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A Comparison of Treatment Effects after Sensor- and Robot-based Task-oriented Arm training in Highly Functional Stroke Patients

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***Abstract*—A large number of rehabilitation technologies for stroke patients has been developed in the last decade. To date it is insufficiently clear what the strengths of these different technologies are in relation to certain patient characteristics, such as the level of muscle strength and/or functional ability. One of the reasons is that research protocols differ so much that comparison of treatment results is impossible. This paper compares, while using the same patient inclusion criteria and training protocol, the effectivity of a sensor-supported versus robot-supported task-oriented arm training for highly functional chronic stroke patients. It appeared that individual improvements over time and Hedges's g effect sizes were twice as large for the sensor-based training compared to the robot-supported training in stroke patients with high functional levels. New research is planned to compare both therapy approaches for stroke patients with low and average functional levels.**

I. Introduction

A LARGE number of rehabilitation technologies has been developed in the last decade, of which a substantial proportion has shown to improve arm-hand performance after stroke [1,2]. The increasing incidence of stroke has been putting high pressure on the health system for the last years, thereby raising the demands for cost-effective treatments [3]. Despite its promising effectiveness, technology-supported training has not yet managed to find its way to the rehabilitation centers or to the patient's home. Most rehabilitation technologies are still in a research or predevelopment stage [4]. Another important obstacle for clinical adoption of such systems is that it is very difficult to compare different technological systems with regard to their training effects, and that it is virtually impossible to know which system is the best one to use for different patients (different functional levels, different pathologies). It has been argued that standardized research protocols should be developed in order to compare the evidence on the benefits of the robotic applications in health care [5]. Clearly, this argument holds for rehabilitation technology in general, in order to offer some guidance to clinicians who have to choose the optimal system (combination) for their patients.

It has been hypothesized that stroke patients with lower functional levels may benefit more from robot-supported training where actuator assistance to movement and/or exoskeleton support may overcome problems such as muscle weakness [6]. Patients with higher functional levels are hypothesized to benefit more from training with sensor-based systems that can offer a) training in mastering redundant degrees of freedom of the upper extremity during normal everyday activities, and b) learning of problem solving strategies that can be used in everyday life activities [1].

The aim of this paper is to test the latter hypothesis and compare treatment effects of two separate clinical trials that used different rehabilitation technologies, but the same patient inclusion criteria and the same training approach (T-TOAT [7]) in a similar training protocol. Training effects after 8 weeks of sensor-based task-oriented arm training are compared to training effects after 8 weeks of robot-supported task-oriented arm training for highly functional chronic stroke patients.

II. METHODS

A. Subjects and study protocol

The participants in the two clinical trials were recruited from Adelante Rehabilitation Centre (formerly Rehabilitation Foundation Limburg) (Hoensbroek, NL). Both clinical studies were approved by the Medical Ethics Committee of Rehabilitation Foundation Limburg (Hoensbroek, NL). Subjects were in the chronic phase after stroke (>9months), and were clinically diagnosed with a central paresis of one arm/hand at entry in the study (upper extremity muscle strength: MRC grade 2-4). In the sensor-

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based training group (n=9), the mean age of the participants was 60.7 years. Mean post-stroke time was 2.5 years (SD=1.9). In the robot based clinical trial, 9 chronic stroke patients completed the 8 week training program with the Haptic Master (and 9 chronic stroke patients completed the training in the control intervention, which will not be reported in this paper). In the experimental group that is training with the robot-support, the mean age was 60 years. Their mean post-stroke time was 3 years (SD=3).

Participants in both clinical trials performed task-oriented arm hand training for 8 weeks (4x/week, 2x30minutes per day). Examples of skills that were trained are 'eating with knife and fork' and 'drinking from a cup'. An occupational therapist or physiotherapist was present in the room to assist when necessary.

