Serious Games for Assessment and Training in Post-stroke Robotic Upper-limb Telerehabilitation

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Abstract: Research shows that better results in post-stroke rehabilitation are obtained when patients receive more intensive therapy. However, the increasing affected population and the limited healthcare resources prevent the provision of intense rehabilitation care. Thus, there is a need for a more autonomous and scalable care provision methods that can be transferred out of the clinic and into home environments. Serious games in combination with robotic rehabilitation can provide an affordable, engaging, and effective way to intensify treatment, both at the clinic and at home. Furthermore, they can offer quantitative assessment of motor performance, allowing individualized treatments and to keep the patient and their therapists informed about therapy progress. Towards this end, a set of games for assessment and training of upper-limb motor impairment after stroke with the ArmAssist is presented. A special effort has been made to design the assessment games in order to be able, not only to measure the effectiveness of the training, but also to compare the assessment results with the standard assessment scales used in the clinic. Feedback from usability testing of previous versions of the system has also been crucial for the final design. Preliminary results of an ongoing clinical testing are presented.

1 INTRODUCTION

Research confirms that better results in terms of rehabilitation outcome are obtained in specialized care centres where patients receive more therapy per day and with more quality for extended periods of time (Sluijs et al., 1993; Kwakkel, et al., 1997).

However, the amount of professionally-supported rehabilitation training provided to the average patient is still far from the ideal. A Dutch report published in 2008 (Peerenboom et al., 2008) reported that the average treatment time for stroke patients in skilled nursing facilities was about 4.5 hours per week, and only about 2 of them was spent in physical therapy.

Healthcare resources are suffering from constant cutbacks due to economic constraints and the prevalence of stroke continues to increase dramatically together with the aging of the population. As a matter of fact, European statistics as a whole report that nearly 1 million people experience a first or recurrent stroke each year (Hesse et al., 2005). In that context, the amount of intensive therapy required cannot be provided in the regular way that rehabilitation care has been provided up to now. There is a need for more autonomous and scalable care that can be transferred out of the clinic. Robot-assisted rehabilitation based on serious games may offer that care.

Robots offer precision and repeatability of movements that can be used to provide safe and intensive rehabilitation exercises. Serious games can provide an enjoyable and effective way to motivate patients to increase both the quality and quantity of therapy by decreasing the monotony of performing hundreds of repeated motions and by providing

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challenging performance feedback. In addition, these technologies can also be used to remotely assess the motor impairment of patients without the need for the therapist to be present. Therefore, a large increase in robotic rehabilitation based on serious games has been seen over the last years (Robertson et al., 2010). Recent commercial players in the field include Telefonica, MediTouch, HomeTelemed, Tyromotion and Hocoma.

However, even with the players involved, commercial success is limited. The solution may lie in the development of a system that can be easily integrated with current practice and which can verify its effectiveness correlating the results of both assessment and training tools with the assessment scales and physical therapy performed at the clinic.

Towards this end, this paper presents a new version of 5 games for assessment and 5 games for training of post-stroke arm used with the ArmAssist together with the TeleReha web platform for at-home telerehabilitation. ArmAssist allows the planar movement of the arm by supporting the arm 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 both at the clinic and at home, while the doctor is able to monitor the progress, update the therapy correspondingly, and communicate with the patient when necessary. The system components and functionality have been previously described in publications (Zabaleta et al., 2011; Perry et al., 2012; Arcas Ruiz-Ruano et al., 2012).

2 GAMES

2.1 Design Process

A first set of requirements for the games was defined after a comprehensive review of the key elements that promote the rehabilitation process and the role of gaming in robot-aided rehabilitation therapy was done (Perry et al., 2011). A more detailed list of requirements and games to be developed was drawn out integrating this preliminary information with a series of interviews and focus groups with clinicians.

Then, 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.

Throughout the game design and implementation process, game design principles and ergonomic and user interface design standards were closely observed. Design criteria considered included aspects such as clarity of instructions and feedback, optimization of the level of challenge in order to keep patient motivation, consistency between games, suitability toward visual or cognitive impairments, and robustness, i.e., tolerance to user error. A detailed description of the methods used for the design was already presented in (Rodriguez-de-Pablo et al., 2012).

