Telehealth using 3D virtual environments in stroke rehabilitation – work in progress

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ABSTRACT

We have now started testing a telehealth system for stroke rehabilitation in a rural area in Sweden (NU- Hospital Group Area). For collection of assessments and audiovisual communication, the telehealth system has bidirectional contact with the home-based units. To date, three stroke subjects' participated; they were instructed to play 3D computer games with the hemiplegic upper extremity. The intervention led to clinical changes for all subjects. The analysis of the audiovisual communication revealed that the both stroke subjects and therapists were not yet effective in regulating their turn taking process. The data suggests the feasibility of a distance based approach using 3D virtual environments for upper extremity rehabilitation after stroke.

1. INTRODUCTION

Rehabilitation aims to improve function, i.e. guide subjects with stroke to reenter the community true active involvement so they can become as independent as possible (Barnes 2003). Hospital Rehabilitation of stroke subjects starts in the acute phase, then when the stroke is no longer immediately life-threatening, the rehabilitation continues in inpatient, home-care, and/or outpatient settings (Adams et al. 2003). During the inpatient setting, the training may consist of getting out of bed, eating and drinking, dressing, bathing, cooking, and toileting (Duncan et al. 2005). These activities subsequently expand to train the ability to handle independence. Once at home, training continues in to enable stroke subjects to return to their normal abilities - day-to-day tasks, such as managing domestic tasks.

Home-based health care is considered cost-effective, and has shown examples which are as successful as hospital-based rehabilitation programs. Surveillance of such programs is normally conducted via telephone interviews or home visits. The prevailing thought is that home visits holds an advantage over telephonic interventions because of the face-to-face contact with subjects, for instance answers have shown to be significantly more reliable (Linden 2006).

This project addresses two major problems within stroke rehabilitation. Firstly, it is a common problem that many subjects with stroke find the daily exercises that they are to perform at home are not very interesting and thereby lose motivation when they return home from the hospital. The second problem is that current methods require subjects with stroke to return to the hospital on a frequent basis for rehabilitation and to be monitored by hospital staff. Traveling to and from the hospital frequently poses, a large cost to hospitals. Our approach is a combination of the two: 3D- computer gaming and follow-up online meetings with audiovisual computer-mediated communications tools.

2. METHODS

2.1   Subjects

Three male subjects were invited to participate in a telehealth care program for stroke rehabilitation. Three subjects were included in this study where referred to an outpatient clinic located in Uddevalla, Sweden (Table 1). All the subjects were living in the community in their own homes and were retired. They were referred from an occupational therapist from that primary care clinic and the referral criteria was 1) diagnosis of stroke; 2) hem paresis in one of the upper extremities, that is, box and blocks score lower than 45 (Mathiowetz et al. 1985); 3) no signs of neglect; and 4) a minimum age of 70 years. Exclusion criteria for all subjects were 1) joint problems or prior injury to arm/hand; 2) language difficulty that affects information reception.

The study was approved by The Regional Ethical Review Board in Gothenburg, Sweden and was conducted according to the Helsinki Declaration. All subjects included in the study gave written informed consent.

Table 1. *Stroke subjects characteristics at admission.*

	Age (Years)	Sex	Months since stroke	Side of stroke	Etiology	Intervention period (days)
S1	87	Male	3	Left	Infarct	87
S2	84	Male	10	Right	Infarct	143
S3	78	Male	6	Left	Infarct	121

2.2   Intervention

The intervention used a pre-/post-test design. The scenario is that the user sits at home in front of a computer monitor with stereoscopic 3D visualization and holds a haptic stick (a robotic arm with a track stick, which mediates a feeling of touch and force feedback) with which he/she performs different "serious games". After the set up was installed in the homes, the subjects' were instructed to play 3D computer games for at least 20 minutes a day during the intervention period. At specific hours an occupational therapist monitored and coached the subjects from a distance. Prior to entering the study, the subjects were trained to utilize the telehealth system. For collection of assessments and audiovisual communication between therapists and subjects, the telehealth system had bidirectional contact with the home-based units. If an Internet connection was available in their homes this was used instead of the mobile internet connection.

2.2.1 System Components and Connections (Fig. 1). The system consists of a desktop-sized immersive workbench (www.curictus.com), which uses a three-dimensional (3D) virtual environment with games with an inbuilt rehabilitation component (serious games) designed for upper extremity (UE) movement therapy, and assessment. A patient care management system (PCMS) enables the transfer of real time system data and log files and maintains an archive of all information. From the management system, clinicians can observe and graph subjects' progress and discuss games to be played by each subject. At this stage we make use of current video conferencing technologies (Adobe connect Pro 7.5), i.e. the video/audio teleconference system was not integrated in the immersive workbench. A separate computer monitor was connected to the workbench with a mobile wireless internet connection, a webcam and headset.

