A Virtual Reality System for Motor and Cognitive Neurorehabilitation

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Abstract. Here we present a virtual reality system developed for the rehabilitation of motor deficits following stroke. A virtual reality augmented feedback system or the Rehabilitation Gaming System (RGS), presents the patient with a training scenario that is designed to promote the rehabilitation of the upper extremities. RGS allows rapid and online diagnostics of the patient's capabilities and the dynamic personalization of the rehabilitation scenario. We present the basic design considerations between RGS, its neuroscientific roots and preliminary results obtained with stroke patients that illustrate the main properties of the system.

Keywords. Virtual reality, stroke, motor rehabilitation, mirror neurons.

Introduction

Disorders of the motor system lead to movement dysfunction, sometimes with life-long impairments. Stroke represents a particularly problematic case, with about 60% of the patients experiencing long term disabilities [1]. Consequently, stroke leads to high societal costs in rehabilitation expenses and loss of productivity. In addition, the psychological impact on the patient and their social environment must not be underestimated, i.e. many patients regress into depression [2].
After stroke, the recovery of the motor capacity of the hand is of particular interest since it is very relevant in overall functionality and the ability to perform activities of daily living. However, the optimal physiotherapy for recovery is still unclear. There is a considerable variety of treatment concepts and therapies, but their effectiveness is difficult to measure and compare due to the number of variables to be taken into account. In case of stroke, most rehabilitation techniques are dominated by occupational and physical therapy, that focus on guided limb manipulation and task-oriented exercises. However, the impact and effectiveness of these techniques on the affected regions of the central nervous system is currently not clear. Hence, there is a need to develop cognitive rehabilitation scenarios that directly impact the neuronal structures that are directly or indirectly affected by stroke. One of the newest approaches consists in using virtual reality (VR) technology that combines game based

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scenarios with specific interface devices [3-6]. Usually, the patients are immersed in a computer generated virtual environment where they can see, hear and navigate in a dynamically changing scenario in which they participate as active users by modifying the environment according to their actions.

Several virtual reality environments have been developed for the motor rehabilitation of the upper and lower extremities following stroke, although there is an emphasis on the upper limbs [3]. Several preliminary results with stroke patients and related neurological disorders show motor function improvement, strongly suggesting that the motor recovery of these patients results from their interaction with virtual environments [3]. Different methods and therapy concepts have been applied in VR, like for example: training reaching movements through imitation of a virtual instructor [4]; training individual hand and finger properties such as range of motion and strength by means of intense exercising of skilled movements [5]; and training general upper limb movements by mental rehearsal and the imitation of movements of the non-paretic arm [6]. Although the results achieved to date show some promise, little work exists on the quantitative assessment of the clinical impact of VR based approaches and their effects on neural reorganization that can further inform the design of these systems and their application.

Together with developing an automated environment for neurorehabilitation our main goal is to evaluate the hypothesis that VR based systems might induce enhanced activity of the central motor system. RGS is based on the hypotheses that it is possible to promote cortical reorganization by means of action observation and imitation, recruiting the mirror neuron system. The mirror neurons are a special group of neurons that are active during the performance of goal oriented movements and during the observation of others performing the same action [7]. They were originally discovered in monkeys and there is now evidence that humans also possess such a system [9]. So far, areas in the human brain with mirror neuron like properties have been identified in the pre-motor cortex and in the inferior parietal lobe [7-9]. We believe that through the mirror neuron system we can induce functionally consistent changes in the activity of the motor system that will facilitate structural and functional recovery. Indeed, it seems to be possible to use action observation and imitation as an approach to the systematic training and the rehabilitation of patients with motor impairment after brain lesion [10]. We hypothesize that virtual reality techniques combined with specific gaming paradigms represent a possible way to achieve this goal. Moreover, embedding the action observation in a goal oriented task will further mobilize learning modulating systems. Preliminary data collected with stroke patients, using a former version of our system, suggests that our approach may have a positive impact on recovery [11].

1. The Virtual Reality System Prototype

1.1. The System

The RGS consists of a number of elements. On one hand we make use of the Torque Gaming Engine (www.garagegames.com) to define rehabilitation scenarios and the user interaction. Torque is versatile and can be easily adapted to different rehabilitation scenarios. Arm movements are tracked by means of a custom vision based motion tracking system (called AnTS) that detects color patches located on specific points of the real arms, i.e., wrist and elbow. The subject wears data gloves equipped with bend sensors to measure finger flexure while arm position is tracked allowing for a complete and realistic capture of the movements of the upper limbs (Figure 1). The tracked real arm movements are reconstructed onto the movements of virtual arms in the VR system.

1.2. The Task

The subject sits in a chair, facing a computer screen (Figure 1). Both forearms are placed on a table with the hand palms facing downwards to help the subject to act against gravity. The table surface allows the subjects to move their arms, without constraints, for the entire range of motion of the forearm. On the display, the subject observes the two virtual arms that mimic the motion of their own arms. Initially, the scenario is a landscape where virtual spheres move towards the patient and that they are asked to intercept with the hands of the virtual arms. Every time there is a successful interception the subject is rewarded with a "positive" sound and points are accumulated for a final score. The difficulty of the task is defined by a set of game parameters including: speed of the moving balls, time interval between consecutive ball appearance, left/right dispersion of the balls and radius of the balls. The system can automatically set and update the task difficulty during the task, depending on the capabilities and performance of the subject. In this way the task can be maximally challenging and motivating for the subject. For upper extremity rehabilitation RGS can present a number of different levels with increasing difficulty and specificity. When the subject scores above threshold in the interception of the spheres, there is a second level with higher difficulty that consists of simultaneous interception and grasping. A third level would include a precision grasp. During all trials the detailed arm position and event data is recorded for subsequent analysis to provide a record of improvement over training sessions and to provide for detailed diagnostics and monitoring.

