Social Integration of Stroke Patients through the Multiplayer Rehabilitation Gaming System

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Abstract. Stroke is a leading cause of serious long-term disability in adults (Go et al, 2013). The impact of stroke induced impairments goes beyond the mere loss of motor abilities. The psychosocial implications caused by changes in performance of the activities of daily living have to be considered in modern rehabilitation processes since they do influence the potential outcome. From the perspective of traditional rehabilitation it is difficult to directly address these social factors. Here we propose to capitalize on a rising trend in rehabilitation to deploy virtual reality environments in order to overcome this limitation. By creating a multiplayer game that enhances performance of the patient through an adaptive mapping methodology, we compensate for motor impairments and allow the patient to interact with other participants on an equal level. We propose that this approach influences psychosocial dynamics as it changes the participant's mutual perception. We conducted a psychosocial study to gain insight into the patients' social environment and tested the system in two at home experiments. The results suggest that our system is able to equalize a healthy and disabled player and benefits the social interaction.

1 Introduction

Stroke leaves survivors mostly with serious long-term impairments that reduce the ability to act, communicate and perform activities of daily living. These physical disabilities also affect the relation and interaction patients have with their social environment (Beth & William, 1999). On the other hand the social environment of the patient plays an important amplifying role in the rehabilitation process (Pellerin, Rochette, & Racine, 2011). Modern rehabilitation attempts should therefore not only focus on physical recovery but also address psychological consequences like social isolation or lower contentment with life. Virtual reality (VR) environments are currently seen to be useful rehabilitation tools to address challenges that could not been solved with previous technologies and methods (Jack et al., 2001; Sandlund, Mcdonough, & Häger-Ross, 2009; Verschure, 2011). Present virtual rehabilitation programs and serious games seem to focus often on regaining the patient's motor

S. Göbel and J. Wiemeyer (Eds.): GameDays 2014, LNCS 8395, pp. 100–114, 2014.

function only and neglect other implications related to the social interaction with the environment. In this study we explore the potential of a VR-system to incorporate the social dynamics into the rehabilitation process (Cameirao, Badia, Oller, & Verschure, 2010). An adaptive mapping diminishes the differences in motor performance between a disabled and a healthy player. Incorporated into a multiplayer game we aim to positively influence the social interaction between stroke patients and their informal caregivers and change their mutual perception.

1.1 Importance and Role of Social Environment in Stroke Rehabilitation

Since stroke patients are left with physical and cognitive impairments, they face radical changes in the performance of daily activities and their social roles. These so called life habits or Activities of Daily Living (ADL) ensure the person's wellbeing in society and depend on the social environment the person is in (Di Loreto, Van Dokkum, Gouaich, & Laffont, 2011). After an acquired brain injury like a stroke the social environment needs to undergo a structural change and redistribute the social roles (Ryan, Wade, Nice, Shenefelt, & Shepard, 1996). As post-stroke rehabilitation techniques have improved over the past years and the pressure to reduce public health costs has increased, more patients return home earlier, forcing families to provide follow-up care at home (Ryan, Wade, Nice, Shenefelt, & Shepard, 1996). Therefore therapists prescribe home exercises as part of the outpatient therapy. Unfortunately patients often do not accomplish these home exercises due to lack of motivation and supervision. It is therefore necessary to find new strategies for encouraging and motivating patients to keep on training at home (Alankus, Proffitt, Kelleher, & Engsberg, 2011). The importance of the patients' relatives in the recovery process needs therefore to be considered in rehabilitation (Pellerin, Rochette, & Racine, 2011; Ryan, Wade, Nice, Shenefelt, & Shepard, 1996). A successful rehabilitation is the result of a close interaction between the patient gaining competence in ADL, their abilities, and the social and physical aspects of the environment. Hence, rehabilitation should assist patients in optimizing the use of their physical, mental, and social abilities, in relation to their daily environment (Lilja, Bergh, Johansson, & Nygard, 2003).

