The Learning Effect of Force Feedback Enabled Robotic Rehabilitation of the Upper Limbs in Persons with MS - a Pilot Study.

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Abstract

Multiple Sclerosis (MS) is an autoimmune disorder resulting in different sorts of physical dysfunctioning, such as loss of limb function, in-coordination, altered muscle-tone, etc. Within limits, these symptoms can be treated by rehabilitational measures such as strength and functional training. The intensity of the rehabilitation is one of the key factors to a possible success. To increase the intensity, rehabilitation robotics can be a promising new technology. In this study, a Phantom haptic device was applied during a force feedback enabled training program focussing on the upper extremities in persons with MS. Seen the fact that we found no significant learning effect during the first contact with the environment and seen the improvements of the upper limb performance after 4 weeks of robotic training, this pilot study shows that force feedback supported rehabilitation can be a promising emerging new therapy. However, further research is needed to refine the technology behind it and to explore the full potential of the patient's enactive knowledge while transferring training effects of the computer generated environment to daily life functional capacity.

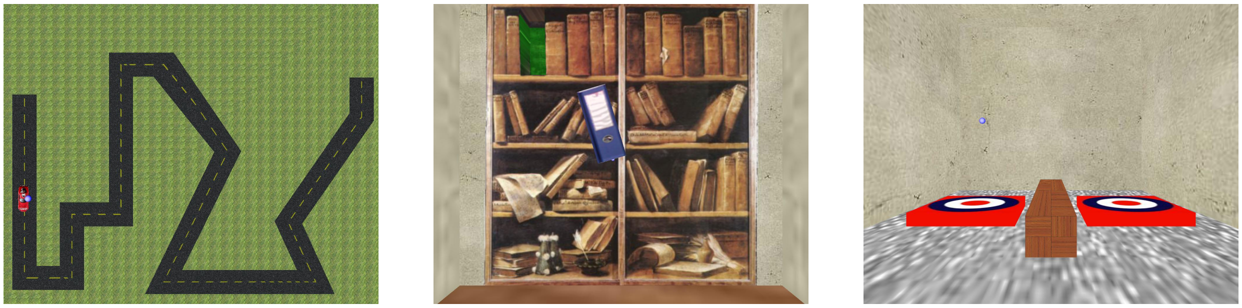
***Keywords:* Robotic Rehabilitation, Multiple Sclerosis, upper extremity, Task Performance**

1 Introduction and Related Work

Multiple Sclerosis (MS) is an incurable chronic and progressive disorder of the central nervous system, resulting in secondary symptoms such as impairments of strength, muscle tone, sensation, co-ordination, balance, as well as visual and cognitive deficits. These symptoms, caused by an autoimmune response, progressively lead to severe limitations of functioning in daily life, while still no final cure exists. Besides, the recent use of medication only focussed on slowing down or reducing the worsening of the disease or the symptoms. Therefore, still an important part of the therapy consists of physical and occupational training and exercises

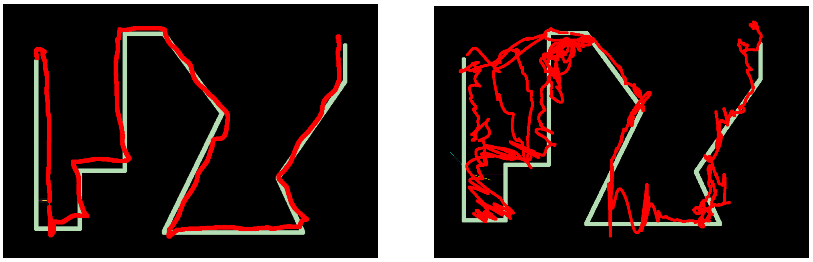
Evidence can by found in literature that the intensity and duration of a rehabilitation session are key factors for its efficiency [6]. Indeed, studies of exercise therapy focusing on balance and walking parameters, have shown a beneficial effect with regard to e.g. muscle strength [15]. From this point of view, over the last years, several research projects have been conducted in order to provide the patients with (virtual) environments that can be used in a more independent way at a level customised to his or her abilities. Ultimately, this approach should open perspectives for the patients to practice at home under the (remote) supervision of a therapist [9, 7].

