Preliminary findings of feasibility and compliance of technology-supported distal arm training at home after stroke

G.B. Prange, PhD[1,2], S.M. Nijenhuis, MSc[1], P. Sale[3], MD, A. Cesario[3], MD, N. Nasr[4], PhD, G. Mountain[4], PhD, F. Amirabdollahian, PhD[5], J.H. Buurke, PT, PhD[1,6]

[1] Roessingh Research and Development, Enschede, the Netherlands
[2] Department of Biomechanical Engineering, University of Twente, Enschede, the Netherlands
[3] Department of NeuroRehabilitation, IRCCS San Raffaele Pisana, Rome, Italy
[4] School of Health and Related Research, University of Sheffield, Sheffield, United Kingdom
[5] Adaptive Systems Research Group, University of Hertfordshire, Hatfield, United Kingdom
[6] Department of Biosystems and Signals, University of Twente, Enschede, the Netherlands

***Abstract*— After stroke, intensive and active training is important to regain functional use of the arm and hand. By applying a telerehabilitation system (SCRIPT1) supporting active, distal arm practice at home, a patient can practice independently, which enables a larger dosage of treatment than possible during one-to-one supervised rehabilitation. Currently one of the major, but rarely addressed, questions concerning telerehabilitation is whether patients actually use such a system in a self-administered training approach. This paper presents preliminary results about feasibility of self-administered post-stroke home-based SCRIPT1 training. So far, data of 20 chronic stroke patients is available, who have trained for six weeks at home using interactive gaming exercises and a passive wrist/hand orthosis supporting hand opening (SCRIPT1). Findings so far indicated positive perceptions of usability and showed actual use of the system with a mean training duration of 107 min/week. This was accompanied by modest improvements in motor function and dexterity, correlated positively with training duration. These preliminary findings indicate that self-administered, technology-supported distal arm training at home is feasible for chronic stroke patients.**

I. INTRODUCTION

Functional recovery from stroke requires extensive rehabilitation. Research into motor relearning and cortical reorganization after stroke has provided a neurophysiological basis for key aspects that stimulate restoration of arm function (Schaechter, 2004; Krakauer, 2005): high training dose, active initiation and execution of movements, and application of functional exercises. In the setting of the rehabilitation centre, intensive training of arm and hand is supervised by highly skilled professionals. However, the time that can be spent on training in such intramural settings is limited. Due to the high costs of clinical neurorehabilitation, post-stroke treatments are limited to only a few weeks with limited treatment resources in many countries.

Technological innovations provided an opportunity to design interventions that take many key aspects of motor relearning into account, of which rehabilitation robotics is a well-known example. With such a device, the required amount of movement support can be provided, allowing active practice when this is not possible otherwise. This increases the potential to train intensively, with the patient's active contribution to functional exercises. Contemporary robot-aided therapy focuses mainly on the proximal arm, and results in improvements in the proximal arm only, without generalization to the wrist and hand (Prange, 2006), while the wrist and hand play a major role in a person's functional independence. In order to maximize independent use of the upper extremity in daily life, it is important to include functional practice of the wrist and hand [1].

If a system that supports active, distal arm practice can be applied in a patient's home within a telerehabilitation concept [2], a larger dosage of treatment can be delivered while the patient practices independently with remote supervision by a healthcare professional. Augmented dosage of treatment is a major determinant of functional outcome after post-stroke neurorehabilitation, with a recommended amount of added practice of at least 16 hours to improve functional recovery [3]. Besides the amount of treatment available, the adherence of a patient to the training programme affects the actual dosage of treatment delivered [3], which is unclear in many cases. In addition, a technology-supported home-based application enables distributed practice throughout the day or week instead of massed practice, which is associated with better retention performance as well [4].