A first version of the games was implemented and tested in a 12-week clinical pilot test with 9 patients. This usability testing and its results were further described in (Perry et al., 2013). Then, a second version of the games was developed in order to first, include the usability feedback obtained in previous testing and second, improve the assessment methodology in order to be able to properly evaluate the effectiveness of the system and compare the results of that assessment with the standard scales used at the clinic. Finally, a shorter usability testing of the new version of the software was carried out in the Rehabilitation Service at 'Hospital Universitario de Álava- Sede Txagorritxu' (Spain). The feedback extracted from that testing was used for the design of the final version of the software, which is currently being used in an ongoing clinical study.

2.2 Requirements

In this section, the requirements for the redesign of the games are presented. A detailed list of the initial requirements of the games was already presented in (Rodriguez-de-Pablo et al., 2012).

The main goal of the redesign was to improve the games in order to be able to properly evaluate the effectiveness of the system and compare the assessment results with the standard scales used at the clinic. For that, first of all, levels in the assessment games needed to be removed in order to facilitate intra- and inter-patient comparison. They had to be kept, however, for the training games in order to adapt the challenge, motivate the patient and avoid frustration. Also, it was necessary to make some of the games simpler and faster; for example different versions of the *Control of Force* assessment game were developed and later determined to be too time consuming and cognitively taxing for a rapid assessment. Others needed a redesign in order to avoid undesired movements; therefore, the new version of the *Control of Movement* game asks only for reach movements, and the new *Range of Movement* game measures only when the user stops in order to avoid counting ballistic movements. It was observed to be of major importance the fact that the score was perfectly aligned with the metric evaluated, as that is what the patients focused on when trying to improve. In that way, the reaching movement requirements have been removed from the new *Control of Force* in order to focus on the control of the lifting force and its smoothness evaluation. And last, some improvements needed to be done in the data collection to address some issues detected in the post-processing work of data from the previous games.

In addition, most of the feedback obtained in the usability testing was taken into account for the redesign. Some examples of the changes included are:

- The improvement of the selection/de-selection strategies, with an optimization of the timing in the waiting strategy and a refinement of the feedback in the lifting force strategy;
- The improvement of feedback, e.g., in the *Point to Point* game when a piece is inserted; this was not always properly understood by patients and they kept trying to insert it;
- The clarification of some instructions, e.g., providing the hint in the *Words* game or allocating a concrete space where the *Jigsaw Puzzle* has to be assembled;
- The improvement of the visualization, e.g., making the back image of the cards in the *Memory* game unmistakable with the content itself;
- The empirical adjustment of the time-outs and level parameters.

2.3 Games' Description

2.3.1 General Features

There exist two kinds of games. The assessment games are short tasks (1-2 min.) designed to provide the therapist with an objective evaluation of the different parameters that define the arm movement and to adjust correspondingly the training games. The training games are longer, more complex and entertaining tasks, which can also integrate cognitive components and whose objective is to motivate the patient to train harder and longer. In both of them, reach extension movements are encouraged, which require simultaneous abduction/ adduction of the shoulder and extension of the elbow.

In all the games (Fig. 1) the level is composed by two aspects: the Movement level (ROM) and the Force Level (ROF). The ROM, the range of movement that each game requires, is determined by the performance of the patient in the first assessment game, *Range of Movement*. For accessibility reasons, the visualization of the games is always the same, that is, the objects keep their sizes and their positions; however, the area of the mat where the ArmAssist has to be moved varies according to the range of motion of the patient. This avoids some visualization problems when the range is too small and has proven to be well understood by patients. The ROF is the range of vertical force required by each game, i.e. the percentage of the arm weight that the patient must lift. This is determined by the performance of the patient at the second assessment game, *Range of Force*.

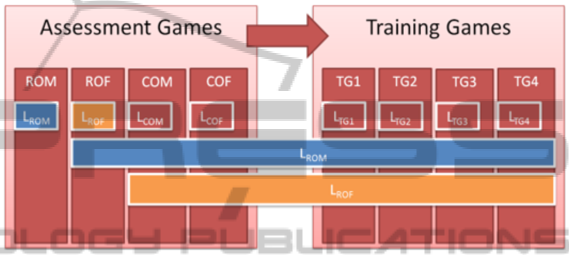


Figure 1: Influence of the result obtained at ROM and ROF in the other games.