1.2 The Rehabilitation Gaming System (RGS)

Virtual reality (VR) technologies have proven to be beneficial for a variety of neurological conditions (Lucca, Castelli, & Sannita, 2009). VR-tools can help to enhance velocity and walking distance, attention, speed, precision and timing or provide opportunities for practicing ADLs (Johansson, 2011) and they allow to flexibly deploy scenarios addressing specific needs (Cameirao, Bermúdez i Badia, Duarte Oller, & Verschure, 2010). One of these virtual reality systems is the Rehabilitation Gaming System (RGS), a VR-based rehabilitation tool that integrates a paradigm of action execution and action observation with a number of specific theoretical neuroscience based principles of learning and recovery (Fig.1). RGS includes an interactive interface where the user controls and observes a virtual body (avatar) from a first-person perspective. Execution of goal-directed movement is thus coordinated with observation of the same movement. The rationale for using this action-observation paradigm is the understanding that the observation of action can in turn lead to activation of secondary motor areas such as the so called mirror neurons system (Pellegrino, Fadgia L., Fogassi, Gallese, & Rizzolatti, 1992; Small, Buccino, & Solodkin, 2010). RGS is based on the hypothesis that this link between perception and action, when combined with methods to drive neuronal plasticity, creates optimal conditions for functional recovery after stroke. The usability and effectiveness of RGS for motor recovery of upper limbs has been evaluated in acute and chronic stroke patients, showing that it leads to significant improvements as compared to baseline and/or control conditions (Cameirao, Zimmerli, Duarte Oller, & Verschure, 2007; Cameirao, Bermúdez i Badia, & Verschure, 2008; Cameirao, Bermúdez i Badia, Duarte Oller, & Verschure, 2009; Cameirao, Bermúdez i Badia, Duarte Oller, & Verschure, 2010; da Silva Cameirao, Bermúdez i Badia, Duarte Oller, & Verschure, 2011). In addition, the ability of RGS to drive the mirror mechanisms of the human brain has been validated in dedicated fMRI experiments (Prochnow et al., 2013).

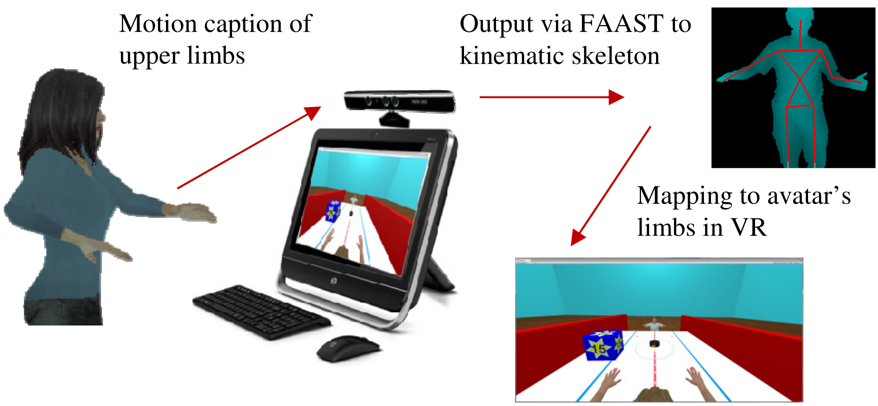

Fig. 1. Set up and functionality of the RGS-system. The user's motion are tracked by a motion capture system (Kinect, Microsoft, Seattle) and mapped via the Flexible Action and Articulated Skeleton Toolkit (FAAST) on the virtual limbs of the avatar. By adapting the mapping the user performs different tasks viewing the avatar from a first person perspective.

