Ergotact: Including Force-based Activities into Post-stroke Rehabilitation

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ABSTRACT

Ergotact introduces the possibility of including force-based rehabilitation activities of the upper limb of post-stroke survivors. These activities are integrated into a dedicated game which is deployed on a tabletop. The patient interacts in the game with a tangible object which has to be moved, rotated, tightened/untightened and lifted according to the gameplay. The surface of the object is equipped

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Figure 1: Ergotact is composed of a serious game on a table top. The therapist holds a tangible object covered with force sensors distributed around the surface. This tangible object is used to interact with the game deployed on the tabletop.

Figure 2: Left : One of the prototype featuring 63 mm (Bottom part) and 28 mm (top part) handle diameters, Right : Object prototype revealing one unit of force sensors. Weight : 250 g

with a matrix of force sensors which allows to introduce force-based activities into the game; for the purpose of the game, the object also includes an accelerometer and a gyroscope. The paper presents the concept and first feedbacks from therapists.

CCS CONCEPTS

• **Applied computing** → **Life and medical sciences**; • **Hardware** → **Tactile and hand-based interfaces**; *Emerging interfaces.*

KEYWORDS

Rehabilitation; tabletop; tangible; evaluation

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INTRODUCTION

Stroke is the leading cause of disability of adults in developed countries. A third of all stroke survivors experience various levels of disabilities which generally impact seriously their daily life. Most of stroke survivors are affected with hemiplegia with a deterioration of the motricity of the upper limb and hand. Regular upper-limb rehabilitation uses complex motions involving repetitive movements of the arms and hands [6]. The need for regular and repetitive rehabilitation sessions may affect the motivation of patients in the long run [8]. Many solutions have been developed and tested during the last decade to find a viable alternative to traditional exercises and activities used in rehabilitation services. The majority of the innovative solutions are based on games, serious games or exergames as the literature agrees that games can contribute to enhance the engagement of patients [4]. Digital environments in games can monitor patient's performance and provide variability into the proposed activities as well as feedbacks tuned to the patients. But these applications and other research developments [1, 3] barely consider the ecological gripping of real objects and the forces applied to them. Finally, there is little data in the literature regarding the grip strategies used by stroke persons and the force developed by the hand on the objects [9].

The paper presents Ergotact, a prototype that includes game-based rehabilitation activities that take into account the efforts exerted by the hands of post-stroke patients and the results of a preliminary evaluation by therapists.

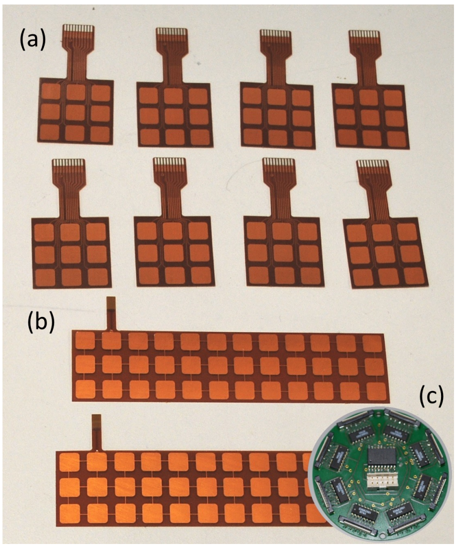

Figure 3: Sensor skin for the bottom part of the object corresponding to one unit of measure with a total of 72 capacitive sensors. (a) : flex-PCB capacitor plates for signal excitation (72 inputs); (b) : flex-PCB capacitor plates for signal reception (2 outputs). When assembled, plates (a) are positioned on top of plates (b) separated by a layer of polyethylene foam. (c) : electronic for capacitance measurement.

DESIGN OF ERGOTACT

The starting point of the project was the possibility of using the prototype of distributed force sensors on a flexible substrate on an upper limb rehabilitation device that would measure the forces applied by the hand [10]. The objectives of the project were to be able to combine both a paretic upper limb assessment device by taking into account the natural gripping strategies and the forces exerted on objects with a game-based rehabilitation device. The specification was based on an analysis of the patients' and therapists' needs gathered during interviews and the design process was organised through iterative working sessions with therapists.

The game is displayed on a tabletop that provides the game's digital environment and can support the tangible object manipulated during the game. Tabletops have shown their potential in rehabilitation [7]. Tabletops have a particularly rich rehabilitative potential by combining the manipulation of tangible real objects, their representation and interaction in the digital world of the interactive table.

Before starting the game itself, an evaluation phase of calibration quantifies the patient's motor skills and allows to adapt the game to the patient's working space on (and above) the tabletop surface and to their maximum effort capacities. This evaluation will allow to quantify the patient's motor skills and thus monitor his or her improvements in terms of range of motion, grip, speed, reaction time and acceleration of the required movements.

