Running head: STROKE REHABILITATION USING THE RGS

Stroke Rehabilitation using the Rehabilitation Gaming System (RGS): initial results of a clinical study.

Mónica S. Cameirão[1,*], Sergi Bermúdez i Badia[1], Esther Duarte Oller[2], and Paul F.M.J. Verschure[1,3]
[1]Laboratory of Synthetic Perceptive Emotive and Cognitive Systems (SPECS), Institut Universitari de l'Audiovisual (IUA), Universitat Pompeu Fabra, Barcelona, Spain
[2]Servei de Medicina Física i Rehabilitació, Hospital de L'Esperança, Barcelona, Spain
[3]Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain

* Corresponding author: monica.cameirao@upf.edu

Abstract

In the last few years, Virtual Reality (VR) has shown to be a promising tool in neurorehabilitation that can be used to diagnose, monitor and induce functional recovery after lesions to the nervous system. We developed the Rehabilitation Gaming System (RGS), a VR tool for the rehabilitation of motor deficits of the upper extremities. This system combines movement execution with the observation of a correlated action by virtual limbs that are displayed in a first-person perspective. We hypothesize that through this visual-motor pathway we can promote cortical reorganization and enhance recovery following a lesion in the brain.

The RGS is a multi-level adaptive tool that provides a task oriented training of graded complexity that is online adjusted to the capabilities of the patients. In addition, this system retains qualitative and quantitative information of the performance of the patient during the tasks, allowing for a detailed assessment of the deficits of the patients. We believe that all these properties make the RGS an appropriate tool for rehabilitative training. The RGS is currently being used in a randomized clinical study with two control conditions. Although at this moment the sample size is too small – only 2 patients completed the entire protocol – to draw final conclusions, we expect our system to have an impact in functional motor recovery, as well as in the management of daily living.

Introduction

In the last decade several Virtual Reality (VR) systems have been developed for the rehabilitation of motor deficits, with special emphasis in arm rehabilitation following stroke (see (Cameirao, Bermudez i Badia, & Verschure, 2008) and (Holden, 2005) for reviews). It is estimated that stroke is and will be one of the main causes of burden of disease during at least the next 20 years (Mathers & Loncar, 2006), and consequently there is a need to develop efficient rehabilitation strategies. Following a stroke recovery is possible by means of cortical plasticity, meaning that the surrounding areas of the lesion or the contralateral hemisphere take over lost functionality (Fisher, 1992; Nudo, Wise, SiFuentes, & Milliken, 1996). Therefore, rehabilitation after stroke mainly focuses in maximizing this effect. Different approaches can be found based on specific hypotheses such as intensive rehabilitation (Kwakkel et al., 2004), tasks directed training towards specific deficits (Krakauer, 2006), mirror therapy (Altschuler et al., 1999), constraint-induced movement therapy (Blanton, Wilsey, & Wolf, 2008), motor imagery (Gaggioli, Meneghini, Morganti, Alcaniz, & Riva, 2006), action observation (Ertelt et al., 2007), etc. Here we can also find VR methods that often follow several of the above mentioned rehabilitation strategies. A number of studies point out the benefits of VR in stroke rehabilitation, suggesting an increased impact on recovery (Cameirao et al., 2008; Holden, 2005). However, the quantification of the effects of VR systems in patients and the understanding of the different parameters of the system is still very anecdotal. There is a need for developing scenarios that are not only based on the knowledge of the mechanisms of recovery, but that also take into account the individual responses of the subjects to the virtual task in order to deploy an optimal and individualized training.

We are investigating the impact of VR methods in stroke patients using the Rehabilitation Gaming System (RGS), a VR system for the rehabilitation of the motor deficits of the upper extremities (Cameirao, Bermudez i Badia, Mayank, Guger, & Verschure, 2007; Cameirao, Bermudez i Badia, Zimmerli, Duarte Oller, & Verschure, 2007). This system combines movement execution with the observation of correlated actions of virtual limbs that are displayed in a first-person perspective. We hypothesize that within such a scenario we can promote cortical reorganization and enhance and/or speed-up recovery. This could be achieved through the activation of undamaged primary or secondary motor areas (August et al., 2006), recruiting alternative motor networks such as the mirror neuron system (Rizzolatti & Craighero, 2004). In addition, the RGS has the advantage of offering a rehabilitative training that is online adapted to the capabilities of the patients. Moreover, it proposes tasks of different complexity at different stages of the rehabilitation period, and it allows a continuous quantitative monitoring of the patient over time. In a first study of the RGS with stroke patients we investigated performance and the transfer of movement deficits between real and virtual tasks (Cameirao, Bermudez i Badia, Zimmerli et al., 2007) and the effect of different task conditions on stress and arousal measurements (Cameirao, Bermudez i Badia, Mayank et al., 2007). We observed that our system retains qualitative and quantitative information of the patient’s performance during the tasks, allowing for a detailed assessment of a patient’s deficits.