1.3 Adaptive Mapping

RGS incorporates two forms of adaptation. First, it adjusts the difficulty level of the task to the performance of the user optimizing motivation and learning. Second, it can amplify and/or adjust the actual movement trajectory in order to amplify the functionality of the user in the virtual environment. Stroke patients are often unable to perform certain arm movements, thus limiting their range of movements. RGS can be used to enhance the movement of the virtual arms to match them to the patients intended movement, movement goal and its corresponding kinematics. The mapping between the real and virtual limb of the user is modulated by amplifying as well as steering the virtual movements towards the current target to a degree that supports the users in their attempt to reach it. The RGS adaptive mapping assesses the individual performance level of the patient and adjusts the difficulty accordingly, so the task is never too hard nor too easy, ensuring optimal arousal and motivation customized to the patient (Nirme, Duff, & Verschure, 2011).

1.4 VR-Based Multiplayer Environments for Rehabilitation

How can the advantages of VR-systems and the need for social interaction in rehabilitation be combined? Studies have shown that playing interactive games may not only lead to improvements in movement quality and mobility but also to a higher motivation, self-efficacy and feeling of social acceptance (Sandlund, Mcdonough, & Häger-Ross, 2009). Multiplayer games in particular offer a shared experience, collaboration possibilities and the reward of being socialized into a community of players (Ducheneaut, Yee, Nickell, & Moore, 2006). These games are especially beneficial for physically disabled individuals as limited mobility causes a lack of social interaction possibilities. They help to form new bonds and bridges by providing social interaction in the virtual space (Trepte, Reinecke, & Juechems, 2011). So far RGS covers only individual physical training of impaired motor functions. By implementing a multiplayer game we explore if such a VR-system can assist patient in overcoming social barriers despite their physical limitations. Through the adaptive mapping we can diminish the motor disabilities of the patients, enabling them to compete on equal levels. Besides lifting their self-efficacy and changing the perception of their own abilities, we assume to influence the valuation that the social environment has of them. To validate and test our hypothesis we analysed the social environment of patients, evaluated the system with healthy subjects and ultimately conducted two at home experiments with patients and their informal caregivers.

2 Materials and Methods

2.1 The Task

The aim of this study was to explore the potential of the adaptive mapping in RGS to enable a patient and a family member to play together in a multiplayer environment and thus to enhance social functioning and acceptance. For this purpose we designed and developed a gaming scenario that resembles the popular two-player air puck or air hockey game. This game requires speed and precision, two attributes that are also requested in many rehabilitation tasks. The goal of the game is to hit with the hand a puck over a playing field towards the other player. Whenever a player fails to hit the puck back, the opponent player scores and a new puck is spawned. The puck only moves on the horizontal plane over the playing field (maximal range of x-offset: 1.15 m). In addition, players are awarded with extra points when hitting any of the bonus boxes appearing in random locations on the playing field (Fig. 2).

Fig. 2. Picture of the two-player network RGS air hockey game. Two players facing each other and tossing a puck with the movement of their limbs over the playing field. The pink bonus box, which appears at random moments and locations in the game, offers 10 extra points to the player.

The adaptive mapping applied to the players facilitates the accomplishment of the goal. The system adapts to the individual capabilities of the patients and learns how much aid the users' movements need in order to achieve the task, thus allowing the patients to perform movements in the virtual environment they otherwise could not achieve. By enhancing their performance we aim to provide the patients with a better match between intended action and observed result. The adaptive mapping applies a gain to the user's virtual movement and partly steers the virtual arm towards the expected target position, which is relative to the current position of the given target, in this case the air puck. The function that determinates the target positions was a result of a pre-test conducted with three healthy subjects using RGS. The subjects were asked to catch spheres arriving at different x-offsets. The target positions and the interpolation between them were calculated as a best fit to the average positions of the hands at five different x-offsets (Nirme, Duff, & Verschure, 2011). The value of the gain applied to the movement of the limbs is the inverse of the reach ratio. The reach ratio is calculated by dividing the vector of the user's real movement towards the target by the vector of the starting position of that movement to the target. The reach ratio sets the modification of the virtual arm for the next arriving target, resp. puck. The gain is then applied to the movement vector as well as to its projection on the vector from the start position to the target position. The interpolation between these two vectors results in the angle of the modulated virtual arm position. The higher the reach ratio, the closer the modulated virtual arm movement is to the real arm movement resp. the less gain and steering are applied. Before the angles are finally applied to the visible virtual arms, they are weighted by blending 80 % of the modified mapping with 20 % of the original mapping. This ensures that the mapping will never help the user too much, keeping a good balance between challenge and help. Although the virtual movements are constantly modulated, the perceived correlation of real and virtual arm movements and the sense of ownership are preserved (Nirme, Duff, & Verschure, 2011). The adaptive mapping algorithm is applied to the movement of both players.