2.3   Outcome Measurement

2.3.1 Rehabilitation. Grippit was used to measure grip force (N) this is a electronic device used clinically that registers force generated by the muscles of the hand (Nordenskiold et al. 1993). The Box and Block Test (BBT) evaluates gross movements of the hand/arm. The test requires moving, one by one, the maximum of blocks from one compartment of a box to another of equal size within 1 min. The Action Research Arm test (ARAT)) assess arm/hand functions using functional activities such as gripping, moving objects or pouring water from one glass to another (Lyle 1981). The EQ5D VAS score was used to assess general health status (Brooks 1996). It records the subject's self-rated health status on a graduated (0–100) scale, with 100 indicating the best health status. We considered a change of 10% as clinically relevant (Alon et al. 2003).

Figure 1. *Telehealth system: a desktop-sized immersive workbench, PCMS with activity data (velocity graph), and screen shots from the user interface, and video conferences. "Pictures showing subjects are approved for scientific publication by the person in the image"*

2.3.2 Patient Care Management System (PCMS). Automatically stored performance data captured with the PCMS was; 1) results of each game; 2) number of times run ; 3) performance for each run; 4) raw hand movement data, captured at 1000 Hz; 5) game events time stamped to match the raw hand movement data. We administered a UE test developed in a previous study (Broeren et al. 2004). Movement kinematics were measured with the PHANToM Omni® (haptic stylus end-point)) before and after the intervention. From this, time (duration) and distance to complete the test were recorded. From this movement speed, i.e. velocity (m/s) and movement quality (HPR: this is the distance traversed by the haptic stylus, calculating the length of the pathway divided by the straight-line distance to obtain a hand path ratio) were calculated.

2.3.2 Video Conferencing Technology. Conversational Analysis (Riseberg et al. 1997) were used on the recorded meetings as follows: first the conversation was categorized into the topics of a follow-up meeting such as *social talk, health status, planning*, *speech synchronization,* and *technical support*, and the duration was timed. Each topic was labelled as a "type of talk", i.e., instruction, interrogation, confirmation, negotiation or decision, which indicate the strategy used to achieve a goal. Then, for each topic unit, the turn-taking process was analysed and phenomena which decreased fluency of the conversation, such as *talking simultaneously, interrupt partner, disruption in discourse, confused silence*, and *repeating answered question*, was counted.

3. RESULTS

3.1   Rehabilitation Outcome Measurements

The data suggest that the intervention led to clinical changes in grip force (N) for S2 and S3. Manual ability, according to the BBT and ARAT improved for all three subjects (S1-S3). The subjects' self-rated health status (EQ5D VAS score) increased for all three subjects (Table 2).

TABLE 2. *Rehabilitation outcome measurements for the paretic UE for S1-S3.*

	S1		S2		S3	
	Pre	Post	Pre	Post	Pre	Post
Grippit (N)	244	259	248	315*	26	102*
BBT	40	49*	16	24*	48	56*
ARAT	43	55*	**	38	48	57*
EQ5D VAS score (%)	30	50	30	70	70	90

*clinically significant improvement ≥ 15 %
** no data available

3.2 Patient Care Management System

The plots in Fig. 2 suggest the possibility of linear trends; to be verified in larger scale investigations to come.
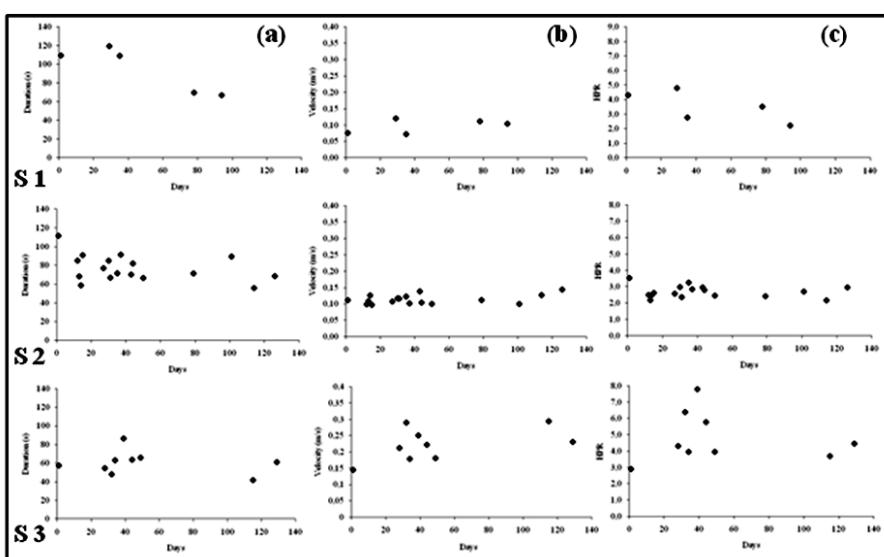

