34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Development of computer games for assessment and training in post-stroke arm telerehabilitation

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Abstract—**Stroke is the leading cause of long term disability among adults in industrialized nations. The majority of these disabilities include deficiencies in arm function, which can make independent living very difficult. Research shows that better results in rehabilitation are obtained when patients receive more intensive therapy. However this intensive therapy is currently too expensive to be provided by the public health system, and at home few patients perform the repetitive exercises recommended by their therapists. Computer games can provide an affordable, enjoyable, and effective way to intensify treatment, while keeping the patient as well as their therapists informed about their progress. This paper presents the study, design, implementation and user-testing of a set of computer games for at-home assessment and training of upper-limb motor impairment after stroke.**

I. Introduction

According to the American Heart Association, each year in the United States alone, 795,000 persons experience a new or recurrent stroke and this adds to a combined total estimate of 7 million persons currently living with the long-term effects of a prior stroke [1]. Improved medical treatment has contributed to decreased mortality, but 90% of the survivors have significant neurological deficits [2]. Impairments in the upper limb tend to persist long-term with only 14-16% of stroke survivors with upper extremity hemiparesis regaining complete or nearly complete motor function [3].

Published research confirms that better results in terms of rehabilitation outcome are obtained in specialized care centers where patients receive more therapy per day for extended periods of time [4]. However, interviews with clinicians and therapists have confirmed that therapy on the lower extremity is the primary concern in early inpatient stroke therapy in order to enable mobility of the patient. Recovery of the upper extremity has a slower progression and is usually gained through outpatient and home therapy. Yet, few patients regularly perform the typically boring and repetitive exercises recommended by their therapists [5]; moreover, neither the quality nor quantity of training performed can be objectively tracked.

Computer games can provide an enjoyable and effective way to motivate patients to increase both the quality and quantity of therapy at home by decreasing the monotony of performing hundreds of repeated motions and by providing challenging performance feedback. In addition, games can also be used to remotely assess the motor impairment of patients without the need for the therapist to be present. Therefore, together with cheaper robotic solutions for training at home, computer games represent an affordable way to both facilitate the patient access to rehabilitation and reduce the strain on the healthcare system.

This paper presents the design and implementation of 4 games for assessment and 4 games for training of post-stroke arm motor impairment to be used with the ArmAssist device together with the TeleReha web platform for at-home telerehabilitation. Armassist assists the horizontal movement of the arm by supporting its weight while measuring the movement parameters (2D position, orientation and arm support/lifting force) that are used to control the games. The TeleReha platform allows the patient to perform game-based rehabilitation at home, while the doctor is able to monitor the progress, update the therapy correspondingly, and communicate with the patient when necessary. Further information about both systems can be found in [6-8].

II. METHOD

The study began with a comprehensive review of the key elements that promote the rehabilitation process and the role of gaming in robot-aided rehabilitation therapy [9] in order to define a first set of basic requirements.

Integrating this preliminary information with a series of interviews with clinicians involved in stroke rehabilitation, we produced a set of storyboards with game proposals. For the selection of games it was considered that, given the provided input data from the ArmAssist (x, y position and vertical force), the device could be used to play most genres of standard PC games. Then, a thorough search and selection of existing games that might train the different rehabilitation tasks defined in the previous study was done. When no game could fit the assessment or training of a concrete task a custom designed game was proposed. A clear distinction was made between games for assessment and games for training, where the first should be short (1-2 minute) tasks that involve a targeted movement with defined parameters for the evaluation of the arm motor impairment, and the second, exercises that engage the subject in longer training sessions for intensive rehabilitation.

The storyboards were then presented to a focus group of experts that evaluated the games. The group was formed by 9 clinicians working with stroke (4 medical doctors, 2 occupational therapists, 2 physiotherapists and 1 nurse). They were asked to give a numerical evaluation of the level of entertainment, benefit and adequacy on a Likert-type scale

[1] This work has been funded in part by FIK and the Spanish Ministry of Science (Project PID-020100-2009-21).

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of consideration (1 to 3, where 1 is the least and 3 the most desirable outcome) for each game presented. Written comments on the games and other general aspects were gathered, and a list of requirements and games to be developed was drawn out.