Furthermore, in the training games a task level component is included. This is avoided in the assessment games in order to facilitate the intra- and inter-patient comparison of the evaluation results. Each game presents five levels and is scored based on a combination of evaluated features. The game levels are automatically adapted by the platform based on performance. The adaptation method adopted is the following: a game score of 100 percent or two consecutive scores of at least 80 percent prompt a level increase. Still, if considered inadequate, the level can be modified by the therapist from within the platform at any time.

Each time that a game starts, the user will be asked to move the device slowly over the mat in order to calibrate the device position. This will not take more than two seconds. Also, before playing any game, the user is asked to calibrate the weight of his arm in a relaxed state in order to calibrate the vertical force component of the device. This second calibration needs to be done only once; however, it can be repeated when desired for changes in the position of the table or chair that may affect the weight of the arm.

There are two strategies for selection/ de-selection of objects in the training games. ArmAssist's natural strategy is the use of the vertical force, that is, lift the arm to pick up a piece, move and relax the arm to leave it. However, for some patients this strategy has proven to be more difficult to understand or to control in the early stages of rehabilitation. Therefore, another strategy is provided which does not require the use of the vertical force, requiring instead a brief pause over the piece to select it. The piece will be deselected when the patient pauses after having moved it. Moreover, in order to avoid unwanted selections, to reactivate the selection of a part, the user must bring the cursor out of the piece and place it back over briefly again. Proper timing is key for this strategy to work properly. When the therapist deems appropriate, he will enable the use of force in the patient's profile. In both cases, the strategy that should be used to pick or drop an object is indicated by a message and icon at the top of the screen (Fig. 2). In order to facilitate the comprehension of the vertical force selection strategy, the feedback force is also displayed, indicated in green when the required threshold lifting force is being performed, and in red when not.

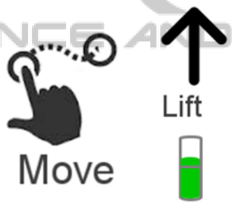


Figure 2: Indications for the two selection strategies.

Strict overall times and intermediate countdowns in the case of inactivity are employed in all the assessment games to ensure that assessments are carried out efficiently. The intermediate countdowns ensure, for example, that the cursor is placed at the required area or that the achieved value is improved in a determined amount of time. In the training games, the total time can be assigned by the therapist. In the games in which the time is associated with the task level, the game will be launched successively as many times as necessary to complete the total time assigned. A 'direct exit' has been enabled in case the user or therapist wants to finish a game before the assigned training time; this can be done pressing the center bar of the device with both hands. However, when exited in this way, no data is stored, nor the level updated, etc. thus, it should not be used as a normal course of action.

General performance indicators are stored for all the games in each session. During the assessment games, full force and trajectory information is also stored in order to allow a detailed post-processing analysis. The data collection has been improved in order to solve some problems found in previous data analysis. The sampling frequency has been increased from 10 to 100Hz and descriptive data of every state of the game is collected. In addition, data is split in blocks, each block corresponding to analog groups of movements, e.g., extension and flexion; for each of them the target position and force, events, times and performance are stored.

2.3.2 Assessment Games

The *Force Calibration* game (Fig. 3(a)) serves to weigh the patient's arm in a relaxed position and thereby calibrate the vertical force characteristic of the device. Therefore, it should be performed before any other game. Moreover, without any limitation of time, it helps the patient to have an initial contact with the vertical force characteristic of the device, which generally causes some confusion for the patients at first. In this way the patient can try as much as needed to use this feature and see the feedback result of his actions on the screen. When the patient understands this concept and is prepared, correct posture of the torso and the relaxation of the arm must be checked and then the calibration can be started. This arm weight calibration needs to be done only once; however, it can be repeated at any time.

The *Range of Movement* game (Fig. 3(b)) evaluates the range of extension movements from a central position towards the different directions of the transverse plane. Being the one that defines the ROM required by the rest of the games, this should always be the first game to be played; or just after the *Force Calibration* game in the case that this later was never played before. In the game, different sectors have to be deleted with a reach extension movement of the arm from the central ball to the furthest point reached in that direction as indicated by the white arrow. The patient needs to stop at the furthest point reached in order for the result for that sector to be saved, thereby avoiding the acceptance of ballistic movements. Then he must return to the centre ball and start again with another sector. In order to improve the user feedback, there are two ways in which sectors are visually erased (Fig. 3(b)): instantaneously as the cursor passes (in light green), which gives real-time feedback to the user; and once they stop (in white), when the score is really saved, and that part of the sector deleted permanently. The patient must ensure that he remains upright during the game. The game detects if the patient leans over the table in order to achieve a greater range of movement; in that case the game is interrupted until he corrects the posture.