Figure 2. *Kinematic data for the UE test for S1-S3: (a) duration (s), (b) velocity (m/s) and (c) HPR.*

In table 3; the subjects' choice of games (Preferred Game Activity), the amount of each game played and the total time (duration) played during the intervention period.

3.3 Video Conferencing Technology

3.1.1 Technological Problems. A non-reliable internet connection was a problem that made it difficult to have the e-meeting with one subject. The internet connection on the computer was disabled two times and it could not be explained how it could happen. The mobile internet connection used on the therapist computer gave to low bandwidth depending on where the therapist was located. This gave problem with the video and voice transmission and two e-meetings were interrupted and could not be continued. For each of the installations in the subjects' home the system was tested and a brief introduction to the user-interface, web camera and microphone was held with the subject.

To be able to learn how to use the system in a convenient way, training with the therapist on how to use the system was performed when the therapist was visiting in the subjects' home. They were present in different rooms, both using the desktop videoconferencing system and when something failed the therapist could easily help the subject with the difficulties on place. A manual on how to use the system was developed to both the therapist and the subjects' to be at hand when starting up and joining the e-meetings, it was

distributed at the time of the training. For every e-meeting in the desktop videoconferencing system, a user support person in the e-meeting room was available to help the participants if there were any technical difficulties at that time.

Table 3. *Preferred Game Activity Category for S1-S3 with the amount and duration for each game played.*

SUBJECTS	ACTIVITY	TIMES PLAYED	DURATION (min.)
	FISH TANK	34	96
	MATHS	29	108
S1	MEMORY	159	110
	SPACE TENNIS	42	25
	MEMORY	63	60
S2	FISH TANK	139	313
	MATHS	4	23
	FISH TANK	35	62
	LIGHT PUZZLE	2	17
	MATHS	9	17
S3	MEMORY	95	58
	SPACE TENNIS	29	15
	TARGET BALL	7	88

3.1.2 Conversational Analysis of Online Meetings. Three recorded meetings were analysed, one for each subject. The durations of meetings were approximately 7, 9 and 13 minutes. The first two meetings were mainly therapist-subject conversations (with a short period of technical support in the beginning), whereas the third was an example of a learning situation where the subject was supported by a therapist at his location.

In the Content analysis (Fig. 3) representing relative duration of different topics in the meetings, we have grouped speech synchronization and technical support into one group: communication management, since these are meta-topics of the conversation and are undesirable. Notably, at this early stage of the learning process, communication management activities represent as much as 40-60% of the time. Considering the limited duration of active engagement that is generally possible due to mental fatigue for stroke subjects, it is most important to avoid communication management as much as possible.