2.2 The Setup

The setup for this study consists of two Desktop PCs and two Microsoft Kinects that are placed behind and above the displays. The game is played over a network connection (server and client connection) by connecting the two PCs via LAN. We developed the game scenario in Unity 3D game engine (http://unity3d.com/unity/).

2.3 Subjects and Experimental Protocol

Study 1. Psychosocial study
We conducted a pre-study to gain a deeper insight into the relation between patients and their social environment. Patient and informal caregiver described and evaluated their relation through two separate questionnaires. This allowed us to understand to which extent a multiplayer game in RGS could be beneficial for the rehabilitation process from a psychosocial point of view.

We interviewed 21 stroke patients (13 male, mean age = 56.6, *SD* = 14.86) recruited from the Rehabilitation Unit of Hospital de l'Esperança in Barcelona. They were selected through the occupational therapists in charge of their rehabilitation. All subjects had suffered a stroke and displayed different deficits in motor function of varying levels of severity. The patients were interviewed in the hospital during their rehabilitation program. Subsequent to the interview, the patients were asked to pass the questionnaire to their closest informal caregiver. 17 informal caregivers (14 female, mean age = 52.8, years *SD* = 15.7) filled out the questionnaire. The first set of

Table 1. Questions regarding perceived capabilities in performing various ADLs which were answered by patient and informal caregiver on a 6-point scale (very uncertain, moderately uncertain, slightly uncertain, slightly certain, moderately certain and very certain)

Number	Statement
S.1	How certain are you that you / the patient can continue most of your / his/her daily activities?
S.2	How certain are you that you / the patient can walk 1 km on flat ground?
S.3	How certain are you that you / the patient can lift a 4 kg box?
S.4	How certain are you that you / the patient can perform the daily at-home rehabilitation program?
S.5	How certain are you that you / the patient can perform household chores?
S.6	How certain are you that you / the patient can shop for groceries or clothes?
S.7	How certain are you that you / the patient can engage in social activities?
S.8	How certain are you that you / the patient can engage in hobbies or recreational activities?
S.9	How certain are you that you / the patient can engage in family activities?

questions in the questionnaires was based on a previous study that analysed the psychosocial variables associated with the informal caregivers' burden of dependent older people in Spain (Garcés, Carretero, Ródenas, & Sanjosé, 2008). The second set of questions was taken from a study that elaborated the Chronic Pain Self-Efficacy Scale (CPSS) which measures chronic pain patients' perceived and their self-efficacy to cope with the consequence of chronic pain (Anderson, Noel Dowds, Pelletz, Edwards, & Peeters-Asdourian Ch., 1995). The patients had to rate how certain they feel in performing various ADL's on a 6 point scale from very uncertain to very certain (see table 1). The informal caregiver evaluated the capacities of the patient through the same questions but from their own point of view. This part was used again in the questionnaire of the at-home intervention. This enabled us to cross-validate the perception of patient and informal caregiver.

Study 2. System evaluation

In order to validate the RGS adaptive mapping in the RGS hockey scenario, we tested the system on 18 healthy participants (8 female, mean age = 27.72 years, *SD* = 4.74). The subjects played in pairs one gaming session that consisted of five subsequent rounds of the game. The first round served as a training round and provided baseline data. In the four following rounds the right hand of one player was constrained to the table (each player two rounds) by using a rubber band to simulate a motor impairment, while the other player was able to move freely. The adaptive mapping was alternating switched on and off. All participants experienced four different conditions while playing (Table 2): constrained with adaptive mapping, non-constrained with adaptive mapping, constrained with no adaptive mapping and non-constrained with no adaptive mapping. Through this system evaluation we ensured that the adaptive mapping mechanisms can level out the differences when constrained and non-constrained subjects are playing together.