An iterative approach was used for the games' design and implementation, meaning that the games were tested by patients and therapists all along the implementation process. First, a set of 4 assessment games was developed and tested with therapists in different focus groups until the final design was defined. Then, an additional set of 4 training games was developed. In subsequent iterations different usability testing was performed (2 focus groups with a total of 11 experts, and 5 sessions of direct participant observation involving 9 stroke patients in total, always assisted by a therapist), and the existing games were consequently adapted to solve the identified problems.

Together with the ArmAssist hardware and TeleReha web platform, the games are currently involved in ongoing long-term studies of clinical and domestic usability at Hospital La Fe in Valencia and the Guttmann Institute in Barcelona. The qualitative assessment of the experience of both patients and therapists is based on the use of structured interviews and focused questionnaires administered periodically along the training program. The aim is to collect all the relevant information related not only with usability and accessibility aspects of the system but also the level of involvement and motivation driven by the games. The results of this study will be presented in future publications.

III. Game requirements

A. Requirements definition

Careful attention must be given to the way in which the user interface is designed to incorporate motivation for active user involvement. It is extremely important to keep the level of challenge optimal in order to stimulate intrinsic motivation to train in the patients. This means that the task should be challenging, but not too difficult to achieve, always adapted to the patient's capabilities. The task should have a clear goal and uncertain outcome, with feedback that rewards effort and success. The task should be presented in a playful manner and should elicit a game-like experience, but it should also be designed to fulfill the rehabilitation purposes, reflecting activities of daily living (ADL) of the user and providing the opportunity to train cognitive skills and promote social interaction.

In addition, the tasks and the parameters recorded should be determined based on current theories of best practice in neurorehabilitation. The games must be meant to assess and train the patient's ability to perform reaching out and lifting up movements, essential for the recovery of functional abilities of the upper-limb. Range of motion (ROM), range of force (ROF), speed, precision and accuracy, endurance, control and task execution time were defined as the main features to be trained and evaluated while performing these tasks. The therapeutic outcome should be the improved ability of the patient to perform functional movements assessed by standard assessment like the FIM scale (Functional Independence Measure).

B. Storyboards and discussion group results

For assessment, the games proposed were: 1) follow a spiral *Trajectory*, 2) measure the *Range of vertical force*, 3) *Discover the picture* erasing sectors of a semicircle, 4) move a bucket to catch the drops on a *Rainy day*, 5) *Drag and Drop* each ball into its box, 6) remove blocks at the correct timing to *Collide* balls, 7) set the correct initial direction and launch the ball to play *Petanque*, and 8) move the cursor to collect as many moving black *Squares* as possible while avoiding the red ones.

For training, *Puzzles*, cards games like *Solitaire*, completing *Words,* and *Calligraphy* games were proposed, as well as the classic *Ping Pong* and *Helicopter* games, two controlled trajectory games (*Adventurous Erik* and *At the Farm*), and a force control game called *Drag the Ball*.

All the professionals considered the games very interesting for stroke rehabilitation, being very motivating, entertaining, and appropriate for adult patients. The most valued features were: 1) tasks that were simple and easy to understand, 2) interface designs that were challenging, entertaining, and attractive, and 3) the integration of cognitive stimulation and ADL-related tasks. Therapists considered the vertical force component, used to select/unselect objects in some games, too difficult for early post-acute patients as it may lead to undesired synergistic movements. They suggested instead incorporating the feature only in later stages of training and using a simpler strategy in the early phase. As a result, the clinicians recommended implementing different levels so that the games are adapted to different user profiles, and promoting primarily extension tasks to train abnormal synergies while avoiding movements that typically elicit increased spasticity. They considered 2D appearance as a better way to start, incorporating 3D components as the patient practices and gains abilities.

Based on the discussion group results, the following games were selected for assessment purposes: *Discover the picture* for the assessment of range of motion, *Range of vertical force*, *Trajectory* for the evaluation of control of movement along a trajectory, and *Drag and Drop* for the speed and precision evaluation in point to point movements. Although *Rainy day* had received a better score than *Range of vertical force,* it was considered redundant with *Drag and Drop.* According to several clinicians, *Range of vertical force*, on the other hand, provides another interesting metric to assess: the patients arm support/lifting capacity.