Some of these solutions, such as the Rutgers Ankle rehabilitation interface [2] or the MIT-MANUS project [5] , apply force feedback technology successfully into rehabilitation training. It must be stated that these research projects were mostly conducted on hemiparethic stroke patients. Although dysfunctions caused by stroke, which is not a progressive disease, improve naturally as time progresses from the cerebro-vascular



(a) The car-trajectory task (b) The object manipulation task (c) The speeded-tapping task

Figure 1: Screenshots of the three applications



(a) Resulting path of a healthy person (b) Resulting path of an MS patient

Figure 2: Resulting paths of some example trials of the car-trajectory game

incident on, these studies reported promising results in speeding the rehabilitation progress and augmenting outcome-level in these patients compared to controls. Therefore the use of haptic rehabilitation technology could be useful in a degenerative disease as MS, as well. The application of force feedback can be considered to be part of one of the following classes [8]:

- Passively moving the patient's limbs
- Actively assisting the patient's movements by restricting false movements and facilitating correct motions.
- Actively resisting the patient's movements, evoking higher forces from the patient for the execution of the movement.

This creates an opportunity for the therapist to set up a personal training plan, according to the patient's physical abilities and/or needs. Moreover, the available haptic feedback provides the patient with a very direct (first order) feedback loop, also stimulating the patient's sense of proprioception [1].

2 Objectives

Very few studies have properly investigated the therapeutic potential of the integration of force feedback in upper limb training in persons with MS. In this project a virtual environment (VE), in the form of three simple games, has been realised, stimulating MS patients to improve their skills. Both visual and haptic feedback is presented to the user while performing these tasks. The performance of execution and its results are permanently logged.

The overall aim of the investigation was to assess the potential of a force feedback enabled VE as a training tool in the context of the rehabilitation of lost upper limb function of persons with MS. We took into account any improvements concerning the specific tasks in the VE, but also possible functional improvements in everyday tasks, as well as a potential increase of the overall muscle strength of the patient's arm. Moreover, the motivational aspect (how well are patients motivated to practice with the proposed setup during an entire training period) was another point of uncertainty during the training program, lasting four weeks.

3 Training Environment

The training environment consisted of a standard desktop PC, with speakers and a 19" CRT monitor. The Phantom 1.5 haptic device was used by the patients to control the training tasks. To reach the abovementioned 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 for a *trajectory* task, an *object manipulation* task and a *speeded-tapping* task (see figure 1).

In the first task, the patient had to steer a virtual car over a pre set trajectory. The patient was aided in this task by restricting the movements of the Phantom 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 and large, each changing the spring stiffness with a factor 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 shelf and they 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 from 0.5, 1.0 and 1.5 kilograms.

The third task was a virtual implementation of the well-known speed tapping task (Eurofit Test Battery) [14]. 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 available: the first level created two stiff walls where the cursor was kept in between. The second level implemented a spring force centering 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.

4 Experimental Setup

The experimental setup was approved by the local ethics committee of the University of Hasselt and by the ethics committee of the Rehabilitation & MS-centre Overpelt. The inclusion criterion for the MS-group was a dysfunction of the arm due to muscle weakness. The exclusion criteria were a relapse of MS or treatment with corticosteroids in the last month prior to the study, upper limb paralysis, severe cognitive dysfunction and severe visual dysfunction. After their written agreement 21 persons with MS (from the Rehabilitation & MS-centre Overpelt) were included in this study (13 female and 8 male, mean age 59,7 ± 1,16 years). Additionally, ten healthy subjects, selected among the rehabilitation centre's personnel (n=10, 4 female and 6 male, mean age 48,00 ± 6,5 years) participated in a 'healthy control' group. The experiment lasted for a duration of nine weeks in total. In the first week, all patients participated in the intake sessions. Subjects had to pass several functional tests (Nine Hole Peg Test, Purdue Pegboard test, ARAt and TEMPA [13, 4, 12, 3]); also their maximum force at the upper extremities was measured (JAMAR handgrip force and MicroFet isometric muscle testing (Biometrics, Gwent, UK)) and an EMG/Accelerometer measurement was done while performing simple everyday tasks (combing hair, pouring water in a glass, reaching for an object). For the healthy control group normative data, available in literature, was used for all of these tests, except for the EMG-accelerometer test.