Table 2. Condition scheme of the four applied conditions in one experimental gaming session. All participants experienced all conditions; each player was constrained for two rounds, while the adaptive mapping was alternating switched on and off.

	Adaptive mapping	Non-adaptive mapping
Constraint	1. Condition	3. Condition
No constraint	2. Condition	4. Condition

Study 3. At-home intervention with stroke patients

After the pre-study we tested the system through a home-based intervention, as social interaction between patient and informal caregiver mainly takes place through the daily activities at home. Out of the subjects that were part of the pre-study survey (study 2), two patients (PL, PJ) and their respective informal caregivers (CP, CA) were selected by an occupational therapist. The patients were two male subjects (age 61 and 66). The informal caregiver was in both cases their spouse (age 60 and 65).

In the case of one patient and caregiver pair (PJ and CA), the daughter (CS) conducted one experimental session instead of the caregiver. In order to conduct the experiment the system was stationary set up at the subjects' home.

Over three subsequent days, patient and informal caregiver participated in three gaming sessions. In each gaming session the subjects were asked to play two rounds of three minutes each, but they had the opportunity to play more if they liked to. The limited time intervention period was due to time constraints from patient's side. After each session we applied a questionnaire to detect changes in the mutual perception between patient and informal caregiver. The questionnaire was based on two existing questionnaires: The same set of questions used in the psychosocial study related to the Chronic Pain Self-Efficacy Scale (CPSS), and the Perceived Competence Scale (PCS), which measures the subject's feelings of competence about a particular activity or domain. Besides the qualitative assessment we measured the physical activity and performance of the patient during the gaming sessions.

3 Results

3.1 Psychosocial Study

The pre-study provided us with new insights about the structure of the social environment of the patient. Most patients that took part in the study live together with their partner and another family member(s). Therefore the informal caregiver was in almost 60% of the cases the spouse. Most patients reported to have frequent contact with friends, followed by the family. Only 5 % stated that they do not have contact with people outside of the caregiving situation. In the majority of the cases the patients receive visits from other persons or they keep up with their social network over telephone or in written form. The lesser part is going out to meet people. The lack of out-of-home social contact could be related to the limited mobility that most stroke patients face due to motor impairments. Further we compared the rating that patient and informal caregiver gave on the patients' perceived capabilities in performing ADLs (Fig. 3 and Table 1). Since not all informal caregivers completed the questionnaire, the statistical analysis included data from only 34 subjects (17 patients and the response of their informal caregivers). In general, patients rated their capabilities higher than the informal caregiver (Fig. 3). Except for the rating pair regarding the rehabilitation at home, all ratings did not differ significantly between patient and informal caregiver (Mann-Whitney test). The patients rating (Mdn = 5) on the ability to perform the prescribed daily rehabilitation program at home was significantly higher than the rating of the informal caregiver (Mdn = 4), U = 60.00, $z = -2.99$, $p < .05$, $r = -.51$.