For use as training games, the following received the highest marks: *Puzzle* and *Solitaire*, *Calligraphy/Words*, and *Adventurous Erik*. However, for technical reasons a *Memory* game was implemented instead of the last game type.

IV. Games' final design

A. Functional description

The *Discover the Picture* assessment game evaluates the range of movement in different directions of the transverse

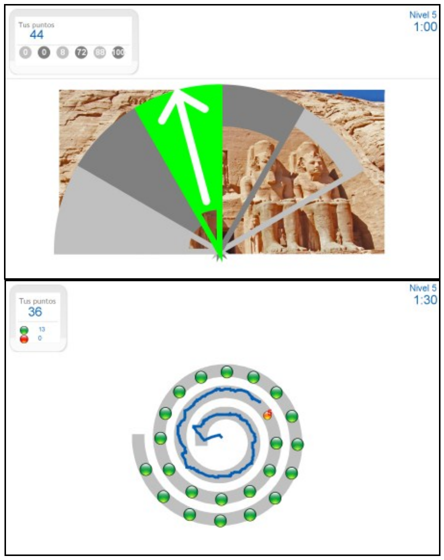

Figure 1. Two assessment games: Discover the Picture and Trajectory.

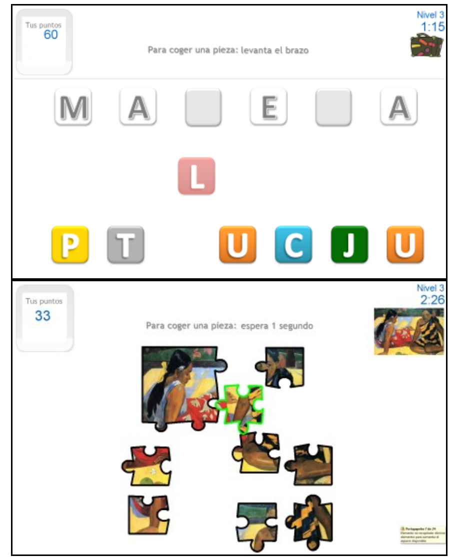

Figure 2. Two training games: Words and Puzzle.

plane. In the game, a picture is discovered by erasing the sectors with an extension movement indicated by the arrows (Fig. 1 - top). Game levels are defined by the number and radius of sectors. The *Range of vertical force* game assesses the arm support/lifting capacity in different points of the plane by placing the cursor over a ball and lifting the arm to increase the size of the ball to the diameter of a peripheral ring. The different levels are configured by the number of balls in the plane and the percentage of arm weight to be lifted to get the maximum score at each ball. The *Trajectory* game (Fig. 1 - bottom) monitors the ability to perform a controlled movement along a trajectory specified by a path of balls. The number of balls, the trajectory difficulty (octagon, star, or spiral) and the path width define the levels. Lastly, *Drag and Drop* evaluates the ability to perform a point to point movement with minimal concern for the specific trajectory, but focusing rather on speed and precision. In this case, different objects must be picked up, dragged, and dropped in the right box. The levels are configured by the number of elements and the accuracy needed to pick and place them. Strict total times and partial inactivity countdowns in all the assessment games ensure that assessments are carried out efficiently.

In the *Words* training game the user has to complete the word selecting from the spare letters at the bottom (Fig. 2 - top). Levels are configured by the number of holes per word, the word length, the difficulty of the task of having to fill in vowels or consonants, and the accuracy needed to pick and place letters. For the *Memory* game the user has to discover pairs of equal cards, remembering the ones previously discovered by the user or the opponent (the PC). The number of pairs and the intelligence of the PC define the levels. The users can also train putting together a *Puzzle* (Fig. 2 - bottom), whose number and size of pieces increases with the levels. As a fourth training game, the user can play the typical *Solitaire* game with different numbers of cards dealt and times to complete the task.