The RGS is currently being used in the Hospital de L’Esperança in Barcelona for the rehabilitation of acute stroke patients in a randomized study with controls. Here we review the main properties of the RGS and report on some of the first results of the clinical study.

Methods

Experimental Apparatus

The Rehabilitation Gaming System is composed by a PC with graphics accelerator, a 19 inches LCD display and a color CCD camera (Figure 1). The camera positioned on top of the display allows tracking color patches in specific points of the upper extremities (elbows and wrists) using a vision based motion capture system (AnTS) (a more detailed description of the tracking system can be found elsewhere (Cameirao, Bermudez i Badia, Zimmerli et al., 2007)). Finger flexion/extension is captured by means of 5DT data gloves (Fifth Dimension Technologies, Pretoria, South Africa) that use optic fiber technology to measure finger bending. The captured movements are mapped in real time onto the movements of a virtual character, which is rendered in a first-person perspective. The Torque Gaming Engine was chosen for the implementation of the game scenarios (www.garagegames.com). Thus, on the screen the user observes two virtual arms that move accordingly to his/her movements.

The basic virtual environment consists of a game where flying spheres move towards the user and have to be intercepted using the virtual arms. The difficulty of the task is modulated by the speed of the spheres, interval of appearance between consecutive spheres and the range of dispersion in the field of view. These parameters are computed in such a way that we adapt the difficulty of the task to the individual performance of the subject. Moreover, the proposed task has graded difficulty and specificity: a ‘Hitting’ task to train range of movement and speed; a ‘Grasping’ task to train finger flexure; and finally a ‘Placing’ task to train grasp, displacement and release. These tasks are sequentially presented to the patients at specific time periods during the study.

The task is always preceded by an evaluation phase that allows measuring the reaching distance, precision and speed of arm movements in real and virtual worlds (Cameirao, Bermudez i Badia, Zimmerli et al., 2007). First, the subject is asked to touch a sequence of targets marked on the table surface in a specific order. Second, the subject is asked to perform the same task in the virtual world using the virtual arms and a virtual replica of the table with the targets.

Figure 1. The Rehabilitation Gaming System. A subject faces a display with the arms resting on a table. The arm movements are tracked by a camera positioned on top of the display. The tracking system detects in real-time the position of the color patches located on the wrists and elbows. Data gloves are used to detect finger movements. This way, on the display two virtual arms reproduce the movements of the subject’s arms.

Study Protocol

The clinical study with stroke patients includes three different therapy conditions: the RGS group and two control conditions. Patients are randomly assigned to one of the three groups. For the first control group (Control A), the effect of the virtual visual stimulus is removed. Here subjects perform motor tasks as the one promoted by the RGS, but in the absence of the VR system. The tasks are performed on a table and include object manipulation, grasping and placement with increasing complexity. The second control group (Control B) controls for computer use and gaming effect. The subjects of this group perform non-specific games with the Nintendo Wii (Nintendo, Tokyo, Japan) which require upper limb motor control.

Each subject follows a 3 month program, with 3 weekly sessions of 20 minutes. The patients in the control groups perform the “real” evaluation phase of the RGS once per week. Thus, we also record quantitative information on the properties of the movements (range of movement, speed and precision) for these patients. Clinical evaluation of function is performed at admittance, at session 15 (approximately 5 weeks after the beginning of the study), month 3 (end of the program) and month 6 (follow-up). The evaluation scales include among others the Functional Independence Measure (FIM) (Keith, Granger, Hamilton, & Sherwin, 1987), the Barthel Index (Mahoney & Barthel, 1965), the Motricity Index (Collin & Wade, 1990), the Fugl-Meyer Assessment Test for the upper extremity (Fugl-Meyer, Jaasko, Leyman, Olsson, & Steglind, 1975) and the CAHAI (Chedoke Arm and Hand Activity Inventory) (Barreca et al., 2004).

