and 1.5 kilograms.

The third task was a virtual implementation of the speeded-tapping task. For this task, a guiding force which restricted the patient's movement to a vertical plane could be set. As in the other two tasks, an incremental 3-level force-feedback adjustment was available: the first level created two stiff walls where the cursor was kept in between. The second level implemented a spring force centring the cursor, and the third level provided no guiding plane at all.

Finally, according to the patients' needs, the scaling factor between the real and the virtual movements (Control Display Gain) could be adjusted. A large scale required larger but less accurate movements, while a small scale appeared to be more difficult due to the required accuracy.

These rehabilitation tasks were successfully assessed during a clinical study. More information can be found in (Coninx et al., 2008).

Although the tasks presented in this section have shown the potential of using force-feedback as a rehabilitation tool, they are too simple to use in a real-life setting. Certainly, in order to motivate patients to perform these exercises intensively over a prolonged period of time, they have to be engaging.
In our current research we are defining a number of mini-games, where a patient needs to do some movements, which are identified as beneficial for the therapy, in order to

score points or win the game. It is beyond the scope of this paper to provide details on the way the training for different skills and movements is built up using different training tasks and games, but Figure 2 shows such a game to illustrate the approach. The patient has to move a monkey, connected to a spring, while fishes are trying to jump to the monkey. This movement is realized by pulling the handle of the force-feedback device upwards or downwards, while the device tries to counteract the movement. Every time a fish hits the monkey, the user loses a life (indicated by the balloons in the lower left). The patient is challenged to "stay alive" for 30 seconds, as indicated by a progress bar.

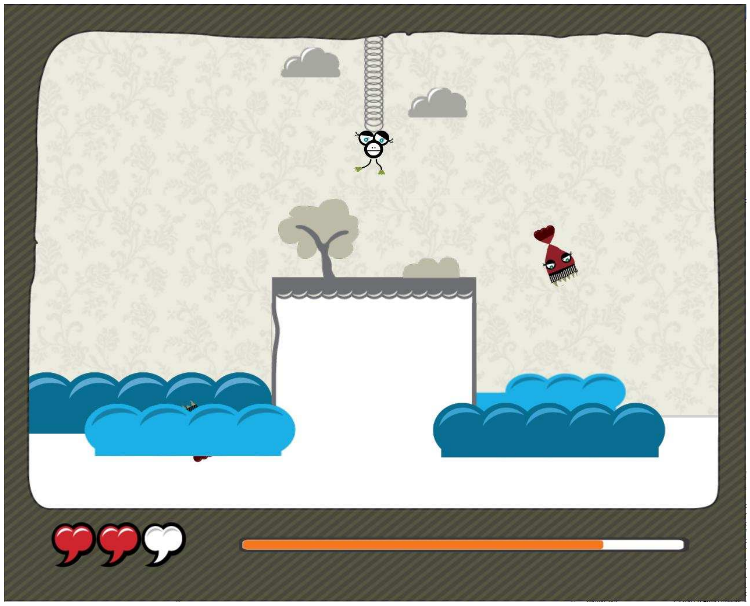

Figure 2 Game-like training task

In preparation for an extensive effect study further in the research project, individual design factors with respect to visual feedback and force-feedback have been assessed in a formal experiment with patients. Furthermore, training tasks and games have been discussed several times informally with patients to find out design guidelines to steer the fine-tuning and further development of the game concepts used for rehabilitation.

From Single User Rehabilitation to Collaborative Rehabilitation

The studies discussed until now have shown the added benefit force-feedback systems can have for rehabilitation. These are, however, still focussing on training as a single user activity: i.e., the patient may train in the presence of a physiotherapist, and they are still performing a task on their own. In addition to this user-centric approach and based on our former research results, we are currently investigating how social support can be beneficial for the motivation of patients. Importantly, family and friends can provide social support, but it can also come from other support groups like fellow patients or physiotherapists for instance. Social support also has the potential to go beyond an increase in motivation for patients to continue training. Additionally, social interaction (a likely side-effect of co-play) may also result in patients gaining viable social interaction, allowing them to share stories with fellow patients, and provide or receive support.

The way collaboration has been realized in the proposed game concept for rehabilitation is inspired by former research. The collaborative mobile games built on the ARCHIE framework that is used during a museum visit of groups of youngsters (Schroyen et al., 2008) nicely illustrate that social interaction is beneficial to train social learning skills. Learning about the museum and learning social skills are built into the game design. Different ways and communication channels are used to stimulate social interaction mainly in a co-located situation. Division of a task over several players is a powerful technique that we also apply in the social rehabilitation game presented in this paper. Extensive user testing has shown the effectiveness of the approach, and highlights the engagement of the players in their task.