In the present ongoing study (Supervised Care and Rehabilitation Involving Personal Tele-robotics, SCRIPT), a custom-designed orthosis that passively supports wrist and hand function is combined with a motivational user interface with gaming environment, connected to a remote module for off-line supervision by a healthcare professional. This system (SCRIPT1) is intended to be used independently at home by chronic stroke patients for distal arm training. Besides feasibility of technology-supported arm/hand training at home in chronic stroke patients,

GP, SN and JB are with Roessingh Research and Development, Enschede, the Netherlands (e-mail: g.prange@rrd.nl). GP is also with Department of Biomechanical Engineering, University of Twente, Enschede, the Netherlands , JB is also with Department of Biosystems and Signals, University of Twente, Enschede, the Netherlands.

PS and AC are with Department of NeuroRehabilitation, IRCCS San Raffaele Pisana, Rome, Italy. NN and GM are with the School of Health and Related Research, University of Sheffield, Sheffield, United Kingdom. FA is with the Adaptive Systems Research Group, University of Hertfordshire, Hatfield, United Kingdom.

currently one of the major, but not often addressed, research questions concerning telerehabilitation is whether patients actually use such a system when provided with the opportunity. Therefore, the present paper aims to examine the feasibility of post-stroke home-based SCRIPT1 training in terms of usability, compliance and associated changes in arm function.

II. METHODS

The present feasibility study applied a longitudinal (pre-post) experimental study design, with an intervention of six weeks of home-based arm/hand training with the SCRIPT1 system. The SCRIPT1 system was custom developed involving a user-centred design approach, taking needs and abilities of stroke patients, their carers and healthcare professionals into account through repeated usability testing.

A. Participants

In total, 24 chronic stroke patients with impaired arm/hand function have been included in this study across 3 clinical sites: Roessingh Research and Development (the Netherlands), IRCSS San Raffaele Pisana (Italy) and University of Sheffield (United Kingdom). Main inclusion criteria were between 6 months and 5 years after stroke and 18-80 years of age, displaying limited arm/hand function (having at least 15° active elbow flexion and a quarter range of active finger flexion). Also, participants had to be able to accommodate the SCRIPT1 system at their homes. The study was approved by the local medical ethics committees of the 3 sites and all participants provided written informed consent before entering into the study.

B. Intervention

Participants performed six weeks of self-administered distal arm training at home. They were recommended to exercise 180 minutes per week with the SCRIPT1 system, but they were free to train more (or less) if they preferred. They trained independently using custom-designed games displayed on a touchscreen, while they were supervised remotely, off-line, by a trained healthcare professional (HCP). During training, they wore a custom-designed hand/wrist orthosis (Fig. 1) that passively supported wrist extension and hand opening across all fingers of the affected arm (Ates 2013).

Figure 1. SCRIPT1 passive hand/wrist orthosis

During weekly home visits, the HCP adjusted the amount of support by adjusting elastic bands over the wrist and fingers to provide enough support to achieve hand opening of at least 2.5 cm. Additionally, all participants used the SaeboMAS (Saebo Inc, Charlotte NC, USA) arm support for the proximal arm, set to provide 100% of arm weight compensation. The HCP remotely selected suitable games for each participant in terms of number and type of wrist and hand movements involved in the exercises, once a week through a web-based, secured portal.

C. Measurements

Evaluation of feasibility involved usability measured by the System Usability Scale (SUS), compliance in terms of actual use (training duration in minutes), arm motor function measured by the upper extremity part of the Fugl-Meyer assessment (FM [7, 8]) and dexterity measured by the Action Research Arm Test (ARAT [9-11]). The SUS is a 10-item questionnaire giving a global view of subjective assessments of usability of a technological system [5]. Scores are translated to a scale of 0% to 100%, indicating: <50% = system will almost certainly have usability difficulties in the field; 50-70% = promising, but guarantees no high acceptability in the field; >70% = high chances for acceptance in the field [6].