B. The T-TOAT training method

T-TOAT is a skill training method, developed at Adelante Rehabilitation Centre, to facilitate the implementation of task-oriented training exercises in rehabilitation technologies [7]. The method is based on skill segmentation in meaningful skill components (part practice [8]), that can be practiced first isolated and later in combination with subsequent parts (chaining). The method combines principles of training physiology (e.g. goal dependent training load) and motor learning (e.g., over-learning, feedback, and exercise variability) and offers exercises of increasing difficulty levels. T-TOAT has been implemented in sensor-based [9] and robotic rehabilitation [7] systems, that are used in the clinical trials reported in his paper; and also was implemented in a system for stroke patients to relearn writing [10].

FIGURE I
T-TOAT training with Haptic Master (above) and Philips Stroke Rehabilitation Exerciser (below)

C. Apparatus

In this paper results of two separate clinical trials with rehabilitation technologies are reported and compared.

In the first trial, a sensor based system was used for T-TOAT training, namely Philips Stroke Rehabilitation Exerciser [9,11] (fig.1). The system comprises of a patient and of a therapist interface. The patient is equipped with wireless sensors [12] for measuring joint kinematics, an active exercise board (Serious Toys BV, Den Bosch, NL) [13] that interacts with real-world objects and a PC with a touch screen via which exercises are offered and feedback on performance is provided. The therapist interface allows for exercises to be programmed for the individual patient.

In the second trial, the Haptic Master robot (MOOG, the Netherlands) (fig.1) was used for T-TOAT training. Haptic Master is a commercially available 3 degrees of freedom admittance controlled haptic robot. A customized gimbal (for attachment of the patient's arm to the robot) and special software, named "Haptic-TOAT" [7] were developed at Adelante to enable T-TOAT training with Haptic Master. The patient's (desired) movement trajectory is recorded (and saved), using the Haptic Master as a recording device (3D positions are logged with a sample rate of 100Hz). The recorded movement trajectory can be used in a passive mode or an active mode. During the passive mode the robot guides/moves the patient's arm. The patient can concentrate on the trajectory and prepare his/her active participation. In the active mode, the patient actively performs the movement along the recorded trajectory. Deviation from the recorded movement trajectory is corrected by haptic feedback (sensation of bouncing into a wall and spring-like forces that pull the patient's arm back towards the desired trajectory). The amount of deviation allowed and the strength of the spring-like forces can be set by the therapist to be suitable for the individual patient.

D. Outcome Measures

Patients were measured at baseline, after 4 and 8 weeks training (and 6 months after the training stopped). In both clinical trials primary outcome measures were the following: Fugl Meyer Assessment, upper extremity section (FM)[14], Action Research Arm Test (ARAT) [15] and Motor Activity Log (MAL)(Amount of Use, and Quality of Use) [16].

E. Data Analysis

Mean individual improvement over time was calculated by averaging the individual improvements per participant over time for the primary outcome measures, relative to their baseline values.

Hedges's g effect size [17] was calculated for the three primary outcome measures in both clinical trials. This was done by calculating the difference between the means of baseline and post-intervention outcome, divided by the pooled standard deviation. Hedges's g was bias-corrected for sample size. Cohen's classification categorizes effect sizes smaller than 0.2 as small, effect sizes between 0.2 and 0.5 as medium and larger than 0.5 as large [18].

III. RESULTS

Table 1 provides an overview of the mean individual improvement over time after 8 weeks T-TOAT training with the Philips Stroke Rehabilitation Exerciser and Haptic Master. Also Hedges's g effect sizes after training with both systems are depicted.

TABLE I
Treatment effect sizes and mean individual improvement after 8 weeks of T-TOAT training

Test	**Sensor-based T-TOAT**		**Robot-based T-TOAT**	
	IIT %	**Hedges's g (95% CI)**	**IIT %**	**Hedges's g (95% CI)**
FM	14.2	0.73 (-0.22-1.68)	6.1	0.29 (-0.64-1.22)
ARAT	15.4	0.43 (-0.51-1.36)	6.4	0.28 (-0.65-1.21)
MAL AU	43.4	0.77 (-0.19-1.73)	11.6	0.42 (-0.52-1.35)
MAL QU	34.1	1.02 (0.04-2.00)	13.0	0.54 (-0.40-1.49)

Abbreviations: IIT: Mean individual improvement after 8 weeks training relative to baseline values, CI: confidence interval, FM: Fugl Meyer Assessment, ARAT: Action Research Arm Test, MAL: Motor Activity Log, AU: Amount of Use score, QU: Quality of Use score

Effect sizes on function (Fugl-Meyer) and activity level (ARAT and Motor Activity Log) were large after 8 weeks sensor-based T-TOAT training. Preliminary data after robot-based T-TOAT training indicate medium effect sizes for FM, ARAT, and MAL amount of use. The effect size after training on the MAL quality of use was large.