Results

The RGS allows us to record hand position, arm joint angles, finger flexure and event related game data (spheres hit, grasped and placed). Moreover, with the evaluation phase (see Methods) we can analyze the movements of paretic and non-paretic arms in real and virtual worlds.

In a pilot study with stroke patients we observed that our system clearly allows measuring the asymmetries between paretic and non-paretic arms, and that these were preserved in the virtual environment (Figure 2) (Cameirao, Bermudez i Badia, Zimmerli et al., 2007). This means that the RGS can be used for monitoring the evolution of a patient across sessions, that the properties of the movements are transferred from real to virtual worlds, and that the training in both worlds is similar.

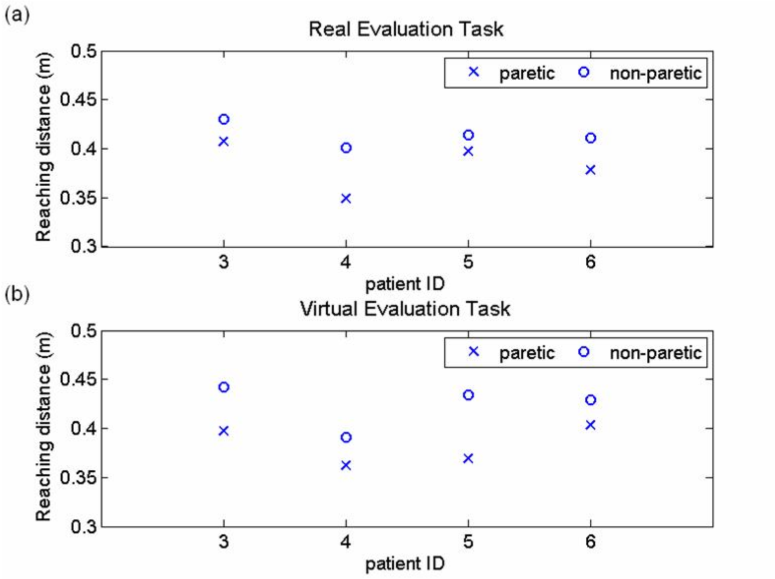

Figure 2. Maximum reaching distance of paretic and non-paretic arms across four stroke patients in the real (a) and virtual (b) evaluation tasks. The mean difference of the reaching distance between paretic and non-paretic arms was not significantly different (p=0.318) (Adapted from (Cameirao, Bermudez i Badia, Zimmerli et al., 2007)).

Concerning the current randomized clinical study, to date 2 patients (1 RGS and 1 Control A) completed the 6 month protocol (3 months training + 3 months follow-up), 5 patients (2 RGS, 1 Control A and 2 Control B) completed the 3 months therapy, 3 patients (2 RGS and 1 Control B) reached the 5 weeks of therapy stage, and 4 patients (2 RGS and 2 Control A) are in the first weeks of therapy. To summarize, to date a total of 14 patients are involved in this study.

Here we show the data of the 2 patients that completed the entire protocol. The scores of four clinical scales, namely the Functional Independence Measure, the Motricity Index, the Fugl-Meyer Assessment Test for upper extremities and the Chedoke Arm and Hand Activity Inventory (CAHAI) were used to perform an analysis of the percentage of improvement over time (Figure 3). The patient in the RGS group had the following scores at admittance: motor FIM = 24, Motricity Index = 29, Fugl-Meyer = 23 and CAHAI = 14. The patient in the Control A group had the following scores at admittance: motor FIM = 31, Motricity Index = 34, Fugl-Meyer = 24 and CAHAI = 13. When we look at the improvement over time obtained for the motor part of the FIM we can see that both patients showed the same type of pattern (Figure 3a). On the other hand, on what concerns specific properties of the movements, evaluated by the Motricity Index and the Fugl-Meyer Assessment Test, the patient in the RGS group obtained better results in the Motricity Index at every time step (Figure 3b). On the Fugl-Meyer, the patient in Control A group presented a higher improvement at week 5, but then stabilized over the entire study period; the patient in the RGS group presented a sustained increase from week 5 until follow-up at week 24 (Figure 3c). Finally, the patient in the Control A group presented higher improvements in the Chedoke Arm and Hand Activity Inventory at the end of the protocol (Figure 3d). Although the data on two patients 1 on each group) is not enough to draw any conclusion, it helps us understanding that the analysis of the progress of the patients is ambiguous depending on what clinical scale we are considering. For instance, in the Motricity Index the patient in the RGS group had better results than the patient in the Control A group. However, this trend was opposite in the CAHAI. In these cases, the data obtained by the RGS (speed, range of movement and precision) can provide information that helps to solve ambiguity.