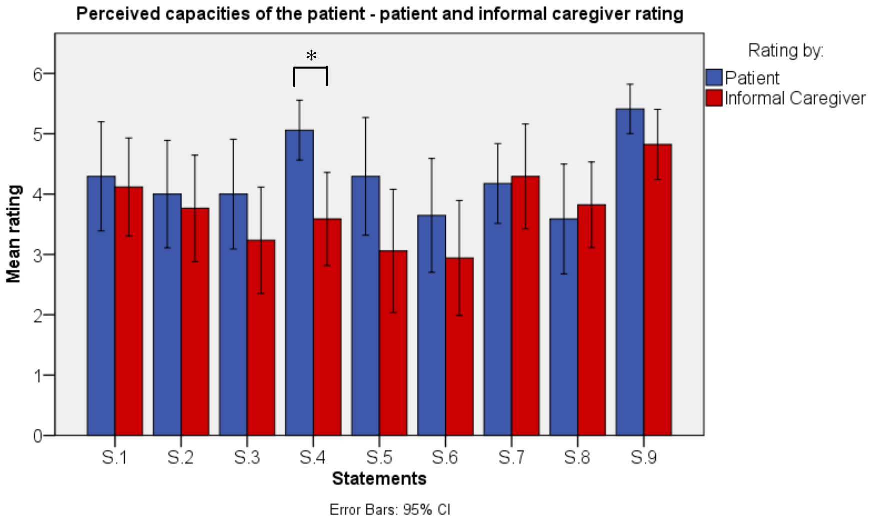

Fig. 3. Comparison between the patients self-rating and the rating of the informal caregiver on the perceived secureness of the patients' ability to perform various ADLs

3.2 System Evaluation

In order to test the efficacy of the system to level out differences between a handicapped (constrained right hand) and a healthy player (non-constrained) we analysed the 4 different conditions (Table 2).We compared the distance covered with the real non-modulated hand to the distance covered by the virtual modulated hand, steered by the RGS adaptive mapping. As shown in figure 4 the right constrained real hand in condition 1 covered significant less distance than the right non-constrained real hand in condition 2 (paired samples t-test, $p < .05$). The adaptive mapping is overcoming this handicap and converts the movement effectively in the virtual modulated right hand. There was no significant difference in the distance covered between the constraint modulated hand of condition 1 and the non-constraint modulated hand of condition 2 (*ns*). The distance covered by the left hand (modulated and non-modulated) shows no significant difference (*ns*) in both conditions, which suggests that the adaptive mapping is not affecting the non-impaired movement. Regarding the score there is no significant difference (repeated-measures ANOVA test, *ns*) between the points made in condition 1 (M = 8.75, SD = 5.604) and in condition 2 (M = 6.81, SD = 4.415). All distances were significantly normal (Kolmogorov-Smirnov test, $D(18)$, *ns*)

3.3 At-Home Intervention with Stroke Patients

In order to test the system in a real social context, two at home experiments with patients and their informal caregiver were conducted. Although the subjects were asked to play only two rounds each session, they all wanted to play more. In total both case study groups played 21 gaming rounds with a total of 63 minutes (3 minutes per game round). In the end both groups played 75 % more than they were requested.

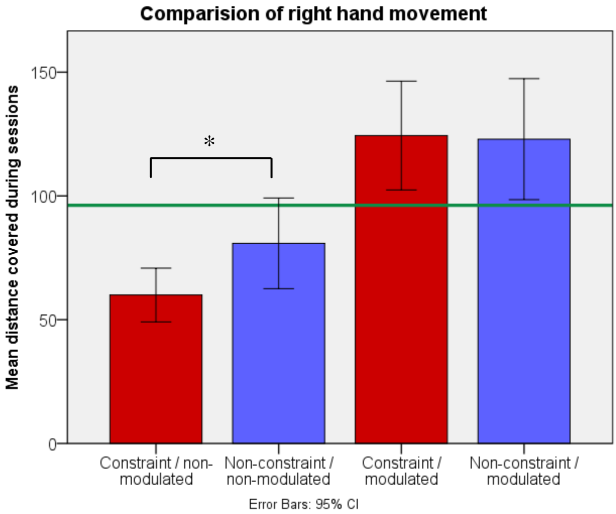

Fig. 4. Comparison of mean distances covered with the right hand (non-modulated and modulated) between condition 1 (constraint in red) and condition 2 (non-constraint in blue). The green line marks the grand mean of the movement of left and right hand gained in the test round (baseline).