The *Range of Force* game (Fig. 3(c)) assesses the arm support/lifting capacity in different positions of the plane by placing the cursor over a circular target and lifting the arm. As the arm is unloaded from the device, the size of the target is increased in proportion to the lifting force in order to reach the diameter of a peripheral ring which indicates the target unloading level. Being the one that defines the ROF required by the rest of the games, this should always be the second game to be played, after the *Range of Movement* game.

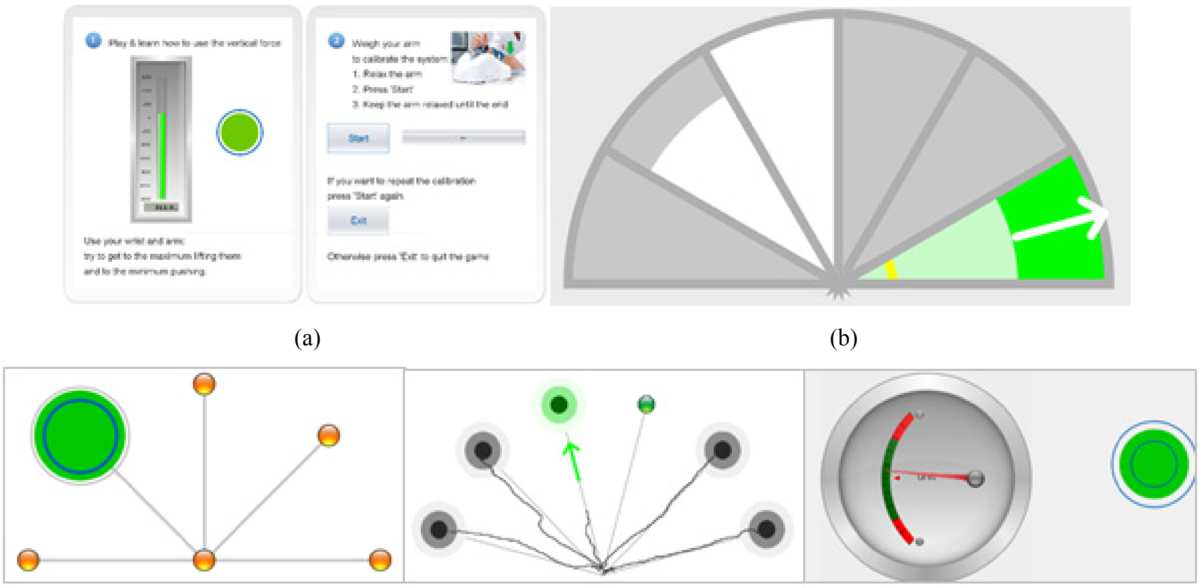
The *Control of Movement* game (Fig. 3(d)) evaluates the patient's motion control when he has to follow a path from one point to another and stop in a very restricted time. For that, the user must first, move the cursor to the centre ball; second, to the target that is blinking and stop in the centre as quickly as possible. Then, go back to the centre and start the task over moving to the new ball that blinks. As in the Range of Movement game, the patient must ensure that he remains upright during the game; otherwise, the game will be interrupted until he corrects the posture.

The *Control of Force* game (Fig. 3 (e)) evaluates the patient's ability to control the level of vertical force, that is, the ability to lift the arm. Keeping the arm in a centred position on the mat, the patient must lift the arm slightly trying to keep the needle in the middle of the dial, always in the green area. This area will become narrower, and therefore will require a greater control of the arm as the time passes. The patient should keep this position until the progress bar completes. The goal value is based on the ROF evaluated in the *Range of Force* game. For consistency with other games, in the case that the user prefers the feedback on the right side of the screen, the user must try to keep the green circle within the two blue circles.

2.3.3 Training Games

These games aim to train in an enjoyable way the reach extension movements of the arm, generally having to pick objects and move them to different positions of the plane. To accomplish this, the user has to first, place the cursor over the corresponding object and stop briefly, or lift the arm in the case that the vertical force component is being used, which will be indicated; second, move it to the corresponding position; and third, stop briefly again or rest the arm in the previously mentioned case. Each game presents five levels and is scored based on a combination of evaluated features. Time available is also adjusted according to the level in each case.

