Using a Multi-Task Adaptive VR System for Upper Limb Rehabilitation in the Acute Phase of Stroke

Mónica S. Cameirão, Sergi Bermúdez i Badia, Esther Duarte Oller and Paul F. M. J. Verschure

***Abstract*— Nowadays, stroke has become one the main causes of adult disability leading to life-lasting effects, including motor and cognitive deficits. Here we explore the benefits of the use of virtual reality (VR) for the rehabilitation of motor deficits following stroke. We have developed the Rehabilitation Gaming System (RGS), a VR-based apparatus designed for the treatment of the upper extremities. The RGS is a multi-level adaptive system that provides a task oriented training of graded complexity that is online adjusted to the capabilities of the patients. We show results from an ongoing study that evaluates the impact of this system on the recovery of patients in the acute phase of stroke (n=14). The results suggest that the system induces a sustained improvement during treatment, with observed benefits in the performance of activities of daily living.**

I. INTRODUCTION

STROKE is one of the main causes of adult disability worldwide with projections estimating that in 20 years it will still be among the leading causes of burden of disease [1]. A stroke often leads to life long impairments with strong incidence in the motor system. This has important implications in the performance of the activities of daily living, as restoration of normal motor function in the hemiplegic upper limb is observed in less than 15% of patients with initial paralysis [2]. After a stroke, recovery is possible by means of cortical plasticity mechanisms, meaning that other brain areas take over the functions of the injured one. This mechanism of the brain has been observed by a transfer of function to the surrounding areas of the lesion [3] and in other cases by a shift to the contralateral hemisphere [4]. Rehabilitation after stroke focuses in maximizing this effect for an increase in recovery. Several methods and therapy concepts have been proposed and many of them rely on a putative promotion of activity within surviving motor networks [5]. Different approaches can be found such as intensive rehabilitation [6], techniques geared towards specific motor deficits of patients [7], constraint-induced movement therapy [8], mirror therapy [9], motor imagery [10], action observation [11], etc. In this role we can also find virtual reality (VR). A number of studies with stroke patients point out the benefits of including VR methods in the rehabilitation process (see [12] and [13] for reviews). Although there is a significant amount of work done in this area with promising results, the quantification of the effects of VR systems in patients and the understanding of the effective parameters of the systems 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 also that take into account the individual responses of the subjects to the virtual tasks in order to deploy an optimal and individualized training.

Another relevant aspect in VR based stroke rehabilitation is that the majority of the studies focus on chronic stroke patients. We believe it is important to investigate the impact of these techniques in the early stages of stroke. Most of the main outcomes and improvements happen in the first few months after the stroke [14], so we should not disregard to take action during this period.

We are investigating the impact of VR methods in the acute/sub-acute stages of stroke using the Rehabilitation Gaming System (RGS), a virtual reality based system for the rehabilitation of the motor deficits of the upper extremities [15, 16]. The working hypothesis of the RGS is that simultaneous action execution and observation of correlated movements of virtual limbs may enhance and speed-up recovery. This could be achieved through the activation of undamaged primary or secondary motor areas, recruiting alternative networks that can help to remap the brain [17]. 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 for a continuous quantitative monitoring of the patient over time.

The RGS is currently being employed for the treatment of acute stroke patients (within the first three weeks of stroke) in a randomized study that includes three different therapy conditions: the RGS group and two control conditions. Here we report on the first results obtained and discuss the progress in the different groups.

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Mónica S. Cameirão is with the Laboratory of Synthetic Perceptive Emotive and cognitive Systems (SPECS), Institut Universitari de l'Audiovisual (IUA), Universitat Pompeu Fabra, C\Tanger 135, 08018 Barcelona, Spain (phone: 0034 93 542 13 68; fax: 0034 93 542 22 02; e-mail: monica.cameirao@upf.edu).

Sergi Bermúdez i Badia is with SPECS-IUA, Universitat Pompeu Fabra, C\Tanger 135, 08018 Barcelona, Spain (e-mail: sbermudez@iua.upf.edu).