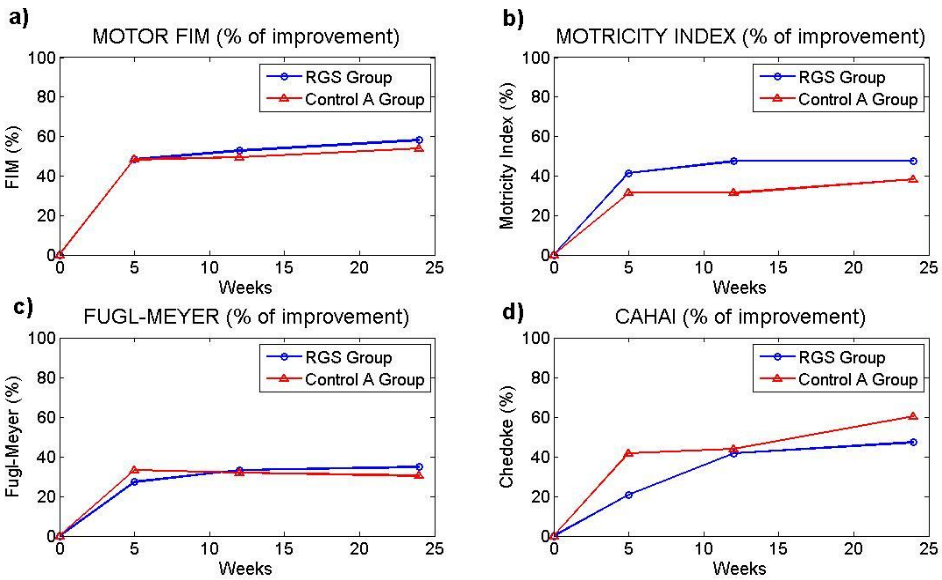

Figure 3. Percentage of improvement in standard evaluation scales obtained at different stages - week 0 (admittance), week 5, week 12 (end of treatment) and week 24 (follow-up) - for two patients. a) Motor part of the Functional Independence Measure. b) Motricity Index for the upper extremity. c) Fugl-Meyer Assessment Test for the upper extremity. d) Chedoke Arm and Hand Activity Inventory.

For the rest of the patients that are currently involved in the study but did not yet reach the follow-up stage, the data suggests that this VR therapy in the acute phase of stroke may have a measurable impact approximately from the second month on. Our data indicates that the RGS may induce a sustained improvement over the whole training period, whereas the control groups tend to stabilize at the second phase of the treatment.

Conclusions

Here we presented the Rehabilitation Gaming System (RGS), its design and the results of pilot studies and an ongoing clinical study. The RGS is a tool for the rehabilitation of motor deficits that has a number of properties that make it suitable for an appropriate rehabilitative training. First, it is built taking into account what is known about the mechanisms of recovery and correspondent efficient rehabilitation strategies. Second, it is VR based, allowing creating specific scenarios directed towards the disability in question. Third, the tasks follow a model that deploys an individualized training, adjusted to the capabilities of the user. Fourth, the tasks have increasing complexity and are presented to the patients at specific time periods in accordance with rehabilitation standards. And fifth, it allows continuous monitoring of the patient to evaluate its progress over time during the rehabilitation program. Moreover, the same task performed in real and virtual worlds showed that performance and movement properties are transferred from real to virtual worlds, indicating the equivalence of training in the virtual world (Cameirao, Bermudez i Badia, Zimmerli et al., 2007).

The RGS is currently being used in a randomized clinical study with two control conditions. Although at this moment the sample size is too small to draw any conclusion, we expect our system to have an impact on functional motor recovery, as well as in the management of daily living. In the following months we intend to assess the impact of this technique in a larger number of patients using not only the clinical evaluation scales at different stages of the treatment but also the quantitative data delivered the RGS.

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