Evaluation of arm function and dexterity was done before (T01) and after training (T08) and at 2 months follow-up after the end of training (T15). Because the dataset isn't complete yet in this ongoing study, only available data of T01 and T08 is presented here. Usability was assessed at T08 only and training duration was recorded within the SCRIPT1 system throughout the 6-week training period.

D. Data analysis

Since the data presented here represents a subset of the complete dataset, changes in motor function and dexterity were compared between pre- and post-training evaluation sessions using the non-parametric Wilcoxon signed-rank test (significance level $\alpha < 0.05$). In addition, a correlation analysis of training duration with changes in FM and ARAT and SUS score was performed using Spearman's correlation.

III. RESULTS

At present, 23 chronic stroke patients (10 from the Netherlands, 10 from Italy and 3 from the United Kingdom) have completed T01 and T08 evaluations. Of these, 3 have stopped participation during the training, due to shoulder complaints acting up, dislike of the system and technical issues. Mean age of the remaining 20 participants was 58 years; mean time post-stroke was 17 months.

The group average of the SUS score is 69%, indicating that usability of the SCRIPT1 system is promising with a good chance of acceptance in the field. Individually, "usability difficulties in the field" (SUS <50%) was scored by 4 participants, usability was perceived as "promising" (SUS 50-70%) by 8 participants and 8 reported the SCRIPT1 system to have "a high chance of acceptance" (SUS >70%).

TABLE I: Clinical outcomes pre-post training

Mean (±SD) values		
Outcome measure	***T01***	***T08***
FM (points)	34 (±15)	38 (±16)
ARAT (points)	27 (±21)	29 (±21)
SUS (%)	n/a	69 (±17)

Average training duration was 107 (±67) minutes per week. Overall, this amounted to a total training duration of 644 (±403) minutes (i.e., 10 hours and 44 minutes) per participant over 6 weeks. This comes down to about 15 minutes of self-administered training each day for 6 weeks. Individually, training duration varied substantially, ranging from 13 up to 284 minutes (4 hours and 44 minutes) per week.

Clinical outcomes showed improvements after training (Table I). FM scores increased significantly by 4.0 points (±4.9) on group level (p=0.002). Similarly, ARAT scores increased significantly by 1.8 (±3.7) on group level (p=0.014). On individual level, 4 out of 20 participants exceeded minimal clinically important differences (MCID +6.6 points [12]) on FM and 1 approached MCID with FM improvement of 6 points. For ARAT, 2 participants exceeded MCID (of +5.7 points [12]).

To further examine associations between training duration and clinical outcomes correlation analysis was performed, showing that training duration was correlated (Fig. 2) with changes in ARAT (ρ=0.70, p=0.001), indicating that a higher training duration is associated with a larger improvement in ARAT. Correlation of training duration with change in FM was weak (ρ=0.34, p=0.143), but there was a positive trend associated with SUS (ρ=0.40, p=0.094).