Esther Duarte Oller is with the Servei de Medicina Física i Rehabilitació, Hospital de L'Esperança, Sant Josep de la Muntanya, 12, 08024, Barcelona, Spain (e-mail: EDuarte@imas.imim.es).

Paul F. M. J. Verschure is with SPECS-IUA, Universitat Pompeu Fabra, C\Tanger 135, 08018 Barcelona, Spain, and also with the Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain (e-mail: paul.verschure@iua.upf.edu).

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II. METHODS

A. *The Rehabilitation Gaming System (RGS)*

The RGS consists of: a PC with graphics accelerator; a 19 inches LCD display; a color CCD camera positioned on top of the display that through a vision based motion capture system (AnTS) tracks color patches in specific locations of the upper extremities (elbows and wrists) (a more detailed description of the tracking system can be found elsewhere [16]); and 5DT data gloves (Fifth Dimension Technologies, Pretoria, South Africa) that use optic fiber technology to measure finger flexure (Fig. 1).

Fig. 1. The Rehabilitation Gaming System. A subject sits on a chair with his/her arms resting on a table and facing a screen. 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 positioned on the wrists and elbows and maps these onto a biomechanical model of the upper extremities. Data gloves are used to detect finger movements. Thus, on the display two virtual arms reproduce the movements of the subject's arms.

The virtual environment was developed the using Torque Game Engine (www.garagegames.com), a system that provides both 3D rendering plus a physics engine. We generated a high-resolution model of a human character, which is rendered in a first-person perspective. The real movements of the arms of the patient that are captured with the motion tracking system are then reconstructed onto the movements of the virtual arms. Moreover, the data gloves provide finger flexure allowing for a realistic capture of the movements of the upper limbs.

The basic virtual scenario consists of a game where flying spheres move towards the user. These objects have to be intercepted using the virtual arms. The difficulty of the task is modulated by a number of parameters: the speed of the spheres, interval of appearance between consecutive spheres and the range of dispersion in the field. These parameters are computed following a model derived from a study of user performance subject to different game parameters combinations. The gaming parameters are online computed in such a way that the performance level of the patient is kept around 70%. This means that the difficulty of the task increases or decreases depending whether the performance is above or below 70% (computed as the number of touched spheres in a trial of 10 spheres). This way the task is always adapted to the individual performance of the subject.