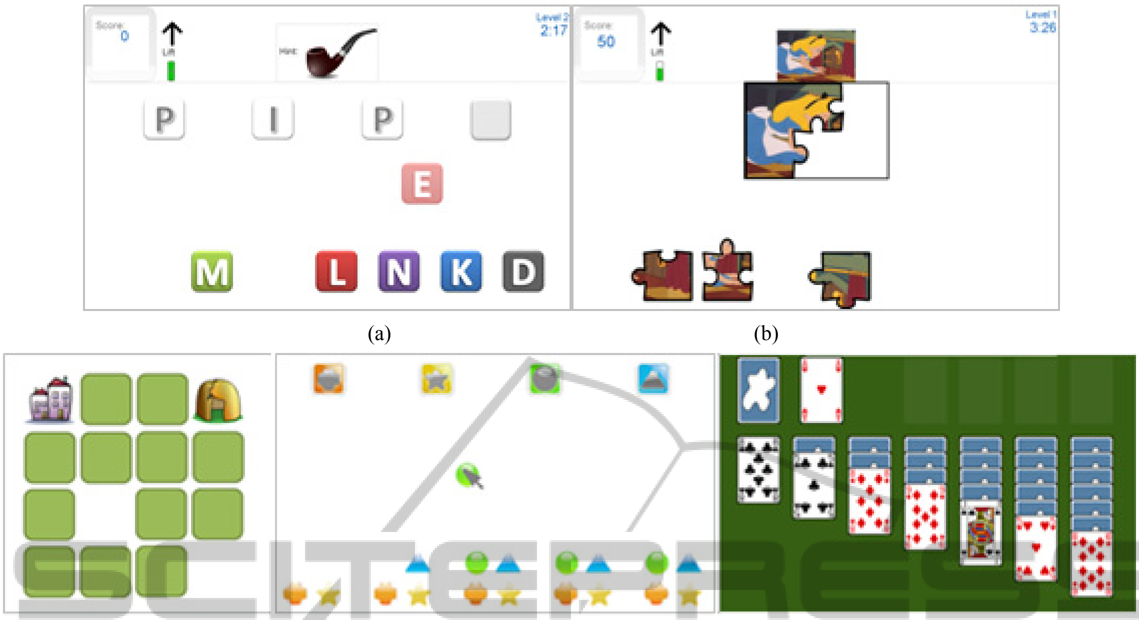
In the *Words* game (Fig. 4(a)) the missing letters in the words have to be completed with the spare letters at the bottom of the screen. The letter will go back to its initial position if it is introduced into the wrong space or is released, that is, if we stop for 1 second after moving the piece or rest the arm. As the level increases, the number of missing letters to be filled in each word, the difficulty of the word and the



(a) (b)

(c) (d) (e)

Figure 3: Assessment games: (a) Force Calibration (b) Range of Movement (c) Range of Force (d) Control of Movement (e) Control of Force.



(a) (b) (c) (d) (e)

Figure 4: Training games: (a) Words (b) Jigsaw Puzzle (c) Memory (d) Point to Point (e) Solitaire.

difficulty of the task also increase. Task difficulty, for example, increases by having to fill in vowels or consonants and the accuracy needed for a letter to be considered selected or introduced. In the *Point to Point* game (Fig. 4(d)) each object has to be placed in its box. The levels are defined by the number of elements to be introduced and the accuracy needed for an object to be considered selected or introduced. For the *Memory* game (Fig. 4(c)) the user has to discover pairs of matching 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 by putting together a *Jigsaw Puzzle* (Fig. 4 (b)) whose number and size of pieces increase with the levels. As a fifth training game, the user can play the typical *Solitaire* game (Fig. 4(e)) with different numbers of cards dealt and times to complete the task.

3 TESTING

The games are currently being used informally at the Rehabilitation Service at 'Hospital Universitario de Álava- Sede Txagorritxu' (Spain) in order to get further usability feedback.