After the completion of these tests, all subjects (MS and healthy controls) were asked to complete the three virtual applications in random order. For each of the three tests four subsequent trials were completed in the same day. The first trial was used to familiarise the subjects with the haptic device. The second trial was the first trial that was logged. For further analyses this trial was named *'Initial 1'*. The subsequent trials were named *'Initial 2'* and *'Pre'* respectively. This last trial was used to represent the baseline measurement. The first two measurements were added to evaluate the occurring learning effect.

The force feedback and scale settings for all these trials were standardised to the same values for all subjects. After the intake, the MS-group participated in individual training sessions during a period of four weeks. The training volume was three sessions per week during 30 minutes per session in which the intensity of the training was augmented per week at the same level for all subjects. This training frequency is in accordance with the ACSM Guidelines for Exercise Testing and Prescription for elderly people[11]. During each half hour training, patients were guided by an occupational therapist to rehearse every task as much as possible. At the first training session of each following week, the first trial performed for each application was logged using the standardised settings. Afterwards, the force feedback and scale settings were adjusted for al training trials in that week to the same level for al participants. During the training sessions, the MS-group was exposed to different variations for the trajectory task and the object manipulation task. These variations were a change of the form of the track or a change of endposition of the book.

After the training period of four weeks, all patients had to complete the functional tests, the force measuring and the EMG/accelerometer tests again, after which one trial of each of the applications was logged for the last time (post measurement). Four weeks after the last exposure to the experiment, 11 persons with MS were subjected to a follow-up test for the three applications.

For all the experiments, the total execution time and total travelled distances were logged to an SQL database at 200Hz. With the tapping task, additionally the number of correct and false taps was logged. During the execution, other parameters such as the current position, actual velocity, force and deviation (distance) from the ideal path were also logged.

5. Results

In the analysis presented in this paper, only the first 3 measurements (Initial 1, Initial 2, Pre) as well as one measurement after a training period of 4 weeks (post) are taken into account. The difference between a healthy person and an MS patient is immediately visible from the 'Pre'-test data. Figure 2 illustrates the position profile of the car trajectory task. The straight light line represents the ideal path where the car is supposed to stay on the road. The darker curved line shows the actual path driven.

Figure 3 gives a view on the velocity profiles of a tapping task for a typical healthy person and an MS patient. For the healthy person, we see a velocity profile as expected according to the findings of [10]. The velocity profile can be approximated by a (skewed) parabola. With the MS patients, we see a similar profile, but as if there is an additional sine superimposed either in the accelerating side, the decelerating part, or in both.

Figure 4 shows the *average completion time* for the trajectory task and the object manipulation task and the *average velocity* of the tapping application for both the MS group and the healthy control group for the three subsequent logs *initial 1*, *initial 2*, *pre*. This data allows us to draw conclusions on the initial learning effect after a maiden exposure to the virtual tests/tasks and before starting the training program.

Analysing the different parameters using ANOVA for repeated measurements (completion time, total distance, average and peak velocity), globally we find only no significant to small learning effects, except for the following numbers:

- The completion times for the MS group in the trajectory task points out a significant reduction between initial 1 and initial 2: p=0,023485
- For the tapping task, there is a significant raise of velocity for the MS group between initial 1 and initial 2: p=0,028
- The velocities of all the trials of the Tapping task for the control group raised significantly from initial 1 to the pre measurement: p=0,003.