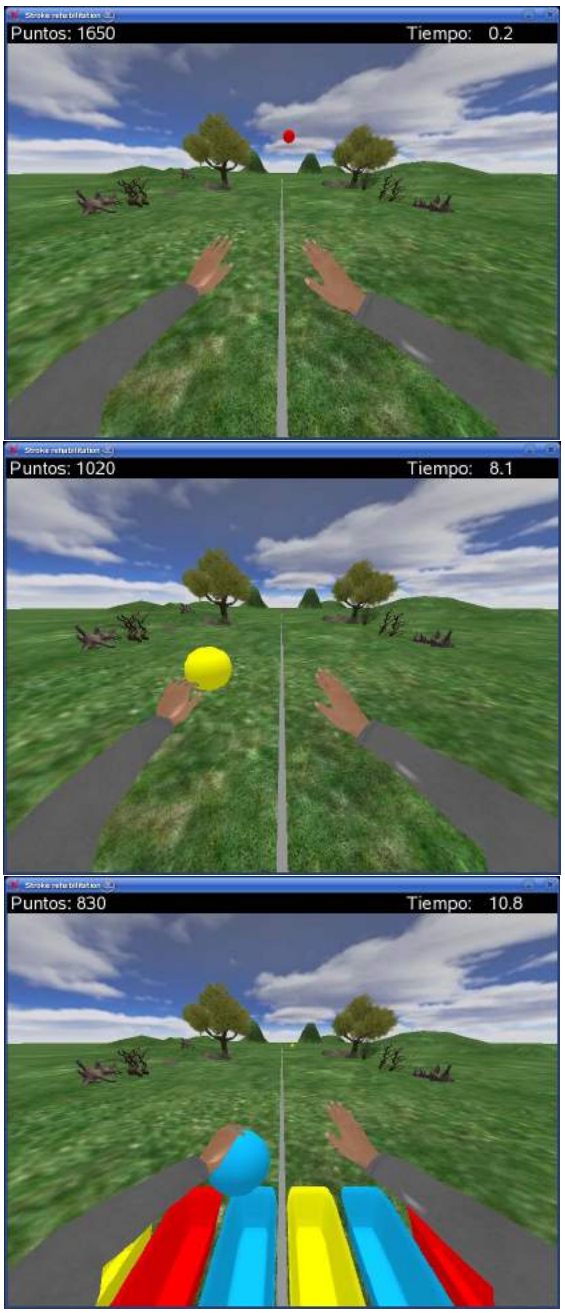

Fig. 2. The virtual tasks with graded complexity. Top panel: 'Hitting'. Virtual spheres that move towards the user have to be intercepted with the movements of the arms. Middle panel: 'Grasping'. The intercepted spheres can be simultaneously grasped by flexing the fingers. Bottom panel: 'Placing'. The grasped spheres can now be released in a basket of correspondent color.

The RGS proposes three tasks following a structured multi-level rehabilitation process with graded difficulty and specificity. On a first stage, 'Hitting' to train range of movement and speed; then 'Grasping' to train finger flexure;

and finally 'Placing' to train grasp and release (Fig. 2 from top to bottom).

B. Protocol

The treatment has a duration of 12 weeks with 3 weekly sessions of 20 minutes. The clinical evaluation of the subjects is performed at admittance (baseline), at session 15 (approximately at the 5th week), month 3 (end of the training) and month 6 (follow-up) (Fig. 3). Patients are randomly assigned to one of three groups: the RGS group and two control conditions (Control A and Control B). The three groups receive the conventional therapy and an additional training condition.

Subjects in the *RGS group* perform the three above mentioned virtual tasks (Fig. 2) that are gradually introduced at different stages of the study: 'Hitting' at session 0, 'Catching' at session 10 and 'Placing' at session 25. To control for the effect of the VR visual feedback, subjects allocated to the *Control A group* perform motor tasks similar to the ones performed by the RGS group, but without the visual VR stimulus. I.e., they just perform a pure "real task", while the patients in the RGS group perform tasks with a virtual representation of their upper limbs. The tasks include object displacement, and object grasp and release, following the same time scheme of the RGS group. To control for the computer use and gaming effects, patients in the *Control B group* perform non-specific games with the Nintendo Wii (Nintendo, Tokyo, Japan).

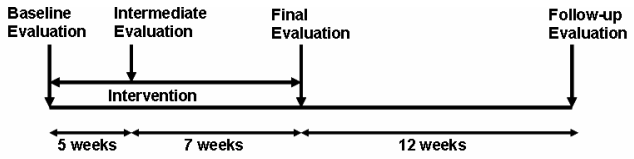

Fig. 3. The timeline of the study. The intervention period has duration of 12 weeks plus a 12 weeks follow-up period, and clinical evaluation of the patients is performed at several stages of the process.

The main inclusion criteria are: first event stroke, patient in the acute or sub-acute phase of stroke (<= 3 weeks post-stroke), age <= 80 years, severe to mild deficit of the paretic arm and absence of cognitive deficits (assessed by the Mini Mental State Examination [18]). The main evaluation scales include the FIM (Functional Independence Measure) [19], the Barthel Index [20], the Motricity Index [21], the Fugl-Meyer Assessment Test [22] for the upper extremity and the Chedoke Arm and Hand Activity Inventory (CAHAI) [23].

C. Participants

To date and since the beginning of the study, out of 76 stroke patients admitted to the hospital, 17 had inclusion criteria and were randomly assigned to one of the therapy groups. 3 patients dropped the study. Here, we only consider the 14 patients that completed at least 5 weeks of training and performed the intermediate evaluation stage. Table I shows the demographic data of the patients and the group they were assigned to. This study was approved by the ethics committee of clinical research of the IMAS - Instituto Municipal de Asistencia Sanitaria and all the patients gave their signed informed consent.