In the analysis of the turn-taking process, we found "simultaneously talking" to be the most common obstacle to fluency in the conversation, which is part of the timing management of a dialogue. Simultaneous talk was often a result of one partner trying to take over the speaking role by interrupting during speech or in a short pause, but where the first speaker kept talking. Sometimes simultaneous talk was followed by confused silence and then simultaneous talk again. The disruption of discourse occurred 4-5 times a meeting, and seemed to be a consequence of unclear speaker/listener roles. Such confusion rarely occurs in face-to-face conversations.
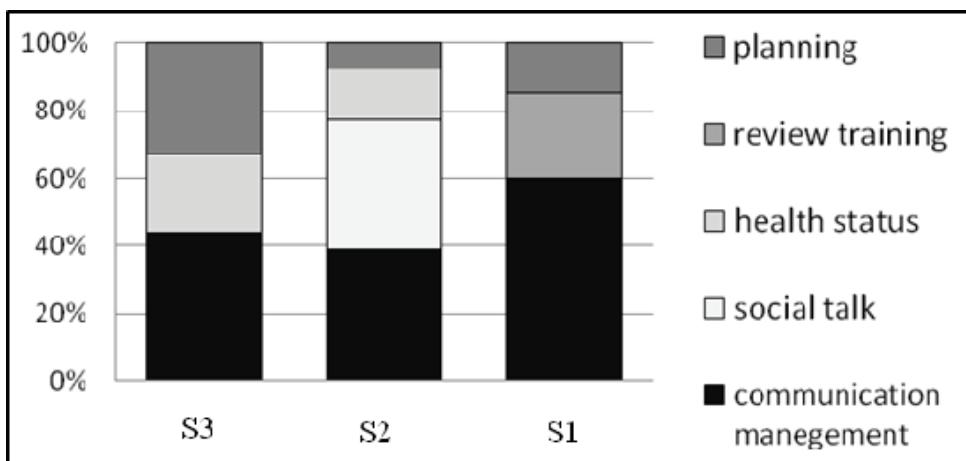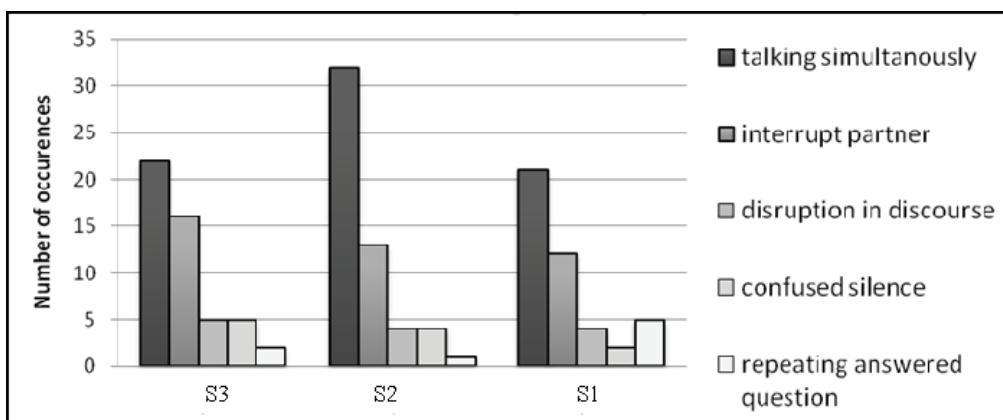
Figure 3. *Content analysis of the e-meetings.*

Figure 4. *Phenomena decreasing fluency in conversation.*

4. DISCUSSION

The current proof-of- concept study shows that the purposed telehealth system can be applied to stroke rehabilitation. The subjects' affected upper-extremity impairment improved in the BBT and the movement kinematics delivered by the telehealth system for all subjects (S1-S3). Two subjects in the ARAT (S1 and S3). Grip force of the hand increased for two subjects (S2 and S3). These clinical changes add information to previous studies suggesting the efficacy telehealth (Kairy et al. 2009).

We used an off-the-shelf video-conferencing system to test the feasibility of e-meetings between therapists and subjects, in order to identify requirements and design implications on a future communication tool which will be integrated in the system. It allows thorough analysis of the conversations since meetings can be recorded. Video recordings are particularly appropriate for Conversational Analysis (a sub-method of discourse analysis), since gestures, face expressions and other body language are often highly relevant in social activities such as conversation (Mazur 2004). Conversational analysis using recorded video has previously shown to be effective for deriving design implications (Riseberg et al. 1997).

Communicating via a computer-based medium differ from face-to-face interaction. Aspects of interaction such as noting gaze, gestures and other body language are often highly relevant to interpret conversation (Mazur 2004), and is either absent (as in non-visual media such as chat, e-mail etc) or more difficult to perceive (as in audiovisual media such as video conference systems or video telephone). Such non-verbal cues are to a large extent used to manage conversations, such as turn-taking and synchronizing speaking/listening roles. Moreover, the medium affect the way affective states can be pursued. Non-verbal cues can be interchanged by verbal cues, but is less efficient and need to be learnt (Walther et al. 2005).

Successful rehabilitation is dependent on a stroke subject's motivation and compliance. Earlier studies have shown that the system is motivational and has benefits beyond real life training (Broeren et al. 2008; Pareto et al. 2008). Variation of activities and levels are essential due to subjects' varying abilities and

experience. Telehealth can open ways for interactive communication, thus allowing for daily monitoring of progress and adjustments to rehabilitation plans (Broeren et al. 2009). The benefits of using telehealth would be enhancing the quality of stroke rehabilitation with more timely and frequent assessments, as well as greater continuity in the healthcare chain (Winters et al. 2004).

5. CONCLUSIONS

The results of this study indicate that home rehabilitation is a promising approach in remote training and may have beneficial effects on quality of life. Further research is necessary to evaluate clinical efficacy and cost effectiveness with a larger population.