Therefore, it seems that 3 trials are enough to get a stable performance on the tasks, developed in this study. This way, the insignificant learning effects were only of short duration and a basic level of performance was reached from whereon the implemented training period could start.

Almost all parameters of the control group were significantly better than those of the MS group, which can be considered as a 'double check' test for the relevance of the selected patients.

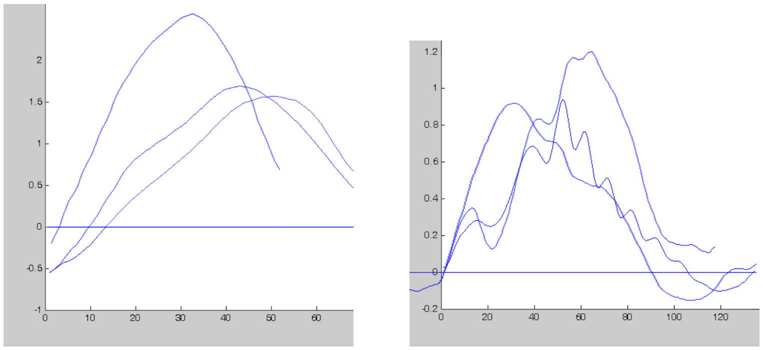
Comparing the same parameters after the training period of four weeks the results for the MS group are given in figure 5. For the Trajectory Task there is a significant improvement between the first trial and the post measurement (p=0,00025), between the second trial and the post measurement (p=0,014) and a borderline trend between the pre en the post test (p=0,062). For the Object Manipulation task we measure a significant improvement over all other measurements (p<0,0004). For the tapping task however, we could not measure any significant training effect.

6 Discussion

As we measured for the MS group only very small (but not significant) learning effects which are in line with the learning effects of the healthy control group, we may conclude that the overall difficulty of our experimental task is suitable for the targeted MS group. We hence have a very 'easy to learn training task', which was one of our objectives. At least this is true for the first two applications. Consequently, we can conclude that the usage of the Phantom as a haptic training device causes no significant problems for the patients to adapt to. Nevertheless, it has to be noted that we observed some severely affected patients having more difficulties manipulating the Phantom in front of their body during the entire duration of a training session, which often led to extremely compensating poses and muscle fatigue.

On the other hand, for the trajectory task and the object manipulation task, we were able to measure a significant training effect after 4 weeks. As there was no significant learning effect, we may conclude that the improvement was the result of the training sessions and not merely an effect of better understanding of the task, which was one of the intended goals.

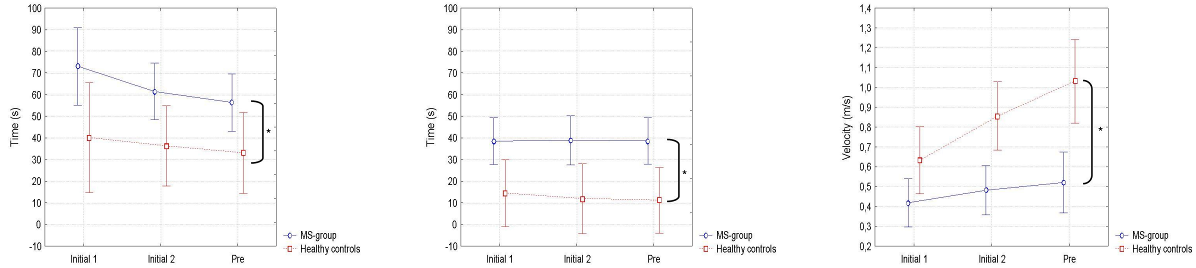
The results are less straightforward for the tapping task. For the MS group, we see a slight (but insignificant) trend towards higher velocities (figure 4(c)). The post test, however, shows no significant improvement at all. On the contrary, some subjects even performed worse! Analysis of other recorded parameters, training data and a comparison with the results of the functional tests will be necessary to explain this outcome. Besides,