Furthermore, a clinical study is being conducted in the Clinic for Rehabilitation 'Dr Miroslav Zotović' in Belgrade, Serbia. The main purpose of this study is to determine the correlation between ArmAssist assessment results and standard clinical assessment scales. Patients included in this study are 40 to 70-year-old stroke survivors in the sub-acute phase with unilateral paresis, able to understand simple instructions, and who have some voluntary movements in elbow and shoulder joints. The program lasts four weeks during which patients have at least one hour of conventional therapy and at least thirty minutes of additional therapy per day, five days per week. The additional therapy differs depending on whether the patient was randomly assigned to the ArmAssist group, where they exercise within the TeleReha platform, or the Control group where they receive work therapy, designed to match the training received by the experimental group. Each group comprises 15 patients.

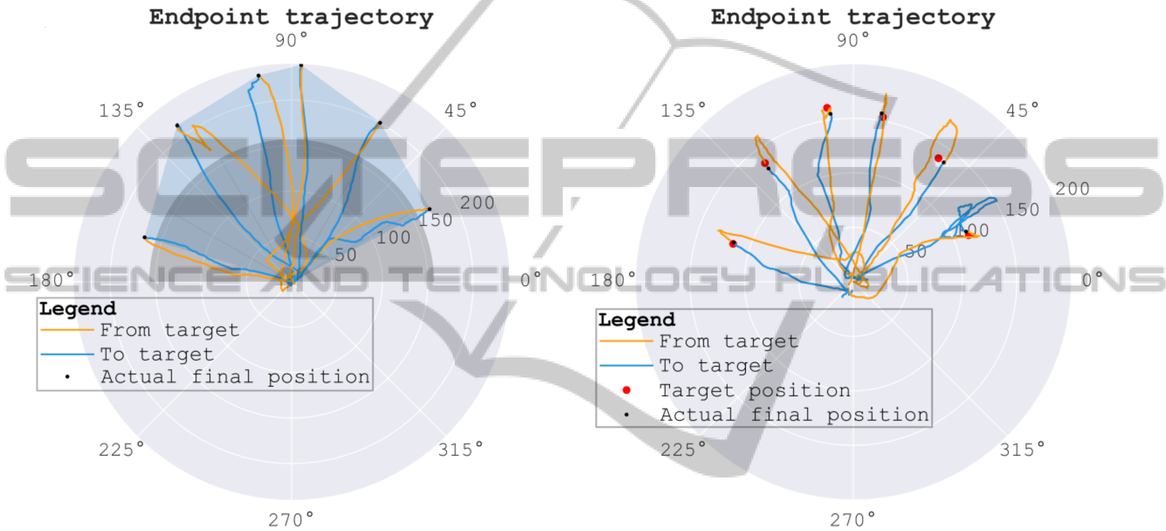
All patients will be assessed at the beginning and the end of the program. The Fugl-Meyer Assessment (Sanford et al., 1993), the Action Research Arm Test (Van der Lee et al., 2001), the Barthel index (Collin et al., 1988), the Modified Rankin scale (De Haan et al., 1995), the Beck depression scale (Beck et al., 1961), the Wolf Motor Function test (Wolf et al., 2001) and the Modified Drawing Test (Kostić et al., 2013) are among the measurements used. In addition, an experimental psychologist interviews patients to evaluate comfort, pain, fatigue, enjoyment, benefits, desire to continue, and motivation to exercise.

4 RESULTS

Initial informal feedback from patients and clinicians at the usability testing has been highly positive. It shows that the system is easy to use and integrates well in the clinical setting. The majority of the issues and feedback items have been addressed in the redesign and this was very much appreciated by the users involved.

Patients felt motivated, trained for longer and their perception of pain and fatigue was lower. The knowledge of performance clearly motivated them to continue the training and to improve in every session. For that reason, it was observed that, in order to avoid frustration, the difference between assessment and training games must be clear for the patients; the significant difference being that the maximum values for the first ones are defined by healthy patients and are not adapted to their capacity as in the case of the second ones.

Therapists considered the system useful and appreciated the fact that it allows them to treat several patients at the same time.



(a) (b)

Figure 5: Full position data visualization for (a) *Range of Movement* game (b) *Control of Movement* game.

