

Motivating arm-hand use for stroke patients by serious games

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Abstract—We present a novel technology to support playful rehabilitation of arm-hand performance for stroke survivors. The system combines tangible tabletop interaction with wearable technology, to encourage stroke patients to train their arm-hand skills in a task-oriented manner, while a jacket supporting tilt-sensing and vibrotactile feedback guides patients regarding the correct execution of exercises and specifically to avoid compensatory movements. We present the iterative client centered development of this technology and its on going development.

I. INTRODUCTION

Worldwide, stroke is a leading cause of motor problems [1]. The upper extremity of stroke survivors is often affected by hemiparesis and spasticity. These unilateral motor deficits lead in approximately 40% of the stroke patients to chronic upper extremity impairment, limiting functional use and compromising their quality of life [1], [2]. Task-oriented training methods have been shown to be effective in helping patients improve their performance of daily life activities after stroke [3]. Such methods require that patients train on realistic tasks, relating to their daily life activities, rather than repetitive training that is only aimed at strengthening muscle groups and improving joint movement ranges unrelated to the context where related skills will be deployed. A common complication regarding rehabilitation training for arm-hand performance relates to the phenomenon of compensation. In the (sub-) acute phase after stroke, most hemiparetic patients attempt to achieve task completion through the use of compensation strategies, i.e. by using alternative muscle coalitions [4]. For example, during goal-oriented prehension tasks, individuals with hemiparesis use increased trunk displacement (sagittal and horizontal plane) and shoulder abduction in order to transport their hand to a target compared to healthy individuals [5], [6]. For patients who have enough potential for recovery, compensatory

strategies may be temporary solutions to achieve their goals [7]. Feedback regarding the amount of compensation used during arm movement may thus be used to evaluate progress in arm hand performance. Moreover, to support an optimal potential recovery process, it may be necessary to draw attention on correctable movement performance parameters, such as compensatory movements. With stroke incidence and prevalence on the rise [8], arm hand performance problems are likely to occur more frequently and to increase the burden on the health system substantially in the coming decades. This trend has prompted the development of rehabilitation technologies. A recent review on therapist criteria for rehabilitation technology design [10] concluded that it remains a challenge for rehabilitation technologies to provide engaging patient-tailored task-oriented arm-hand training in natural environments with patient-tailored feedback to support motor learning. We present an arm training system for stroke survivors that aims:

- 1) to invite for frequent movement repetition of ADL with real life objects in a real life context through motivating interactive games, a training approach that has been shown to improve arm hand performance after stroke [11],
- 2) to improve movement quality by supporting awareness of compensation and guiding feedback on compensatory movements, and
- 3) support compliance and motor learning through the provision of information to patients (and their therapists) about progress in arm hand performance during rehabilitation.

II. THE TRAINING METHOD

The T-TOAT (Technology-supported Task-Oriented Arm-hand Training) method been conceived specifically for enabling the implementation of task-oriented training in rehabilitation technologies [12]. This method has been implemented in several supporting technologies: Scribeo [13] was designed to support patients to re-learn how to write in a playful manner; interaction was supported through a tablet device supporting pen-input. The Philips Stroke Rehabilitation Exerciser [11] is a hybrid system supporting tangible interaction and modeling hand movement through accelerometer data on arm, hand, and torso. It supports only a limited set of exercises, which cannot motivate and challenge patients for sustained training periods. The Haptic Master implementation of T-TOAT [12] supports recording of movements and guiding patients through movement trajectories by offering Haptic feedback on deviation of the

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recorded path. The hand is left free in order to let patients train on realistic tasks using every day objects. Clinical trials [9], [11] have shown that the T-TOAT method is effective for the improvement of arm hand performance after stroke, even in the chronic stage after stroke. However, none of the T- TOAT related technologies so far is sufficiently rich and robust to support training over longer periods of time. To improve upon the state of the art it becomes necessary to develop rehabilitation technology that provides sufficient level of challenge, fun, performance feedback and exercise variability.

III. FIRST ITERATION OF PLAYFUL REHABILITATION SYSTEM

A. Concept design and implementation

Building on our earlier investigations [9], [11], [12], a set of interviews was designed and administered with chronic stroke patients (N=12) and a therapist to explore opportunities for supporting training for arm-hand rehabilitation. Three design challenges were identified:

- 1) supporting task oriented training for arm-hand rehabilitation,
- 2) avoiding compensatory movements with shoulder and trunk, and
- 3) ensuring engagement and motivation by means of an interactive game.