The importance of social support for patients' adaptation to chronic health problems, such as MS has not gone unnoticed in literature. Wineman (1990) studied psychosocial adaptation to MS in a patient group of 38 men and 80 women. Path analysis revealed that perceived supportiveness of interactions was directly related to perceived purpose-in-life. Foote et al. (1990) reported on demographic data of 40 individuals with MS and found a statistically significant relationship between hope and social support and social support and self-esteem. Related to physical rehabilitation, Motl et al. (2008) demonstrated relationships between factors of social support, enjoyment and self-efficacy with the amount of physical exercise performed in daily life. Such beneficial effects of social support suggests that collaboration and mutual support during rehabilitation exercises may provide two key advantages over single user rehabilitation: (1) collaboration will make exercises more engaging, thus making adherence to a frequent exercise regime more likely, and (2) collaboration will extend and strengthen perceived social support, giving rise to additional beneficial health and psychosocial effects. On the other hand, Betker et al. (2007) and Sietsema et al. (1992) showed that game-like rehabilitation has a positive influence on people with brain injury, while Deutsch et al. (2008) used a Wii to investigate the rehabilitation of a patient with cerebral palsy.

Within our current research approach MS patients are the primary target group in the research project we are reporting about, given the multiplicity of symptoms and functioning problems that occur. However, the needs of CVA patients are also considered due to similarities in arm dysfunction and rehabilitation approaches that are applied. Van den Hoogen, IJsselsteijn & de Kort (2009) have performed a first requirements analysis into the rehabilitation needs of CVA patients and their social network. Their results indicate that: (1) social support is critical for patient motivation in order to adhere to the necessary regime of rehabilitation exercises in the chronic phase of CVA, (2) there is a perceived difficulty within the intimate social network around a patient (family, friends) in (re)connecting to the patient, and there is a need to engage in meaningful activities with the patient, (3) technology is not yet available that is specifically designed to support such social engagement with the larger social circle around CVA patients. Based on this research, we suggest deploying digital game technology not only for its intrinsic motivational potential, but also because digital games are excellent platforms for social interaction (de Kort & IJsselsteijn, 2008). Such social interactions may occur at a distance (as is the case with most online games, such as World of Warcraft) or may be co-located (e.g., multiplayer options using the Wii). Social interactions in games have been demonstrated to yield positive effects in terms of player experience in healthy subjects (Gajadhar, de Kort & IJsselsteijn, 2009). However, as noted by van den Hoogen et al. (2009), some game design adaptations may be necessary to make a game similarly engaging to CVA and MS patients and to their social network, which may include other patients, but also friends and of course family.

Focussing on the latter, one can imagine a situation, where a patient is visited by a family member (e.g. a grandchild). This family member could help the patient in the rehabilitation program by playing some collaborating games, hence making these exercises more pleasant to perform. Using the digital technologies and the internet it further makes co-play over large distance possible as well, allowing family members to visit and interact with the patient virtually. A recent study using healthy subjects has already proven that this concept of co-play over large distances influences people's motivation of attending to the task (Johnson, Loureiro & Harwin, 2008). In their study, using two force-feedback systems very similar to the one we are using in the current research (HapticMaster with a passive Gimbal attached to it), they had the participants play against a PC or against a real opponent on another continent. They found that the latter, a collaborative force-feedback mediated environment to be evaluated as more valuable, interesting, enjoyable, and they were therefore more willing to spend more time at the task. In sum, playing against a real opponent rather than the PC, increased peoples' motivation to attend to the task. This additional stimulation may also be especially useful in chronic patients with mild cognitive impairment who would need encouragement to practice. An overview of advantages and disadvantages of using such rehabilitation applications can be found in (Burdea, 2003).

Collaborative BalancePump

In order to investigate if collaboration can be applied for motivating MS patients, we developed a proof-of-concept application: a two-player balance pump game (see Figure 3). The goal of this game is to collect all stars by hitting them with a ball. The ball can be moved by lifting both ends of the beam. Each end of the beam is controlled by one of the two players involved in the game. Through a pumping gesture, the players can move their end upwards. By giving the beam an inclination, the ball can roll towards a star. This way both players have to collaborate in order to collect all the stars.

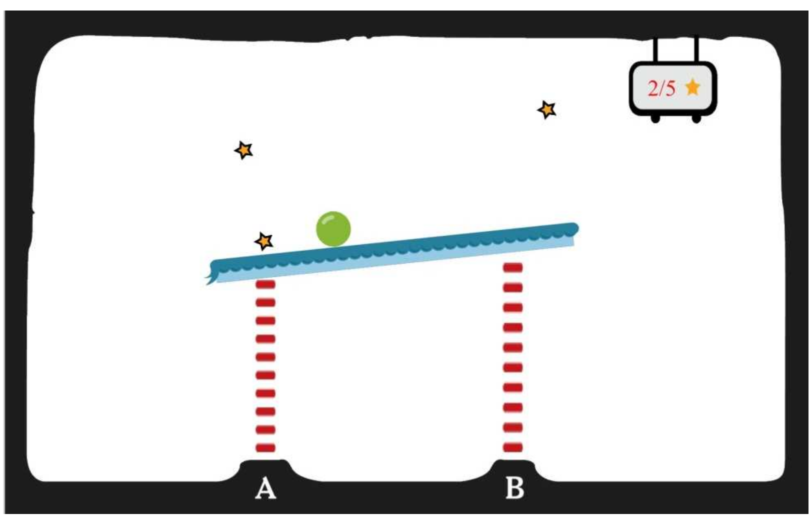

Figure 3: Collaborative training task

Both players can either use a force-feedback device to control the pump (and thus two patients can train together), or a WiiMote. When combining a force-feedback device and a WiiMote as the input devices, the idea is that the game is played by a patient (using the force-feedback device), and by a healthy person (for instance a family member) using the WiiMote. This way, visitors of a rehabilitation centre can help in the rehabilitation of their affected family member and thus enhance the motivation in doing the training.