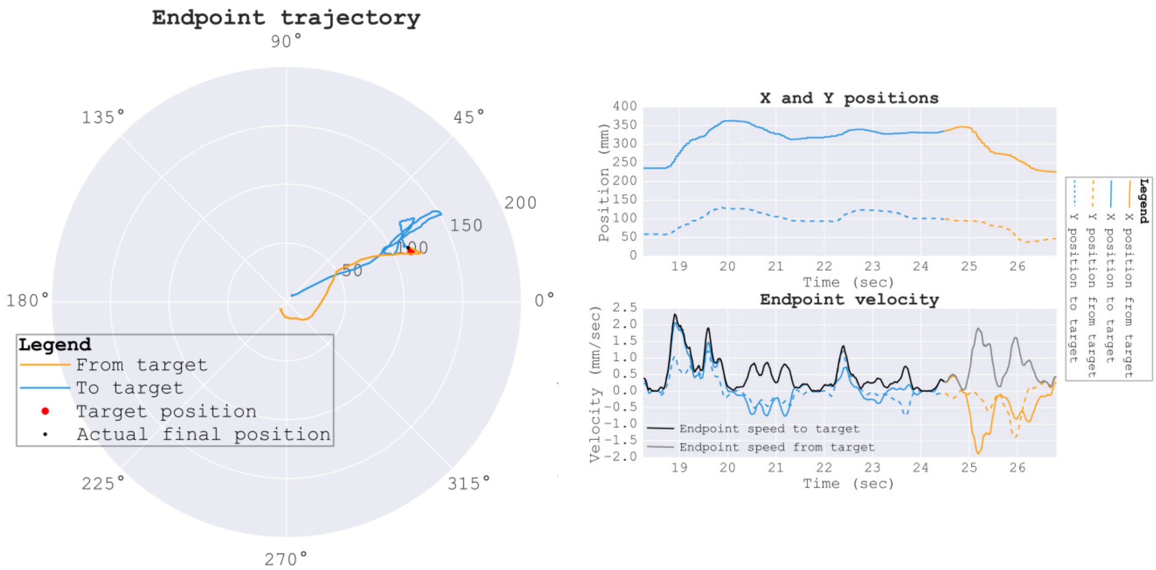


Figure 6: Data block analysis for the *Control of Movement* game.

Still, the number of training games is too low to keep the user motivated after the first weeks. For that reason, a special application is currently being developed in order to be able to use the ArmAssist as a normal mouse and, in that way, be able to surf the Internet and play any other games available. However, standard games in the Internet usually need an advanced use of the cursor; therefore, precision of the cursor positioning must be improved for the application to work properly.

Preliminary analysis of the first data obtained from the ongoing clinical study shows that the quality of the data has been improved, which will facilitate post-processing and conclusions extraction. For example, a one-shot analysis of the range and control of motion of the patient in the different directions of the plane can be performed, shown in (Fig. 5). Also, detailed analysis of each trial, e.g. extension plus flexion movement, can be carried out, providing very visual and useful information of the movement. As an example, the detailed analysis of a block of data of the *Control of Movement* game is presented in (Fig. 6), were smoothness of the movement can be clearly observed.

However, further data is needed in order to extract any trends and conclusions regarding the validity of the assessment and the effectiveness of the training games. This data will be further obtained in the ongoing testing.

5 CONCLUSIONS

A new version of assessment and training games has been developed for at-home post-stroke arm rehabilitation. The aim was to include feedback gathered in previous usability testing and to improve the assessment methodology in order to be able in the future, not only to measure the effectiveness of the system, but also to compare the assessment results with the standard assessment scales used in the clinic up to now. Initial feedback from patients and clinicians of the new version of the games has been highly positive. Preliminary analysis of data from the currently ongoing testing shows that the quality of the data has been improved; this will facilitate post-processing and conclusions extraction regarding effectiveness and assessment validity. Future work comprises the analysis of data obtained from the ongoing clinical study, the corresponding redesign of games according to the results obtained, if necessary, and the development of new training games.

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REFERENCES

Sluijs, E.M., Kok, G.J., Zee, J., 1993. Correlates of exercise compliance in physical therapy, In *Physical Therapy, 73 (11), pp. 771–782.*

Kwakkel, G.,Wagenaar, R.C., Koelman, T.W., Lankhorst G.J., Koetsier, J.C., 1997. Effects of intensity of rehabilitation after stroke, a research synthesis, In Stroke 28.8 (1997): 1550-1556

Peerenboom, P. B. G., Spek, J., Zekveld, I., Cools, H. J. M., van Balen, R., & Hoogenboom, M. J., 2008. Revalidatie in de AWBZ, omvang, aard en intensiteit. Etc Tangram. In *LUMC/PHEG Verpleeghuisgenees-kunde, 31.* [Online]: http://www.vumc.nl/afdelingen-themas/69713/27797/tangram_RapportRevalidatieD1.pdf, accessed April 2013.