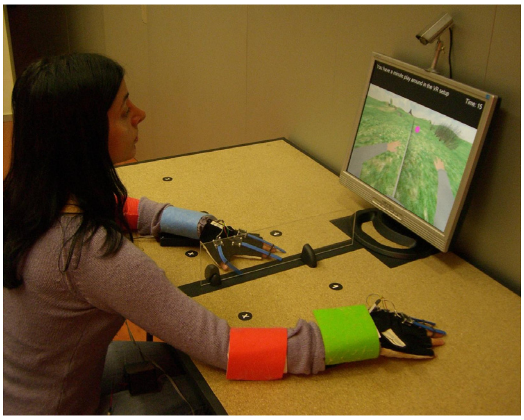

Figure 1. The Rehabilitation Gaming System. A subject sits in a chair with her arms on a table, facing a screen; on the display two virtual arms mimic the movements of the subject's arms. Arm movements are tracked by the camera mounted on top of the display. The tracking system determines in real-time the position of the color patches and maps these onto a biomechanical model of upper extremities. Data gloves are used to detect finger movements. The markers on the table top are used for calibration tasks.

2. Results

In order to assess the impact of RGS, we performed some trials with a small group of stroke patients (N=6) that used our system during single trials. The RGS allows real time data capture, providing robust raw data with a high resolution. The recorded time stamped game event data contains among others the measured hand positions and the position of the touched and missed spheres, suitable for different types of analysis (Figure 2). This graphic provides a general overview of the performance of the patient during the task. On the y-axis we have the positions of the virtual limbs, 0 corresponding to the centre of the display. For this specific example, we can see that the right hand (red line) performed movements of larger amplitude than the left one (blue line). Consequently, there is a larger number of missed spheres on this side, especially closer to the edge. This is in accordance with the limitations of the patient, who was presenting a left side paresis.

Additionally, the system allows us to measure range of motion of the arms, velocity, hitting precision (how close the hand was to the ball when touched) and overall performance; this way we can have measures not only related to movement performance but also to motor control.

Summarizing, the different measures provided by the RGS allow assessing quantitatively the motor deficits of the patients following stroke. Moreover, during the rehabilitation period, this is a system that can be used simultaneously for therapy and for monitoring motor functionality recovery over time.

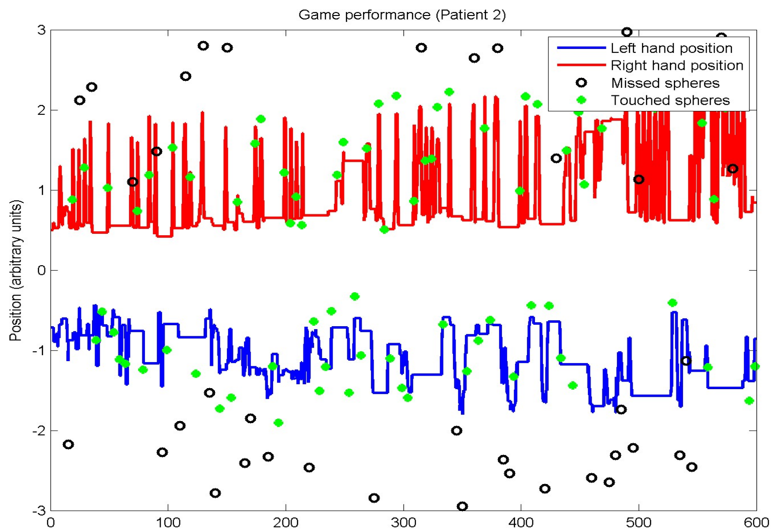

Figure 2. Recorded time stamped game event data of patient 2. This plot shows over time the position of both the left (blue line) and right hand (red line), and events (touched and missed spheres) during a trial. The right hand was more active than the left one; this is accordance with the patient deficits (left side paresis).

3. Conclusion

We have presented the Rehabilitation Gaming System which is a second generation of a novel virtual reality interactive environment for the motor and cognitive neurorehabilitation of patients with brain damage. The system has been tested with 6 stroke patients and we have shown that it is effective in measuring the range of motion, movement precision, patient performance, etc. Although these and previously obtained results are promising [12], experimentation in a longitudinal with a large population is required before making definitive statements concerning the efficacy of the method and its potential applications in areas such as telerehabilitation. We are currently performing such a study with stroke patients and selected control groups in a clinical environment. We expect our system to have an impact in functional motor recovery, as well as in the management of the overall quality of life. Additionally, to consider engagement and effort in the task we will carry out non-invasive physiological measures, namely, heart rate and electrodermic response to assess the affective state of the patients. This allows us to integrate implicit real-time physiology into the optimization of the rehabilitation scenario.

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