The individual improvement over time is more than twice as large for sensor-based compared to robot-based training in highly functional chronic stroke patients on all primary outcome measures. For capacity measures on function (Fugl Meyer) and activity level (Action Research Arm Test), only the patients who trained with the sensor system achieved a clinically meaningful improvement (considered to be an improvement equal or above 10% compared to the baseline score [19]) after training. However, as to perceived performance in the home environment, as measured by the MAL (Amount of Use and Quality of Use), both, robot- and sensor-based training resulted in an individual improvement over time that is clinically relevant.

IV. DISCUSSION

A broad spectrum of technological systems for upper extremity rehabilitation after stroke has been developed in the last 15 years. However, to date it remains unclear which system works best for which patient group. It is likely that different patients are served better by different technologies.

Most technologies that have been developed are robotic training systems [1]. Very few sensor-based applications have been realized so far, despite their advantage of avoiding complexity of actuators and mechanical parts. When robot assistance is provided to the patient's movement, patients with lower functional levels can benefit from the use of rehabilitation technology. Especially interactive systems that guide and support depending on the needs of the patient [20], offer opportunities for motor learning through the active involvement of the patient in a high number of exercise repetitions (patients may practice longer/more as they get support when needed). Also, robotic systems can minimize execution errors (e.g. Haptic-TOAT), thereby supporting motor learning [21]. Sensor-based training systems have though other advantages. They may for example offer more opportunity to patients who have a good functional level to learn how to master the redundant degrees of freedom during voluntary movement so that movement occurs in a way that is as economic as possible for the human body, given the fact that the activity result needs to be achieved [1].

In order to facilitate the adoption of rehabilitation technologies by therapists and patients, the training effects of different systems for different patient categories need to become clearer. In this paper, the results from two clinical trials, using the same patient inclusion criteria and training regime, were compared. It was found that in highly functional chronic stroke patients, 8 weeks of sensor-based training leads to a higher individual improvement in arm-hand performance and to higher treatment effect sizes compared to performing similar exercises supported by a robot. From a motor learning perspective, several explanations for these findings can be given: 1) In case of the Haptic Master robot, the available range of motion is limited, preventing the patient from learning to master the available degrees of freedom outside this range of motion. 2) The fact that a preprogrammed trajectory has to be followed by the arm that is attached to the Haptic Master Robot hinders the learning of adaptation processes to external events, which are essential for successful performance of daily life activities. These adaptation skills can be learned through associations between external events and behavioral motor acts [22]. 3) The fact that the patient's forearm is attached to the gimbal impedes the open chain action that is characteristic for upper extremity movement. 4) It is known that feedback is an important training characteristic that is associated with large post-intervention effect sizes [23]. With the Haptic Master training only real-time haptic feedback is given to the patient on the movement trajectory that is performed. In the training with the Philips Stroke Rehabilitation Exerciser, auditive and visual feedback was given, both real time and after completion of a set of exercises (average and summary feedback). The feedback relates to the quantity and quality of arm movement performance and trunk compensation. Patients were given time after exercise performance to evaluate their movement performance and to use the feedback information for planning the next movements.

It seems that patients who have enough muscle power, as was the case for the patients included in the clinical trials reported, do not benefit enough from the support that the robot offers to compensate for the restrictions it imposes for the performance of 'everyday life movements'.

Further research is needed to compare the systems for patients with lower functional levels, as robot-supported training may be more beneficial for the latter patient group than sensor-based training.

V. CONCLUSION

The results described in this paper indicate that sensor-based training may be more effective for the improvement of arm hand performance in highly functional chronic stroke patients than robot based training.

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