In order to allow the use of different force-feedback devices, the H3D library (SenseGraphics, 2004) is used to realize the game. As a force-feedback device, the HapticMaster with ADL gimbal is being used. This device has the advantage that it can generate large forces, which assists MS patients with more pronounced muscle weakness in the interaction. Furthermore, a special gimbal is used, in which a patient's hand can be strapped (see Figure 4). This way, the patient doesn't need to hold the HapticMaster.

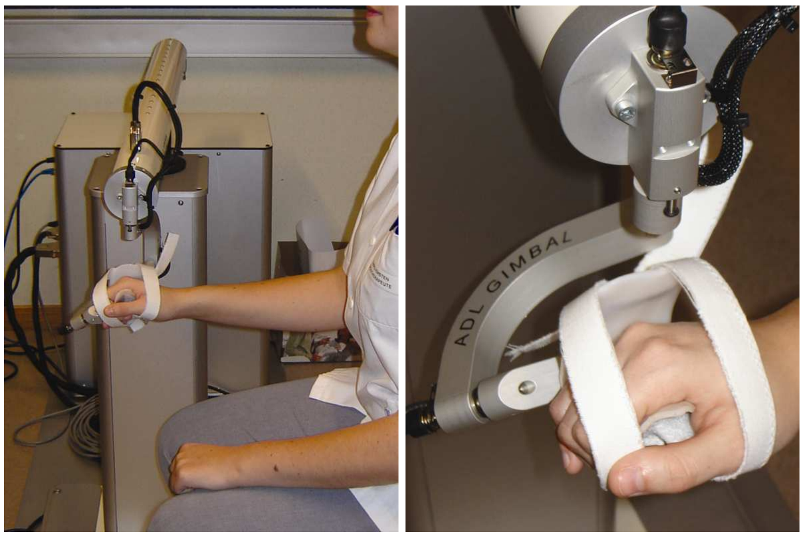

Figure 4 HapticMaster with gimbal

As the beam can only be raised by using a pumping gesture, force feedback is provided, which mimics the feeling of using a hand pump. For this purpose, we use our haptic path implementation (De Boeck et al., 2009), where the patient is restricted to move on a predefined line. Different force effects can be added in order to aid the patient or make it more difficult. Patients, who have much trouble in moving their hand, can be aided by applying a force, which pushes them in the right direction during the pumping motion. A patient, who has less problems, can receive a force, which counteracts the needed movement.

In our current implementation, the patient has to push with a certain force downwards, as this causes the beam to move upwards. When the pump is fully compressed, the patient will be able to move back upwards without feeling any restricting forces.

Support for the WiiMote was added through the Wiiuse library (Laforest, 2008). Here, the healthy player has to make a pumping gesture with the WiiMote, which is detected using the accelerometers of the WiiMote. Figure 5 shows a collaborative game between one person using the HapticMaster and one person playing with a WiiMote


Figure 5 Collaborative game using HapticMaster and WiiMote

It is, however, not always possible for family members to come to a rehabilitation centre during the hours that a patient has access to a force-feedback device. In order to keep the family involved, we therefore added network support to the game, which allows playing the game from two different locations. The game doesn't support communication capabilities (such as speech and video), as this can be realized through other applications.

The flexibility in using input devices and networking allows using the rehabilitation game in a flexible manner. The game can be played between two patients, both using a force-feedback device. Alternatively a patient can use a force-feedback device to play against a healthy person, operating a WiiMote. The game can be played over a network in a remote setup, or alternatively the collaboration can be co-located. In the latter case, both players can use a shared display (as in Figure 5), which is beneficial for the social interaction between the patients (Xu et al., 2008), or they can both have their own display.

Conclusions and future work

Several studies have shown that it is feasible to use virtual environments and force feedback to enhance the rehabilitation of Multiple Sclerosis patients, with particular attention for upper limb training. However, in order to motivate the patients in doing the exercises on a regular basis, these exercises need to be engaging. We have shown how visual feedback and force-feedback is combined with gaming concepts in the training tasks to have an impact on the patient's motivation. In this paper we have explained a promising next step to achieve this, by exploiting social interaction during the game play. More specifically, we have demonstrated how collaboration between a patient and a relative (or alternatively between patients) can be used in order to create a social rehabilitation game. The game concept, visual design and technical setup of the networked gaming infrastructure have been elaborated upon. In order to evaluate the potential of this kind of collaborative games, a user study is planned.

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