In order to see how the game affects the patient's motor behaviour we analysed the interquartile range of movement (ROM) of the patients' hand in the horizontal axis (x-axis). This range strongly depends on the ability of the user to perform shoulder adduction/abduction movements. Results suggest that the interquartile ROM in the horizontal axis was higher for the patients' non-paretic limbs ($M = 0.184$, $SD = 0.081$, $p = 0.063$, Wilcoxon rank-sum test) compared to their paretic limbs ($M = 0.138$, $SD = 0.096$). This difference disappeared after applying the adaptive mapping ($p = 0.4812$, Wilcoxon rank-sum test). In addition, we found significant differences between the interquartile horizontal ROM of the patient's paretic limb ($M = 0.138$, $SD = 0.096$) and the modulated paretic limb ($M = 0.217$, $SD = 0.1545$, $p < 0.001$, Wilcoxon rank-sum test). These differences point out the effect of the adaptive mapping over the range of movement covered by the patient's paretic limb.

Further we compared the patients' performance with the caregiver's performance along all rounds by counting the number of pucks they failed to hit back. A Wilcoxon rank-sum test revealed no significant differences between groups in the number of missed pucks ($p = 0.4215$). This result was confirmed by comparing the amount of scores achieved by each group (Fig. 5 and 6).

Case Study Group PL and CP

This group played nine rounds in total, in which the patient was more successful in gaining points than the informal caregiver (Fig. 5). The patient won five out of nine rounds. The patient's average score was 53.89 ($SD = 16.16$), while his informal caregivers' average score was 40.78 ($SD = 17.39$).

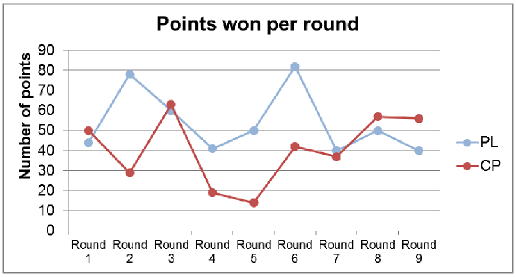

Fig. 5. Number of points won by all subjects in each gaming round. PL: patient and CP: informal caregiver.

In order so see if these gaming sessions had any impact on mutual perception, we analysed results from the questionnaires and compared the ratings of patient and informal caregiver (Fig. 6). Statement 2, 6 and 8 were rated higher by both, the patient and the informal caregiver.

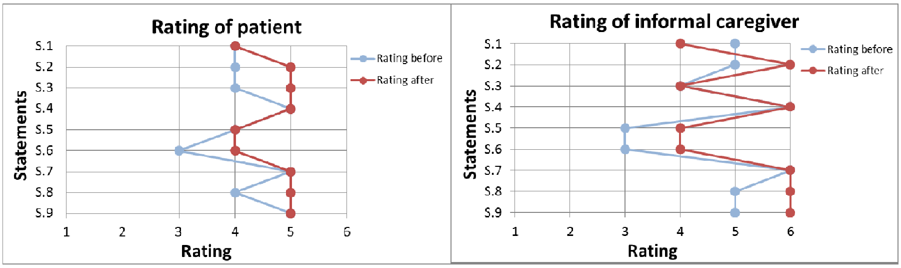

Fig. 6. Comparison of the ratings of each ADL-statements of PL and CP before and after the at-home intervention

Case Study Group PJ and CA

Patient PJ was less successful in gaining points and rounds than his informal caregiver, resp. his daughter, who played the second session with him (Fig. 7). Out of the 12 rounds two were won by the patient. The average number of points he made were 39.67 (*SD* = 12.61), CA average points were 50.14 (*SD* = 11.54) and the average points made by CS were 51.8 (*SD* = 11.01).

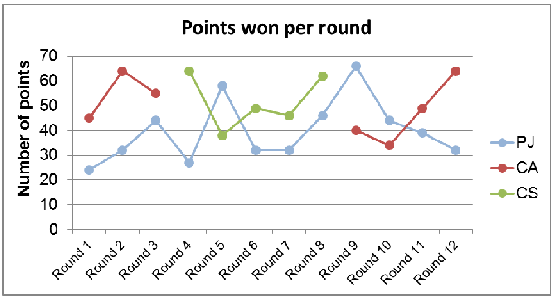

Fig. 7. Number of points won by the subjects in each round. PJ: patient, CA/CS: informal caregivers.