Each game requires a set of initialization variables defining information about the user's ROM and ROF. These are always determined by their respective assessment games; *Discover the picture* for ROM and *Range of vertical force* for ROF. The vertical force requirement, according to the feedback, will only be used in other games when the ROF level is higher than 3. In that case, the selection and unselection of objects will be achieved by lifting or resting the arm whereas in the simplified strategy users are asked to hold the position over an object for one second to achieve the select/unselect task. In addition, each game presents five difficulty levels that are automatically increased as the performance of the user improves. The score for the user (0-100 %) reflects the performance of the patient for that level.

Average performance based on a balance among the evaluated features, time on tasks, partial performance values (for each sector, ball or type of element) and ArmAssist raw data during the game are saved for each game execution. During post-processing of this data, other important features such as speed and smoothness can be extracted.

B. *User interface design*

During the design and implementation process careful attention has been paid to ergonomics and user interface design standards, with the following aspects considered fundamental:

- Suitability for the rehabilitation task
- Ease of use
- Enjoyable, motivating, and challenging design
- Suitability for the target population, which may have cognitive disabilities, vision problems, etc.
- Consistency in the design of all the games
- Clarity of functionality and instructions
- Feedback information about the user's input being timely, perceptible, and non-intrusive
- Status information indicating the continuing state of the application and the input device

- Robustness: error prevention and tolerance
- Suitability for individualization (ROM, ROF, levels)

C. *Technical SW description*

Each game has been developed as a standalone desktop application for the Java Platform (Java 6/7 using the IDE Netbeans 6/7) and the whole core functionality of the games has been developed using the Java 2D API. Java Web Start (JavaWS) allows users to start these desktop applications directly from the Internet using a web browser. Key benefits of this technology are seamless version updating for globally distributed applications and the ability to automatically download and install the Java Runtime Environment (JRE) in the case where the user does not have Java installed. JavaWS implements the Java Network Launching Protocol (JNLP), which consists of a set of rules defining exactly how to implement the launching mechanism. Each game is kept as an independent jar file at the server. Whenever the user clicks on the weblink to play a game, the webserver replies with a JNLP file. The JNLP client (Java Web Start) parses this file, requests the resources specified (jar files), waits for the retrieval of all required resources, and then launches the application that runs locally.

During the execution, as in any game loop, the data of the ArmAssist (position, vertical force, and angles) is periodically sampled (10 Hz), the corresponding updates are made (cursor position, collisions, and related variables update), and the panel is repainted to show the new state of the game produced by the state change of the device. The game ends when a time out occurs or when the task is completed. Then, the data is saved into an XML file that is sent to the server through HTTP as soon as there is an internet connection (in order to support both online and offline versions of the platform).

V. TESTING RESULTS

The outcomes of the testing performed up to now have been positive and met with high levels of interest in all cases. Therapists have found the system to help motivate patients to train more intensively than normally; and patients generally comment on the higher level of entertainment experienced during training as compared to their standard exercises and the feeling of improvement. While these are very good initial results, various feedback aspects still remain to be tackled in next versions of the system, such as:

- Different levels of configurability of the games need to be provided: public hospitals ask for more automatic systems as they have less time per patient; however, private clinics demand complete control.
- Changes in the visualization of games (together with the table and mat design) need to be done in order to allow the training in any part of the table and emphasize the training of the paretic side.
- As they are implemented the *Trajectory* and *Drag and Drop* games seem to have some overlap in the assessment of the patient. A thorough study of which parameters should be targeted in each assessment game needs to be done in order to avoid redundancy and cover every important metric.
- New training games closer to commercial computer games (MarioCart, car races, etc) must be developed. Also, multiplayer/collaborative games should be considered in order to increase motivation and promote socialization.
- Other common requests that require previous HW changes in ArmAssist: grasping exercises, active opposition to transverse movement, etc.

VI. CONCLUSION

A first set of assessment and training games has been developed for at-home post-stroke arm rehabilitation. These have been developed following a close collaboration with clinicians and therapists to ensure a good match between technology development and clinical need. Initial feedback from testing indicates the games may be beneficial in both extending training duration and increasing the intensity of practice during rehabilitation of post-stroke arm deficits.

ACKNOWLEDGMENT

The authors would like to thank A. Belloso, M. Sancho, J.M. Belda, E. Opisso and A. Crespo for their contributions to the design of the games.

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