We designed a system supporting playful rehabilitation, that consists of two parts:

- 1) An interactive tabletop supporting the manipulation of physical objects that provides stimulus and feedback for task-oriented arm-hand training.
- 2) A compensation movement sensing jacket and associated feedback of patient posture.

The interactive tabletop was supported in this version by a simple touch screen device, through which the user can interact with the game content. The sensing jacket contains two wireless sensor nodes that are placed on the chest and on the shoulder of the patients affected side. The nodes consisted in a 3-axis accelerometer (BMA020), a JeeNode module (JeeNode v5) and a small vibration motor. Every node reads accelerometer data and sends it to a central node connected to a personal computer. The graphical interface, running on a personal computer, allows patients or therapists to set a range regarding the compensation with the trunk and shoulder that is considered acceptable. Whenever users trunk or shoulder movement exceeds the specified range, vibrotactile feedback is provided on the corresponding body part. The user is continuously informed on his movement in real-time through a graphical representation consisting of two bars, one for the shoulder and one for trunk movement. The interface contains dynamically generated buttons that start rehabilitation games that are placed in the games- folder on the PC. A simple, interactive game was developed on this hardware set to demonstrate and evaluate the potential of the overall approach. The game focuses on training eating with cutlery and challenges users to catch a virtual bug displayed

on the horizontal tabletop surface using a physical fork. By arranging digital salad pieces with the real cutlery, users can trap the bug. Whenever the users compensatory movement with shoulder or trunk is larger than accepted compensation range, the bug gets smaller and harder to catch (see Fig. 1).



Fig. 1. Task oriented training of dining skills using actual knife and fork, to play the game on a pressure sensitive touchscreen device. The patient wears the motion sensing jacket that is used for providing graphical and vibrotactile feedback regarding posture and to influence directly the game play

B. User test of first prototype

Seven sub-acute and three chronic stroke patients participated in a user test at a clinic in the Netherlands. This involved a walkthrough of all system functions, an exposure to a game, preceded and followed by an interview regarding motivation to train and the time they spend training. Also participants completed the Intrinsic Motivation Inventory (IMI) [14] and the Credibility/Expectancy Questionnaire [15].

C. Results

Participants described the game as something I can relate to and a variation to regular therapy. Many participants missed an option to adapt the difficulty level of the game. All, but one, of the participants were able to sense and use vibration feedback to correct their posture. Some participants would prefer more distinct feedback in the form of auditory cues or spoken encouragements. Participants indicated that on average they would expect to spent about 40 minutes per day longer on exercising using the game than they normally do. The mean credibility score was 22.3 (SD = 2.45) and the mean expectancy (for treatment outcome) score was 16.82 (SD = 5.38), compared to a neutral score of 15 for both scales. The IMI scoring per factor was very positive (Table I).

TABLE I
INTRINSIC MOTIVATION INVENTORY SCORES (N = 10)

Factor	Min	Max	Mean(SD)
Interest/Enjoyment	4,7	7	6,1 (0,8)
Perceived competence	2,3	6,3	5 (1,2)
Value /Usefulness	3,6	7	6,1 (1)
Relatedness	5,4	7	6,4 (0,5)

D. Conclusions

The playful rehabilitation concept was regarded a credible training approach. In line with our earlier experiences in this field [11], patients expectations of the system were less positive perhaps as a result of their belief that there is little room for improvement after discharge from rehabilitation training [12]. However, recent research results [5] have shown that task-oriented training can provide improvements to patients even in the chronic phases after stroke. Feedback regarding posture is now provided through graphical and vibrotactile feedback; patients would like audio and spoken feedback as well, and would prefer this to be personalized and even be used for providing coaching and encouragement.

IV. SECOND ITERATION OF THE PLAYFUL REHABILITATION SYSTEM

The second iteration of the developed system has pursued three paths:

- 1) improving the sensor vest
- 2) upgrading the interactive tabletop technology to improve ease of use
- 3) extending the range of games and the training support offered gaming as a social motivation for training.

These improvements are discussed in turn below.