TABLE I
DEMOGRAPHIC INFORMATION

Patient ID	Age	Gender	Days post-stroke	Paretic Side	Group
1	79	F	18	Left	RGS
2	60	F	4	Left	RGS
3	67	M	9	Left	RGS
4	55	M	13	Left	RGS
5	76	M	16	Right	RGS
6	79	F	7	Right	RGS
7	50	F	8	Right	RGS
8	66	F	14	Right	Control A
9	54	M	15	Right	Control A
10	47	M	22	Left	Control A
11	56	M	11	Left	Control A
12	65	F	8	Right	Control B
13	37	F	12	Right	Control B
14	65	M	19	Left	Control B

III. RESULTS

Out of the 14 patients, all 14 reached the intermediate evaluation stage (5 weeks), 7 accomplished the entire training period (12 weeks) and 5 patients reached the follow-up evaluation performed 12 weeks after intervention. Table II shows the clinical measures at the different stages of evaluation for each patient.

Although group size is relatively small, we can already observe some trends. Generally, and according to most of the clinical measures, the RGS group shows a smaller or similar mean absolute improvement from baseline to week 5 than the control groups. This can be observed in the FIM (38.14, 41, 35.33), Barthel Index (46.1, 53.3, 53), Motricity Index (23.1, 35.5, 32.3) and Fugl-Meyer (14.9, 27.3, 13) scores from the RGS, Control A and Control B groups respectively in absolute values. Nevertheless, the inter-group variability renders this difference not significant. On the other hand, this trend is not followed by the CAHAI, for which the improvement is bigger for the RGS group (35.7, 24.7, 26.7).

TABLE II
CLINICAL EVALUATION

ID	Gr	Measure	Bas	Inter	Final	Fup	ID	Gr	Measure	Bas	Inter	Final	Fup
1	RGS	FIM (motor)/91	24	68	72	77	8	CA	FIM (motor) 91	31	75	76	80
		Barthel/100	38	83	87	91			Barthel/100	37	90	90	92
		Motricity/99	29	70	76	76			Motricity/99	34	65	65	72
		Fugl-Meyer/66	23	41	45	46			Fugl-Meyer/66	24	46	45	44
		CAHAI/91	14	33	52	57			CAHAI/91	13	51	53	68
2		FIM (motor)/91	51	82	-	-	9		FIM (motor)/91	31	80	83	80
		Barthel/100	42	100	-	-			Barthel/100	36	94	99	97
		Motricity/99	55	76	-	-			Motricity/99	28	76	76	83
		Fugl-Meyer/66	37	66	-	-			Fugl-Meyer/66	19	46	51	59
		CAHAI/91	27	76	-	-			CAHAI/91	16	29	54	70
3		FIM (motor)/91	28	70	77	80	10		FIM (motor)/91	41	71	-	-
		Barthel/100	39	88	89	92			Barthel/100	37	83	-	-
		Motricity/99	34	65	77	91			Motricity/99	39	66	-	-
		Fugl-Meyer/66	27	39	53	56			Fugl-Meyer/66	12	45	-	-
		CAHAI/91	13	43	82	82			CAHAI/91	15	38	-	-
4		FIM (motor)/91	42	85	-	-	11		FIM (motor)/91	38	82	-	-
		Barthel/100	41	88	-	-			Barthel/100	34	99	-	-
		Motricity/99	76	99	-	-			Motricity/99	28	61	-	-
		Fugl-Meyer/66	48	63	-	-			Fugl-Meyer/66	15	52	-	-
		CAHAI/91	47	89	-	-			CAHAI/91	15	57	-	-
5		FIM (motor)/91	19	49	-	-	12	CB	FIM (motor)/91	32	87	89	81
		Barthel/100	33	65	-	-			Barthel/100	47	100	100	90
		Motricity/99	55	61	-	-			Motricity/99	61	99	99	99
		Fugl-Meyer/66	24	28	-	-			Fugl-Meyer/66	32	62	64	62
		CAHAI/91	19	38	-	-			CAHAI/91	46	91	91	85
6		FIM (motor)/91	53	85	-	-	13		FIM (motor)/91	41	82	76	-
		Barthel/100	51	100	-	-			Barthel/100	37	100	86	-
		Motricity/99	66	76	-	-			Motricity/99	61	91	76	-
		Fugl-Meyer/66	60	62	-	-			Fugl-Meyer/66	47	50	39	-
		CAHAI/91	48	83	-	-			CAHAI/91	53	85	71	-
7		FIM (motor)/91	44	89	-	-	14		FIM (motor)/91	63	73	79	-
		Barthel/100	52	95	-	-			Barthel/100	42	85	93	-
		Motricity/99	61	91	-	-			Motricity/99	23	52	65	-
		Fugl-Meyer/66	37	61	-	-			Fugl-Meyer/66	17	23	43	-
		CAHAI/91	26	82	-	-			CAHAI/91	17	21	59	-