The game starts with a "training" phase that consists of moving, jumping over obstacles (separated by holes or water currents etc...), and carrying out various attacks (see Figure 1). In order to progress into the game, the player performs actions in the game such as walking (slide the tangible object on the table), jumping (lift the object over the table), punching (squeezing/unsqueezing the object) or hitting it with a stick (rotate the object). Each phase is validated by a virtual battle. If the patient succeeds, he/she moves to the next level, or must start again. After each 30 min game session, a summary screen indicates the score as well as statistics of successful actions.

The Ergotact prototype uses a 3D printed custom-made object covered with distributed force sensors (see Figure 2). The prototype includes an Arduino micro card interfacing a Bluetooth connection, an accelerometer (LSM9DS1 ST Microelectronics) and a linear resonant actuator. The force measurement system is based on a distributed network of capacitive sensors integrated on two layers of flex-PCB (Kapton). Each layer supports the plates needed on each side of the capacitor. The plates are separated by a dielectric polymer for on overall thickness of 0.8 mm. The force is given by the change in capacitance coming from the deformation of this polymer with a range of 0.5 N to 20N, normal force. Capacitance measurements are done by units of 72 sensors (see Figure 3) composed of two Smartec UTI chips each connected to 4 Smartec MucC01 multiplexer. Three units equip each object for an overall of 216 measurement points. Data is acquired by a second Arduino micro connected with the previous one with SPI serial connection. The overall system is powered by a standard 9V battery providing 4 to 5 hours of autonomy. Two cylindrical prototypes were designed providing three handling size of 28 mm, 50 mm and 63 mm. Finally the detection and localisation of the object on the table is done with three copper conductive plates place at the bottom of the object and directly connected to the ground circuit of the sensors [2].

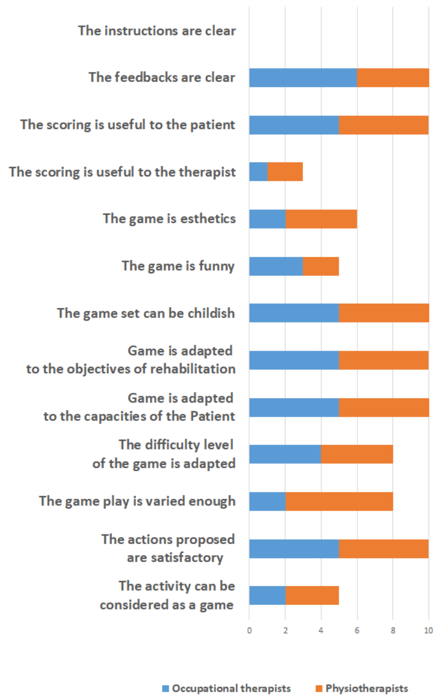

Figure 4: Answers to the semi-structured interviews (Item "The instructions are clear" receives no answer).

EVALUATION METHODOLOGY

The preliminary evaluation was conducted before the clinical evaluation through the assessment of the usability and design of Ergotact. Ten therapists, 5 physiotherapists (PT) and 5 occupational therapists (OT), participated in the evaluation of the prototype. They had a mean 11.8 years (SD 10.32) of experience in rehabilitation. The participants were first informed about the purpose of the study and had to sign an informed consent to participate. As the clinical protocol was not signed at that point, no patient could participate. To make the evaluation more realistic to the therapists, they were introduced with the persona of a patient (a 55 years old hemiparethic woman). Then they had to create the patient's profile with Ergotact, calibrate the patient's capabilities in terms of workspace on the table and maximum grasping force, choose the game level (low/middle/high/automatic law). Then were asked to use Ergotact as if they were the persona. Each session lasted 45 minutes, 30 minutes were dedicated to the use of Ergotact and 15 mn were allocated to a semi-open interview relative to the game set and the tangible objects, about the creation of the patient profile, the game configuration, the game's difficulty management, the report delivered at the end of the session. Then they filled up the AttrakDiff User Experience questionnaire [5].

The AttrakDiff questionnaire provides an overall assessment of the different characteristics of the user experience (pragmatic quality and hedonic quality), as well as the overall perceived attractiveness of the system. The questionnaire is based on 28 items based on opposite adjectives, each of them including seven steps. Attractiveness covers the following concepts : pleasant/displeasing, motivating/discouraging, Good/bad, repulsive/attractive, ugly/beautiful, discouraging/attractive, pleasant/pleasant. The pragmatic quality is defined as the ability to meet the objectives for which the prototype is developed; it is assessed through the following pair words: Practical/Not-Practical; Uncontrollable/Masterable; Predictable/Unpredictable; Tedious/Effective; Simple/Complicated; Human/Technical; Confused/Clear. The AttrackDiff scores are between -3 (worse score, indicating that it is imperative to redesign), to +3 (maximum score requiring no further improvement), via 0 (standard score but perfectible). Values between 0 and 1 indicate that the tool meets its objectives without major negative aspects.