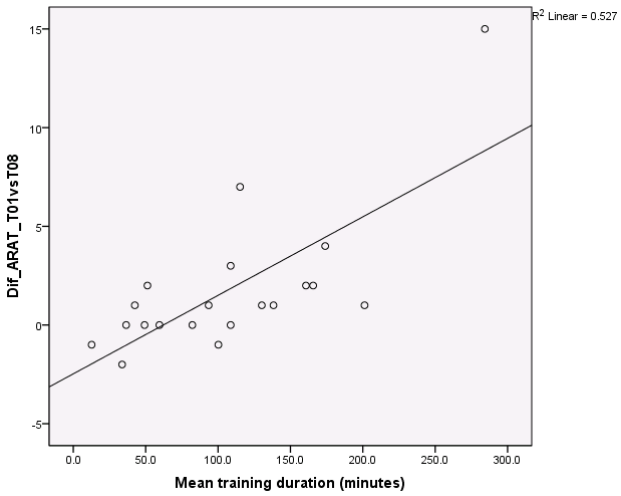

Figure 2. Scatter plot of training duration and change in ARAT

IV. DISCUSSION

Of the 23 participants so far, 20 participants completed the training period and were able to work with and use the SCRIPT1 system independently. Of the 3 participants that dropped out during training (13%), 1 was not related to limited usability of the SCRIPT1 system, as her SUS score was 95%. The other 2 participants (9%) experienced substantial usability problems, as represented by SUS scores of 30% and 38%. Experienced use issues by these drop-outs (and the remaining participants as well) have been noted to provide input for design adaptations for a second generation. Overall, only 9% of participants were not able and/or willing to perform home-based wrist/hand training independently using the SCRIPT1 system, whereas the remaining 20 participants achieved an average compliance of 107 minutes per week. In addition, usability was perceived as positive. These preliminary findings indicate that technology-supported distal arm training at home is feasible for chronic stroke patients.

As this is one of a few studies in which technology-supported arm/hand training is performed in the patient's home, it is difficult to compare the actual training duration with other home-based training studies. A review by Coupar 2012 involved four studies on telerehabilitation focusing on training of the upper limb after stroke in the home situation, indicating home-based upper limb programmes to be no more or no less effective for arm motor impairment outcomes [13]. In all of these studies, the patients were remotely supervised at a fixed time, so with direct real-time (remote) supervision of a therapist. Therefore, the times and duration of training each day were fixed [13], and the actual amount of self-administered training at home wasn't examined. This was also the case for the study by Holden et al., in which therapists in a remote location conducted treatment sessions with a patient located at home using a virtual environment based motor-training system [14], and the studies by Taub and Lum et al., in which a therapist supervised the training from a different room in the clinic [15, 16]. In contrast, the SCRIPT1 system allowed stroke patients to have a more active role in their rehabilitation, involving their family members and carers as well, and make their own decisions about their training schedule. Thus, in our study patients were free to choose their own training time and duration. Anecdotal evidence from physiotherapists involved in the present study have mentioned that the achieved adherence of about 15 minutes per day is rather high for chronic stroke patients to exercise at home after discharge from rehabilitation, which is promising for the potential to engage people in home-based arm/hand training post-stroke.

The improvements in motor function of the arm in the present study are along similar lines as those found in robot-aided studies in chronic stroke [17], as well as actively [18] and passively [19, 20] actuated arm support for the proximal arm. Again, these studies involved face-to-face supervision and a fixed schedule of practice (ranging from 1½ hours per week [18, 20] to 3 hours per week [19]). The preliminary findings in the present study indicate that when provided with the opportunity at home, stroke patients have the personal incentive to perform comparable amounts of practice as a mean training duration of 1¾ hours per week was observed.

It has to be noted that individual variation in training duration was large, ranging from ¼ of an hour to over 4½ hours per week. Since dosage of treatment is regarded as an important determinant of treatment outcome [3], a positive correlation with clinical improvements was expected. This relation was observed for dexterity (although this correlation may have been influenced by one particularly

successful participant), but it was less pronounced for motor function. As the present study is ongoing, it is of particular interest to examine these relations more closely in the complete sample, along with other factors that might be involved as mediators in clinical improvements (e.g., initial stroke severity, age, motivation, etc.).

V. CONCLUSION

The preliminary findings of this ongoing study for usability and compliance are positive and promising. Also, modest improvements in motor function and dexterity have been found at this point. Moreover, on individual level quite substantial improvements have been observed. The data so far suggest a moderate correlation of clinical improvement with training duration, where participants who train more achieve larger improvements of dexterity, but other potential mediators should be investigated as well in the larger sample.

If these results so far are indicative of the ongoing study, technology-supported arm/hand training may be a feasible and promising tool to enable self-administered practice at home for chronic stroke patients. Ultimately, home-based training could be considered as a neurorehabilitation application at an earlier stage after stroke, for instance as soon as inpatient rehabilitation is finished or even as addition to inpatient rehabilitation. In many countries, this would involve patients in the sub-acute phase as well, where larger treatment effects would be expected.

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