Examining the results for the second half of the treatment (from week 5 to week 12), we observe a new tendency. Although in this case all groups present a deceleration in the improvement rate, the patients in the RGS group show a higher mean increase in their scores compared to both control groups. Namely, FIM (5.5, 1, 0.7), Barthel Index (2.5, 0, -2), Motricity Index (9, 0, -0.7), Fugl-Meyer (9, 2, 3.7) and CAHAI (29, 13.5, 8.3) scores from the RGS, Control A and Control B groups respectively in absolute values. Again, these results have to be interpreted with caution since only 7 patients reached the 36th session. Of special interest is the mean absolute accumulated improvement for the CAHAI measure, which is considerably larger for the RGS group (64.7, 38.2, 35).

Another way of analyzing the results is by looking at the percentage of improvement with respect to the measured baseline (Fig. 4). This measure provides us with an improvement measure which is independent of the baseline of the patients and allows direct inter-group comparisons. Here we concentrated on the clinical scales directly related to the upper limb assessment, i.e. Motricity Index, Fugl-Meyer Assessment Test (upper extremities) and the Chedoke Arm and Hand Activity Inventory. The trend of two of these measures, CAHAI and Motricity Index, does show a sustained and slightly larger improvement for the RGS group during the training period (from baseline to week 12), whereas this is not found in the case of the Fugl-Meyer. The follow-up measures (week 24) will not be discussed in this paper due to the current sample size (2,2,1 patients in the RGS, Control A and Control B groups respectively).

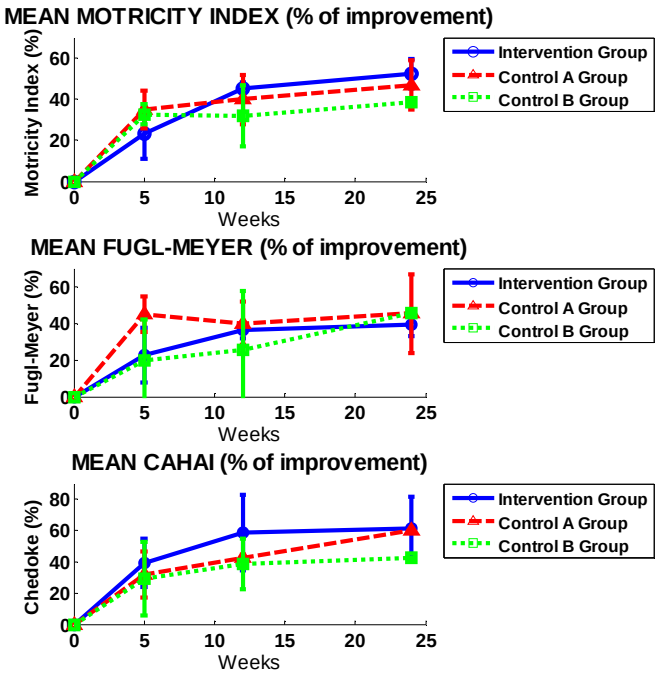

Fig. 4. Percentage of improvement of the clinical scales directly related to the upper limb assessment. Top panel: Motricity Index; Middle panel: Fugl-Meyer Assessment Test (upper extremities); Bottom panel: Chedoke Arm and Hand Activity Inventory.