A. Sensor vest

The first version of the jacket provides only a loose fit, which compromises the accuracy of the measurement. The final vest (see Fig. 2) consists of a rigid fabric which is held together elastically so fitting multiple sized people. The elas-



Fig. 2. Improved Sensor Vest and Sensor Glove for tracking hand movement

tic keeps the sensors at their place and as much as possible in contact with the body. Furthermore, the vest is designed such that this can be achieved without compromising the freedom of movement of the patient, it can be worn on both left and right shoulder, it fits both genders and should be suitable for different sized patients as much as possible. The sensor vest uses accelerometers to measure:

- 1) trunk movements in the horizontal and sagittal planes at the chest sensor on the sternum,
- 2) shoulder girdle movements at the sensor on the acromion, and
- 3) shoulder joint (i.e. upper arm) movements in the frontal plane at the sensor on the lateral part of the upper arm.

A range of movements can be specified for arm, hand and shoulder through the on screen interface.

B. Interactive tabletop device

To support manipulation of every day objects, e.g., a cup, on the interactive tabletop, the need emerges for multi-touch interaction. The touch screen of the first iteration was replaced by a display monitor combined with a Kinect sensor. The advantages of this alternative (e.g., using projection, or multi-touch surfaces) are: the system is relatively small when comparing to the otherwise needed large size touch screens and the hardware costs are relatively low ($\approx 1000Euro$). A disadvantage of the chosen system and in particular of the Kinect sensor is a potential loss of so-called multi-touch points due to the working principle of the sensor (stereoscopic computer vision which is limited by occlusions). A solution is to combine 2 well-positioned Kinect sensors. The Kinect sensor in combination with the NecTouch library [17] is able to detect so-called multi-touch points. The hardware set up is show in Fig. 3.



Fig. 3. The Xbox Kinect together with the NecTouch software is used to turn a normal screen into a (significantly larger) multi-touch screen

C. Extending game content

Based on earlier research that identified what daily skills stroke survivors find most important to learn again a number of single - and multi-player game concepts were generated. The following games have been implemented on the Playful Rehabilitation platform:

- A game requiring patients to reach out for a target.
- A labyrinth game for learning writing again.
- A knife and fork game, where the stroke survivor can relearn how to cut with a knife.
- A game, where the patient has to fill a virtual glass without spilling water, while holding a real glass and wearing the sensor glove.
- A multiplayer game based on the game called Game of the Goose(including mini-games) suitable for playing with their (grand-)children.

One problem with multiplayer games is that the stroke-patient has an impaired arm therefore, to keep these games motivating for the patients, they have to be balanced.

V. CONCLUSIONS AND RECOMMENDATIONS

This research has explored how gaming can support task-oriented training using a combination of a sensor vest and glove and an interactive tabletop. After an initial exploration that served as a proof of concept, we have extended the playful rehabilitation approach to address ergonomic and reliability requirements relating to the sensor vest, and extended the game content to support training of a larger collection of tasks. An example of a developed single-player game is shown in Fig. 4. Our current development efforts

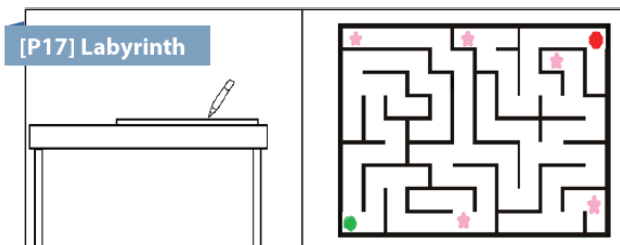


Fig. 4. An example of a single-player game: the labyrinth game

aim at:

- 1) extending our library of games in order to offer substantial exercise variability and in order to offer different difficulty levels so that patients can be challenged at the cutting edge of their abilities,
- 2) offering patient-tailored feedback: it should be the choice of the patient whether sensory feedback on compensation (e.g. vibration of module on location of compensation) or auditory feedback (e.g. instruction: mind your trunk) is given,
- 3) supporting multi-player games especially to support social gaming with fully abled friends and family,
- 4) feedback frequency will be made adaptive; ideally fading frequency schedules should be followed, whereby the feedback frequency is reduced according to the proficiency level of the user [12].

These development efforts will be followed by a clinical validation of the set of games and a field trial to obtain qualitative feedback regarding the motivation of stroke survivors to play this game at their own accord while at home.

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