Hesse, S., Werner, C., Pohl, M., Rueckriem, S., Mehrholz, J., Lingnau, M.L., 2005. Computerized Arm Training Improves the Motor Control of the Severely Affected Arm After Stroke A Single-Blinded Randomized Trial in Two Centers. In *Stroke, 36:1960-1966.*

Robertson, J. V. G., Roby-Brami, A., 2010. Augmented feedback, virtual reality and robotics for designing new rehabilitation methods. In *Rethinking Physical and RehabilitationMedicine, J.-P.Didier and E. Bigand, Eds., pp. 223–245.* Springer.

Zabaleta, H., Valencia, D., Perry, J., Veneman, J., Keller, T., 2011. Absolute position calculation for a desktop mobile rehabilitation robot based on three optical mouse sensors. In *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE (pp. 2069-2072).* IEEE.

Perry, J. C., Zabaleta, H., Belloso, A., Rodriguez-de-Pablo, C., Cavallaro, F. I., Keller, T., 2012. ArmAssist: Development of a functional prototype for at-home telerehabilitation of post-stroke arm impairment. *In Biomedical Robotics and Biomecha-tronics (BioRob), 2012 4th IEEE RAS & EMBS International Conference on (pp. 1561-1566).* IEEE.

Arcas Ruiz-Ruano, J., Perry, J.C., Rodriguez-de-Pablo, C., Keller, T., 2012. TeleREHA: online/offline web platform for telerehabilitation of post-stroke arm impairment. *In Intl. Conf. on Neurorehabilitation, ICNR 2012, November 14-16, Toledo, Spain.*

Perry, J. C., Andureu, J., Cavallaro, F. I., Veneman, J., Carmien, S., Keller, T., 2011. Effective game use in neurorehabilitation: user-centered perspectives. In *Handbook of Research on Improving Learning and*

Motivation through Educational Games, IGI Global, Ch. 32, pp:683-725.

Rodríguez-de-Pablo, C., Perry, J. C., Cavallaro, F. I., Zabaleta, H., Keller, T., 2012. Development of computer games for assessment and training in post-stroke arm telerehabilitation. In *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE (pp. 4571-4574).* IEEE.

Perry, J.C., Rodriguez-de-Pablo, C., Cavallaro, F. I., Belloso, A., Keller, T., 2013. Assessment and training in home-based telerehabilitation of arm mobility impairment. In *Journal of Accessibility and Design for All (CC) JACCES, 2013, Vol 3, No 2: 117-135. ISSN: 2013-7087*

Sanford, J., Moreland, J., Swanson, L. R., Stratford, P. W., and Gowland, C., 1993. Reliability of the Fugl-Meyer assessment for testing motor performance in patients following stroke. In *Physical therapy, vol. 73, no. 7, pp. 447-454*

Van der Lee, J. H., De Groot, V., Beckerman, H., Wagenaar, R. C., Lankhorst, G. J., and Bouter, L. M., 2001. The intra-and interrater reliability of the action research arm test: a practical test of upper extremity function in patients with stroke. In *Archives of physical medicine and rehabilitation, vol. 82, no. 1, pp. 14-19*

Collin, C., Wade, D. T., et al., 1988. The Barthel ADL Index: a reliability study. In *International Disability Studies 10(2): 61-63*

De Haan, R., Limburg, M., et al., 1995. The clinical meaning of Rankin 'handicap' grades after stroke. In *Stroke 26: 2027-2030*

Beck, A.T., Ward, C. H., Mendelson, M., Mock, J., Erbaugh, J., 1961. An inventory for measuring depression. In *Archives of General Psychiatry, 4, 561-571.*

Wolf, S. L., Catlin, P. A., et al., 2001. Assessing Wolf motor function test as outcome measure for research in patients after stroke. In *Stroke 32: 1635-1639.*

Kostić, M. D., and Popović, M. D., 2013. The modified drawing test for assessment of arm movement quality. In *Journal of Automatic Control, 21(1), 49-53.*