IV DISCUSSION AND CONCLUSION

This paper presents a new evolution of the RGS, in which the system has been upgraded with a number of substantial features. In addition to being able to generate task specific training scenarios designed for the rehabilitation of the upper limbs, and monitor and quantify the improvement of the patients [16], the system now incorporates an adaptive multi-task training scenario. On the one hand, the training has been divided in three phases of increasing complexity, ranging from arm extension/flexion ('Hitting' task) to a coordination task that combines arm movement with grasping and release ('Placing' task). On the other hand, the parameters of the game are online adapted to the performance of the patient based on a model of the difficulty of the task derived from data of stroke patients. This allows for an individualized training, while ensuring that all patients are exposed to the same training rule.

The data presented here are the first results of a clinical longitudinal study that is currently being conducted in the physical medicine and rehabilitation unit of the Hospital de L'Esperança in Barcelona, Spain. The data suggest that this therapy in the acute phase of stroke may have a measurable impact at the second half of the training (week 5 to week 12). Our data indicate that the RGS may induce a sustained improvement over the training period, whereas the control groups tend to stabilize at the second phase of the treatment. This is evidenced by the larger mean absolute improvement for all clinical scales from week 5 to week 12. Interestingly enough, the RGS intervention group shows the biggest improvement in the CAHAI scale, both from baseline to week 5, and from week 5 to week 12. Moreover, this becomes more evident if we compute the mean absolute accumulated improvement during the treatment (RGS=64.7, Control A=38.2, Control B=35, out of a maximum score of 91). The CAHAI scale is of special relevance since it evaluates the performance in activities of daily living taking into account the contribution of the paretic arm, as opposed to more general scales such as the FIM and the Barthel Index. Therefore, this measures the functionality of the paretic hand. Nevertheless, it is too early to draw definite conclusions given the small sample size of the study at the moment (n=14). In the following months we expect to assess the impact of this treatment using both the clinical scales and the measures delivered by the RGS (such as range and speed of movements, finger flexion, task performance, etc) in a larger population.

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REFERENCES

[1] C. D. Mathers and D. Loncar, "Projections of global mortality and burden of disease from 2002 to 2030," *PLoS Med*, vol. 3, p. e442, Nov 2006.

[2] H. T. Hendricks, J. van Limbeek, A. C. Geurts, and M. J. Zwarts, "Motor recovery after stroke: a systematic review of the literature," *Arch Phys Med Rehabil*, vol. 83, pp. 1629-37, Nov 2002.

[3] R. J. Nudo, B. M. Wise, F. SiFuentes, and G. W. Milliken, "Neural substrates for the effects of rehabilitative training on motor recovery after ischemic infarct," *Science*, vol. 272, pp. 1791-4, Jun 21 1996.

[4] C. M. Fisher, "Concerning the mechanism of recovery in stroke hemiplegia," *Can J Neurol Sci*, vol. 19, pp. 57-63, Feb 1992.

[5] L. Kalra and R. Ratan, "Recent advances in stroke rehabilitation 2006," *Stroke*, vol. 38, pp. 235-7, Feb 2007.

[6] G. Kwakkel, R. van Peppen, R. C. Wagenaar, S. Wood Dauphinee, C. Richards, A. Ashburn, K. Miller, N. Lincoln, C. Partridge, I. Wellwood, and P. Langhorne, "Effects of augmented exercise therapy time after stroke: a meta-analysis," *Stroke*, vol. 35, pp. 2529-39, Nov 2004.

[7] J. W. Krakauer, "Motor learning: its relevance to stroke recovery and neurorehabilitation," *Curr Opin Neurol*, vol. 19, pp. 84-90, Feb 2006.

[8] S. Blanton, H. Wilsey, and S. L. Wolf, "Constraint-induced movement therapy in stroke rehabilitation: Perspectives on future clinical applications," *NeuroRehabilitation*, vol. 23, pp. 15-28, 2008.