Also in this group we compared the ratings of patient and informal caregiver before and after the at-home intervention (Fig. 8). Statement 4, 7 and 8 were rated higher by both, the patient and the informal caregiver. Especially the 2 point increase in the rating of social interaction by the caregiver is of interest.

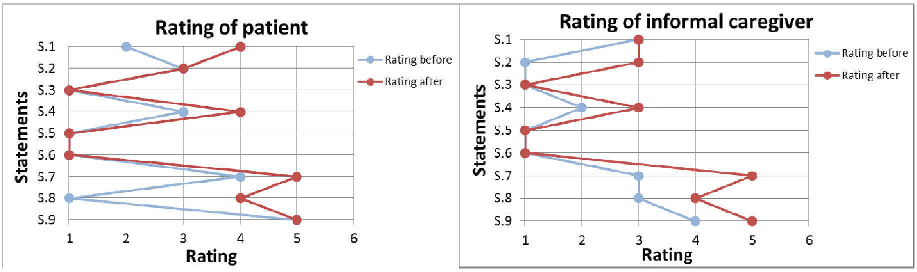

Fig. 8. Comparison of the ratings of ADL-statements of PJ and CA before and after the at-home intervention

4 Discussion

Combining virtual reality with social interaction through a multiplayer game can lead to new ways to mobilize social actors in stroke rehabilitation and to assist in integrating the patient in their social environment. The RGS air hockey scenario allows patients and their social environment to interact in a playful way and to experience a new common ground for equal social interaction. We hypothesized that this will ultimately lead to a changed mutual perception of roles and capabilities.

The results from both, the system evaluation and the at-home experiments, suggest that the adaptive mapping is capable of levelling out performance differences between two players. The system successfully overcomes the difference in moving distance and range between an impaired / restricted and a healthy / non-restricted limb. This influences the outcome of the game insofar that the status of the player (caregiver or patient) does not determine who will win or lose the game. Moreover, it the game appears to be entertaining since the subjects were willing to play more rounds than requested.

The analysis of the patients' social situation revealed many aspects in favour of a multiplayer rehabilitation game. The majority of patients are embedded into a social network of family and friends. Only a few patients live alone and/or have no frequent contact to other people. Since their disabilities limits the mobility, our system would enable the patients to interact with their social network at home or even online.

In our psychosocial study we found a slight discrepancy in the ratings regarding the patient's ability to perform ADL, although not at a statistically significant level. The patients show a tendency to rate most of their own abilities higher than the informal caregiver. The same trend can be observed in the results from the at-home experiments where both the patients' and the caregivers' reported higher ratings after the gaming sessions.

Our findings suggest that a multiplayer scenario could be beneficial in addressing the requirements of modern rehabilitation with an emphasis on an integrated motor, psychological and social approach. As outpatient therapy will become more important and the involvement of the patient's social environment increases, these kinds of scenarios support the reintegration process, ensuring a sustainable rehabilitation method in the service of enhancing quality of life. Moreover, we believe that further investigation based on our results will shed light on the psychosocial changes stroke patients face and helping to better understand the impact beyond the motor impairment.

5 Conclusion

This study evaluated the influence of including social interaction into the VR rehabilitation paradigm Rehabilitation Gaming System. We have shown that the system successfully equalizes the performance differences between a healthy and a disabled player influencing self- and social perception. First observations in this direction could be seen in the change of ratings before and after the at-home interventions. Moreover, the game-like scenarios of RGS provide an entertaining and motivating way to socially interact. Given the relatively small sample, especially in the case of the at home experiments, the preliminary results serve as an initial case study, that shows a trend towards the outlined proposal. Nevertheless we believe that the new multiplayer scenario in RGS is a valuable tool for further investigation of our claims and for assessing its impact on future stroke recovery.

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