RESULTS

The answers to the semi-structured interviews (see Figure 4) indicate that Ergotact is adapted to the capacities of post-stroke patients, even if 7 therapists (out of 10) stress the fact that they must be

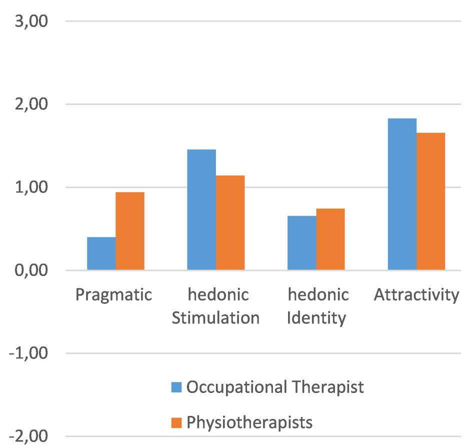

Figure 5: Results at the AttrakDiff by therapists. The maximum is 3 (best score), minimum (-3 worst score)

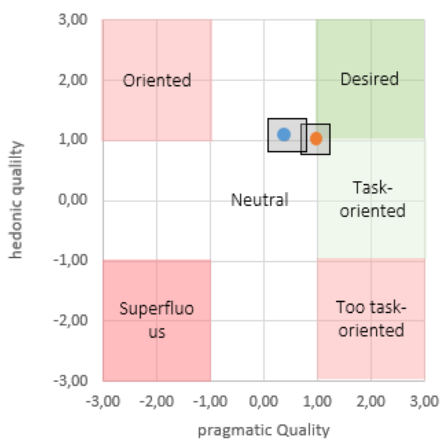

Figure 6: Portfolio of the evaluation (blue: Occupational therapists; orange: physiotherapists)

careful regarding the occurrence of compensations during rehabilitation sessions. The calibration of the patient allows Ergotact to be adapted to the patient's abilities. The predefined parameters (easy, medium and difficult) are considered correct. All therapist are satisfied with the proposed actions in the game (such as sliding, tightening, tightening and sliding, tightening and loosening, lifting and moving, lifting the highest, clockwise and counterclockwise rotation) and 8 therapists (5 OT and 3 PT) find the feedbacks understandable. The performance record is judged positively. All therapists positively consider the proposed data and presentation format to be relevant to the patient but should report performance progress over several sessions. 9 therapists (4 OT and 5 PT) indicate that the assessment will allow to monitor the patients' progress. 9 therapists (5 OT and 4 PT) think that the assessment allows to tune the rehabilitation and finally, all therapists believe that the assessment contributes to motivate the patients.

The evaluation of the tangible objects is overall positive. 6 therapists (2 OT and 4 PT) find that the size and the weight of the tangible objects is adapted to the patients; 9 therapists (4 OT and 5 PT) indicate that the objects are adapted to the patients' rehabilitation objectives. The major issue is that the instructions need to be revised: they are too long (for 7 therapists out of 10), are too difficult to understand (5 therapists out of 10) and require too much concentration to be understood; the instructions are also too wordy so that it can be difficult for the patient to make the distinction between the scenario and the instructions. The synthetic voice is also difficult to understand.

The results to the AttrakDiff confirm these results (see Figure 5). The quality of the user experience is generally satisfactory, with average AttrackDiff scores above 0, indicating that the tool fulfils its functions. However, the average scores on the pragmatic and hedonic identity quality dimensions are lower than 1 (respectively 0.40 for OT and 0.94 for PT; 0.66 for OT and 0.74 for PT), indicating that these aspects could be improved.

The portfolio (see Figure 6) provided by the AttrakDiff is particularly interesting in the context of rehabilitation, which must strike a balance between clinical effectiveness, i.e. the ability of the device to meet the rehabilitation objectives (the pragmatic dimension) and the hedonic qualities. The results show a fairly good balance between these two dimensions. Although the results can be improved, the overall assessment and the global attractiveness of Ergotact is quite positive. While pragmatic quality qualifies the utility and perceived usability of the device, the analysis of the pair of opposite adjectives reveals that the improvements to be made are more about usability, particularly in order to improve the understanding of the instructions (low scores on the predictable/unpredictable and confusing/clear structured items". The negative aspects on the hedonic quality of identity relate to the visual attractiveness ("ugly/ attractive") and the differentiator "separates me/brings me closer". This last item is indeed ambivalent; it is very likely that the answers were oriented towards "separates me" because the game is played alone and not in terms of social use as a community of practice. Caution should therefore be exercised in interpreting the response to this item.

CONCLUSION AND FUTURE WORK

The preliminary evaluation of Ergotact carried out with a sample of therapists shows the potential of Ergotact by proposing various activities allowing the use of tangible instrumented objects in a digital environment. Since this evaluation, the game instructions have been simplified and shortened. The design of the game was made more attractive and therapists can have access to performance progress in a synthetic form. The effects of rehabilitation with the new version of Ergotact is beeing studied in a randomized controlled trial involving 28 stroke patients. The clinical evaluation will be complemented by an ergonomic assessment. The use of instrumented tangible objects in connection with a digital application seems particularly relevant in rehabilitation, even if its clinical contribution has yet to be demonstrated. Ergotact presents also original opportunities for innovation in other fields such as education and vocational training.

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