[9] E. L. Altschuler, S. B. Wisdom, L. Stone, C. Foster, D. Galasko, D. M. Llewellyn, and V. S. Ramachandran, "Rehabilitation of hemiparesis after stroke with a mirror," *Lancet*, vol. 353, pp. 2035-6, Jun 12 1999.

[10] A. Gaggioli, A. Meneghini, F. Morganti, M. Alcaniz, and G. Riva, "A strategy for computer-assisted mental practice in stroke rehabilitation," *Neurorehabil Neural Repair*, vol. 20, pp. 503-7, Dec 2006.

[11] D. Ertelt, S. Small, A. Solodkin, C. Dettmers, A. McNamara, F. Binkofski, and G. Buccino, "Action observation has a positive impact on rehabilitation of motor deficits after stroke," *Neuroimage*, vol. 36 Suppl 2, pp. T164-73, 2007.

[12] M. K. Holden, "Virtual environments for motor rehabilitation: review," *Cyberpsychol Behav*, vol. 8, pp. 187-211; discussion 212-9, Jun 2005.

[13] M. S. Cameirão, S. Bermúdez i Badia, and P. F. M. J. Verschure, "Virtual Reality Based Upper Extremity Rehabilitation following Stroke: a Review," *Journal of CyberTherapy & Rehabilitation*, vol. 1, pp. 63-74, 2008.

[14] S. H. Kreisel, H. Bazner, and M. G. Hennerici, "Pathophysiology of stroke rehabilitation: temporal aspects of neuro-functional recovery," *Cerebrovasc Dis*, vol. 21, pp. 6-17, 2006.

[15] M. S. Cameirão, S. Bermúdez i Badia, K. Mayank, C. Guger, and P. F. M. J. Verschure, "Physiological Responses during Performance within a Virtual Scenario for the Rehabilitation of Motor Deficits," in *PRESENCE 2007* Barcelona, Spain, 2007.

[16] M. S. Cameirão, S. Bermúdez i Badia, L. Zimmerli, E. Duarte Oller, and P. F. M. J. Verschure, "The Rehabilitation Gaming System: a Virtual Reality Based System for the Evaluation and Rehabilitation of Motor Deficits," in *Virtual Rehabilitation 2007* Lido, Venice, Italy, 2007, pp. 29-33.

[17] K. August, J. A. Lewis, G. Chandar, A. Merians, B. Biswal, and S. Adamovich, "FMRI analysis of neural mechanisms underlying rehabilitation in virtual reality: activating secondary motor areas," *Conf Proc IEEE Eng Med Biol Soc*, vol. 1, pp. 3692-5, 2006.

[18] M. F. Folstein, S. E. Folstein, and P. R. McHugh, ""Mini-mental state". A practical method for grading the cognitive state of patients for the clinician," *J Psychiatr Res*, vol. 12, pp. 189-98, Nov 1975.

[19] R. A. Keith, C. V. Granger, B. B. Hamilton, and F. S. Sherwin, "The functional independence measure: a new tool for rehabilitation," *Adv Clin Rehabil*, vol. 1, pp. 6-18, 1987.

[20] F. I. Mahoney and D. W. Barthel, "Functional Evaluation: The Barthel Index," *Md State Med J*, vol. 14, pp. 61-5, Feb 1965.

[21] C. Collin and D. Wade, "Assessing motor impairment after stroke: a pilot reliability study," *J Neurol Neurosurg Psychiatry*, vol. 53, pp. 576-9, Jul 1990.

[22] A. R. Fugl-Meyer, L. Jaasko, I. Leyman, S. Olsson, and S. Steglind, "The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance," *Scand J Rehabil Med*, vol. 7, pp. 13-31, 1975.

[23] S. Barreca, C. K. Gowland, P. Stratford, M. Huijbregts, J. Griffiths, W. Torresin, M. Dunkley, P. Miller, and L. Masters, "Development of the Chedoke Arm and Hand Activity Inventory: theoretical constructs, item generation, and selection," *Top Stroke Rehabil*, vol. 11, pp. 31-42, Fall 2004.