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Lag–lead based assessment and adaptation of exercise speed for stroke survivors

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HIGHLIGHTS

- Our system enabled people with stroke to exercise at home by playing videogames.
- Movement speed was adapted to performance, based on the Optimal Challenge Framework.
- The mechanism of adaptation has been effective in 195 of 248 (78.6%) sessions.
- The efficacy of the adaptation mechanism led subjects to train more intensively.
- Lag–lead based adaptation is a suitable auto-tuning tool for robot therapy.

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ABSTRACT

The SCRIPT project aims at delivering machine-mediated hand and wrist exercises to people with stroke in their homes. In this context, adapting the exercise to the individual needs potentially enhances recovery.

We designed a system composed of a passive-actuated wearable device, a personal computer and an arm support. The system enables users to exercise their hand and wrist movements by playing interactive games which were developed as part of the project. Movements and their required speed are tailored on the individual's capabilities. During the exercise the system assesses whether the subject is in advance (leading) or in delay (lagging) with respect to a reference trajectory. This information provides input to an adaptive mechanism which changes the required movement speed in order to make the exercise neither too easy nor too challenging.

In this paper, we show results of the adaptation process in a study involving seven persons with chronic stroke who completed a six weeks training in their homes. Based on the patterns observed in difficulty and lag–lead score, we defined five session types (*challenging, challenging–then supporting, supporting, under-supporting* and *under-challenging)*. We show that the mechanism of adaptation has been effective in 195 of 248 (78.6%) sessions.

Based on our results, we propose the lag–lead based assessment and adaptation as an auto-tuning tool for machine based exercise, with particular focus on rehabilitation robotics. Also, the classification of sessions among different types can be applied to other studies in order to better understanding the progression of therapy in order to maximize its outcome.

1. Introduction

Due to an ageing society, the number of people suffering a stroke is expected to increase, leading to increased demands for healthcare, while the availability of healthcare professionals is decreasing [1]. Overall, this will have a strong impact on healthcare services and related costs. Therefore, new ways of providing

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healthcare services, such as remotely supervised intensive treatment and self-administered exercises (e.g. in the patient's home), address a major issue for future healthcare organization [2].

1.1. Rehabilitation robotics for stroke

Functional recovery from stroke demands a long period of physical rehabilitation. Research into motor relearning and cortical reorganization after stroke has provided a neurophysiological basis for restoration of arm function: high training intensity, active participation and execution of movements, feedback and application of functional exercises are key aspects [3,4]. Technological innovations as those introduced in the gaming industry (e.g. Nintendo Wii, Microsoft Kinect) provided an opportunity to design interventions that combine many of such aspects. Several of such devices can be integrated within one system for home-based rehabilitation [5]. In addition to motion tracking systems, robotic devices can provide a support towards the completion of a motor task, thereby allowing physically assisted practice when this is not possible otherwise. This facilitates intensive training, while the patient is actively contributing to the movement. Robotic systems have an additional advantage in that they potentially allow independent/self-administered training. Once set-up, a therapist can supervise several patients at the same time. This enables the patient to train frequently without a therapist's presence, in his/her own home environment while remotely supervised by a therapist, off-line. If training time is not limited by therapist availability, this may potentially enable a higher dosage of training, which may stimulate gains in arm/hand function [6]. The remote supervision of the therapist can also be considered as a mean to target the therapy so that best outcomes are possible, while also ensuring patient safety (e.g. preventing over-exercising).

With a robotic device, haptic guidance can be used to stimulate motor relearning. Different types of haptic guidance have been implemented in robotic devices, ranging from passive guidance (no active contribution of the patient needed) to soft or hard guidance, guiding a patient along a pre-defined trajectory where deviations are resisted to a larger or smaller extent [7,8]. There is evidence that guidance modalities which do not restrict movement errors and require the largest effort (active movement without interference from the robot or error augmentation) lead to larger and faster adaptation during reaching movements [9].

Therapy with robotic device has proven effectiveness for recovery of the motor functions of the hemiparetic arm, but the transfer of these effects to activities of daily living is less pronounced [10]. The main focus of robot-aided therapy has been on the proximal arm, resulting in limited recovery of wrist and hand functions [11–13]. Without additional involvement of the distal arm in exercises, the functional nature of the training is not optimally employed. Moreover, 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 involve functional practice of the wrist and hand in an intensive way in treatment [14].

1.2. The SCRIPT project[1]

To accommodate treatment incorporating the abovementioned key aspects for motor relearning, the SCRIPT (Supervised Care and Rehabilitation Involving Personal Telerobotics) project aims to apply robot-aided therapy focusing on hand and wrist exercises at home. This would enable self-administration of more intense and more frequent exercises compared to conventional therapy in a clinical setting, which is often limited by the availability of therapists. An important issue that has specific attention within this SCRIPT project is related to whether patients actually improve their amount of practice when provided with the opportunity of self-administered training at home. These aspects are combined in the first prototype system (SCRIPT1), which is based on a passive-actuated orthosis which provides an off-set force towards extension of fingers and wrist using elastic cords and leaf springs [15]. It is noteworthy that, in the domain of rehabilitation robotics, this device is classifiable as a passive dynamics machine, rather than a robot. It features sensors for measuring joint angles at the wrist and fingers and an inertial measurement unit to detect gross movements of the hand. These data are fused and used to control interactive games that require hand opening/closing and/or wrist movements. These are installed on a dedicated personal computer, installed at a patient's home for independent training with off-line remote supervision by a healthcare professional [16]. We deliberately chose of having only off-line supervision so that subjects could exercise any time they wanted, without having to plan their activity or having to rely on the availability of therapists. However, a patient's exercise plan was programmed by the therapist. The complexity and level of challenge were based on a predefined exercise scheme, and more difficult exercises were presented to patients as they got better in their scheduled tasks.

1.3. The need for adaptive exercises

Besides optimization of the treatment intensity, active contribution of a person to such treatment should be emphasized as well. Self-initiated and self-generated activity stimulates brain plasticity underlying functional reorganization of the cortex after a stroke [17]. The importance of self-generated activity was emphasized in a study on healthy subjects, where training of voluntary induced wrist movements resulted in larger increase in performance and cortical reorganization compared to passively induced movements [18]. Along the same lines, repeatedly completing reaching movements of stroke patients by a robotic device when they could not reach the target (with the patient being passive) was inferior to making active reaching movements without robotic assistance [19].

An adaptive training environment can optimally encourage active contribution of the patients, based on their abilities and needs. It is increasingly recognized that patients respond differently to a certain treatment for the upper extremity, e.g. in the field of robot-aided therapy [8]. The current challenge is to understand how to customize arm training programmes to each patient's needs and abilities.

Stimulating improvement of arm/hand function via optimal engagement and active contribution requires that the exercises are challenging; neither too difficult nor too easy, at all times. According to the Challenge Point framework, this is expected to improve motor learning and neuromotor recovery [20]. This implies that, ideally, the training environment adapts to the performance of the patient. This must also take into account that the stroke population is highly heterogeneous in terms of limitations caused by the stroke and the time course of functional improvement. Given the element of relearning involved in rehabilitation, we used taxonomies from the learning theory towards setting the challenge level to maximize adherence to therapy. In the domain of learning and education, balancing between supporting and challenging allows the trainee to achieve optimal learning [21], as shown in Fig. 1.

When applying support from technology to the upper extremity in order to improve arm/hand function, according to the abovementioned considerations it is important to promote active

[1] Videos demonstrating the SCRIPT system are available on the project Youtube channel http://goo.gl/fpaZUD.