(a) Result of 3 typical healthy subjects

(b) Result of 3 typical MS patients

Figure 3: Velocity profile of the tapping task of a typical tap



(a) Initial Learning Effect: Average **Completion Time** for the Trajectory Task

(b) Initial Learning Effect: Average **Completion Time** for the Object Manipulation Task

(c) Initial Learning Effect: Average **Velocity** for the Tapping task

Figure 4: Results of the first three trials of each application. ($*p \leq 0.05$)

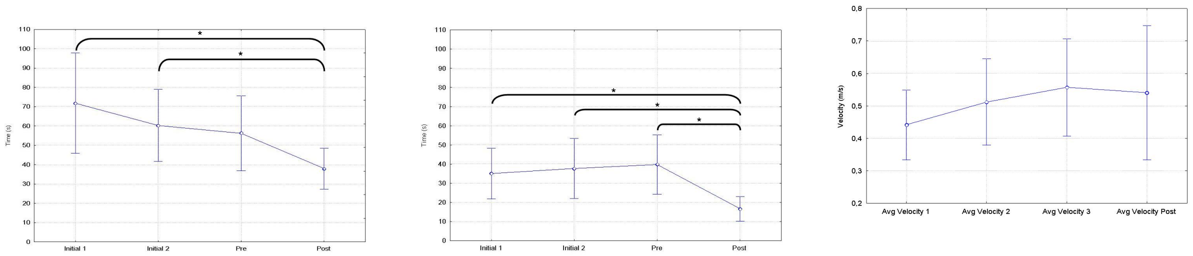
it is remarkable that unlike the other experiments, the subjects in the healthy control group also need a learning period for this task. This makes us conclude that the virtual tapping task behaves somewhat different than the other two tasks.

Another important aspect, which was one of the indications to apply a force feedback enabled training approach, is the patient's motivation. Indeed the relation between the virtual reality task (robot training) and the 'gaming' aspect and the feeling during an according real life task, were enormous motivational aspects for the patients to participate in this experiment. However, due to the limited variations in the different tasks, after a few weeks, patients reported verbally to get tired of always having to complete only slightly varying tasks in the VE. For optimal exploitation of the patient's motivation, more alternatives, or a progressive 'gaming scenario' seems to be necessary.

Finally, in a preliminary analysis, we found no correlation between the patients' performance in the virtual tasks and their muscle strength. This is somewhat surprising, as the Phantom is manipulated in front of the body using all frontal shoulder muscles. Patients reported that the upper limb muscles got tired during the robotic training. Therefore we may suppose that a four-week training session creates a light training stimulus for the patient's arm muscles but that it could not be measured by means of the analysis made at this moment. Although the training interval (3 times a week during half an hour) but not the duration (4 weeks) is conform with the recommendation of the ACSM guidelines for elderly people, further analysis of the data is necessary to confirm this assumption.

7 Conclusion and Future Work

From this pilot study, we may conclude that the training protocol supported by force feedback, beholds beneficial effects concerning the level of performance of the upper limbs for the particular virtual task. According to the found learning effects (Initial 1, Initial 2, Pre), the use of this system should make it possible for the patients to start an exercise programme quite quickly. The level of difficulty at the start of the training period appears to be suitable for this specific group of intended users and the applied force feedback creates the opportunity to start exercising gradually, adjusting the intensity/difficulty according to the capabilities of the patient.



(a) Training Effect After 4 weeks: Average **Completion Time** For the Trajectory Task

(b) Training Effect After 4 weeks: Average **Completion Time** for the Object Manipulation Task

(c) Training Effect After 4 weeks: Average **Velocity** for the Tapping task

Figure 5: Result of the training effect in a) trajectory task, b) object manipulation task, c) tapping task in the MS group after four weeks (last column), results are mean values ± SD ($*p \leq 0.05$)

Future research will be needed to further explore the full potential of robotic upper limb rehabilitation. Also new and different sorts, and a more extensive amount of virtual tasks need to be developed in order to keep this kind of rehabilitation appealing to its users and to further explore the possible transfer to activities of daily living.

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