6. REFERENCES

H. P. Adams, Jr., R. J. Adams, T. Brott, G. J. del Zoppo, A. Furlan, L. B. Goldstein, R. L. Grubb, R. Higashida, C. Kidwell, T. G. Kwiatkowski, J. R. Marler and G. J. Hademenos (2003), Guidelines for the early management of patients with ischemic stroke: A scientific statement from the Stroke Council of the American Stroke Association, *Stroke, 34, 4*, pp. 1056-1083.

G. Alon, K. S. Sunnerhagen, A. C. Geurts and A. Ohry (2003), A home-based, self-administered stimulation program to improve selected hand functions of chronic stroke, *Neurorehabilitation, 18, 3*, pp. 215 - 225.

M. P. Barnes (2003), Principles of neurological rehabilitation, *J Neurol Neurosurg Psychiatry,* **74** *4*, pp. iv3-iv7.

J. Broeren, L. Claesson, D. Goude, M. Rydmark and K. S. Sunnerhagen (2008), Virtual rehabilitation in an activity centre for community-dwelling persons with stroke. The possibilities of 3-dimensional computer games, *Cerebrovasc Dis, 26, 3*, pp. 289-296.

J. Broeren, M. Rydmark and K. S. Sunnerhagen (2004), Virtual reality and haptics as a training device for movement rehabilitation after stroke: a single-case study, *Arch Phys Med Rehabil, 85, 8*, pp. 1247-1250.

J. Broeren, K. Sunnerhagen and R. M. (2009), Haptic Virtual Rehabilitation in Stroke - Transferring Research into Clinical Practice, *Physical Therapy Reviews, 15, 5*, pp. 14.

R. Brooks (1996), EuroQol: the current state of play, *Health Policy, 37, 1*, pp. 53-72.

P. W. Duncan, R. Zorowitz, B. Bates, J. Y. Choi, J. J. Glasberg, G. D. Graham, R. C. Katz, K. Lamberty and D. Reker (2005), Management of Adult Stroke Rehabilitation Care: a clinical practice guideline, *Stroke, 36, 9*, pp. e100-143.

D. Kairy, P. Lehoux, C. Vincent and M. Visintin (2009), A systematic review of clinical outcomes, clinical process, healthcare utilization and costs associated with telerehabilitation, *Disabil Rehabil, 31, 6*, pp. 427-447.

A. Linden (2006), Evaluating the Effectiveness of Home Health as a Disease Management Strategy, *Home Health Care Management & Practice, 18, 3*, pp. 216-222.

R. C. Lyle (1981), A performance test for assessment of upper limb function in physical rehabilitation treatment and research, *Int J Rehabil Res, 4, 4*, pp. 483-492.

V. Mathiowetz, G. Volland, N. Kashman and K. Weber (1985), Adult norms for the Box and Block Test of manual dexterity, *Am J Occup Ther, 39, 6*, pp. 386-391.

J. M. Mazur (2004), Conversational analysis for educational technologists: theoretical and methodological issues for researching the structures, processes and meaning of online talk. In *Handbook of research on educational communications and technology*, (D. H. Jonassen, Eds), Lawrence Erlbaum Associates, Mahwah, NJ, pp. 1073-1098.

U. M. Nordenskiold and G. Grimby (1993), Grip force in patients with rheumatoid arthritis and fibromyalgia and in healthy subjects. A study with the Grippit instrument, *Scand J Rheumatol, 22, 1*, pp. 14-19.

L. Pareto, D. Goude, M. Rydmark and J. Broeren (2008), Virtual reality, haptics and post-stroke rehabilitation in practical therapy Article in conference, *Proc. 7th International Conference on Disability, Virtual Reality and Associated Technologies with ArtAbilitation 2008*, Porto, Portugal, pp. 245-252.

J. C. Riseberg, R. Berkowitz and L. Cunningham (1997), Action and Reaction: Computer-Mediated Dialogues As a Model for Natural Interfaces, Article in conference, *Proc. 2nd International Conference on Cognitive Technology* Aizu, Japan, pp. 109.

J. B. Walther, S. Pingree, R. P. Hawkins and D. B. Buller (2005), Attributes of interactive online health information systems, *J Med Internet Res,* **7,** *3*, pp. e33.

J. M. Winters and J. M. Winters (2004), A telehomecare model for optimizing rehabilitation outcomes, *Telemed J E Health,* **10,** *2*, pp. 200-212.