Robotic-assisted serious game for motor and cognitive post-stroke rehabilitation

S. Dehem (1st author)*, T. Lejeune & G. Stoquart
Université catholique de Louvain
Institut de Recherche Clinique et Expérimentale, CARS
Cliniques universitaires Saint-Luc
Physical Medicine and Rehabilitation department
Brussels, Belgium
{stephanie.dehem, thierry.lejeune,
gaetan.stoquart}@uclouvain.be

V. Montedoro (1st author)* & M. Edwards
Institute for Research in Psychological Science
Université catholique de Louvain
Louvain-La-Neuve, Belgium
{vincenza.montedoro, martin.edwards}@uclouvain.be

S. Heins (1st author)* & B. Dehez
Institute of Mechanics, Materials and Civil Engineering
Université catholique de Louvain
Louvain-La-Neuve, Belgium
{sophie.heins, bruno.dehez}@uclouvain.be

F. Rocca, P.-H. De Deken & M. Mancas
Faculty of Engineering
Numediart Institute - University of Mons
Mons, Belgium
{francois.rocca, pierre-henri.dedeken,
matei.mancas}@umons.ac.be

*S. Dehem, S. Heins & V. Montedoro, all contributed equally in this study and in writing this paper, named in alphabetical order.

Abstract—**Stroke is a major cause of long-term disability that can cause motor and cognitive impairments. New technologies such as robotic devices and serious games are increasingly being developed to improve post-stroke rehabilitation. The aim of the present project was to develop a ROB*i*GAME serious game to simultaneously improve motor and cognitive deficits (in particular hemiparesis and hemineglect). In this context, the difficulty level of the game was adapted to each patient's performance, and this individualized adaptation was addressed as the main challenge of the game development. The game was implemented on the REAplan end-effector rehabilitation robot, which was used in continuous interaction with the game. A preliminary feasibility study of a target pointing game was run in order to validate the game features and parameters. Results showed that the game was perceived as enjoyable, and that patients reported a desire to play the game again. Most of the targets included in the game design were realistic, and they were well perceived by the patients. Results also suggested that the cognitive help strategy could include one visual prompting cue, possibly combined with an auditory cue. It was observed that the motor assistance provided by the robot was well adapted for each patient's impairments, but the study results led to a suggestion that the triggering conditions should be reviewed. Patients and therapists reported the desire to receive more feedback on the patient's performances. Nevertheless, more patients and therapists are needed to play the game in order to give further and more comprehensive feedback that will allow for improvements of the serious game. Future steps also include the validation of the motivation assessment module that is currently under development.**

Keywords: serious game, robotic assisted-rehabilitation, stroke, hemineglect, hemiparesis, upper limb, motivation

I. INTRODUCTION

Stroke affects fifteen million people each year worldwide, with approximately one-third of these patients having persistent neurological sequelae [1] that causes deficits in motor functions and/or cognition. Motor disorders can result in a loss of motor control, muscle paresis, proprioceptive deficits, spasticity and muscle shortening which decrease the upper limb range of motion [2]. Cognitive impairments after stroke can vary, but most frequently, impairments are to memory, executive function and attention [3]. For the latter, the condition of hemineglect results in patients having problems to orient, perceive and respond to stimuli; either on the contralesional side of the space (egocentric hemineglect) or to the contralesional side of objects (allocentric hemineglect), or both in combination [4], [5].

Interestingly, patients frequently have hemineglect with hemiparesis, which together, significantly hinders functional daily activities [6] and prevents functional remission [7]. Although the brain typically undergoes spontaneous recovery after stroke (during the acute phase), one third of patients show persistent symptoms of hemineglect more than a year after the neurologic incident [8], and 25% of patients remain with upper limb motor impairments five years post-stroke [9]. Therefore, there is a crucial need to develop news means of effective motor and cognitive rehabilitation.

Motor rehabilitation of upper limb impairment is usually based on motor learning principles. These principles strongly recommend: (i) intensive practice and associated movement feedback; (ii) task-specific training; (iii) motivating environments to enhance treatment adhesion; and (iv) use of assistance to facilitate or aid the patient's responses [10], [11]. Hemineglect rehabilitation focusses on using (visual, auditory or tactile) cues to attract the patient to explore and attend the neglected contralesional side [12].

The use of serious games in rehabilitation has considerably increased during the last years [13], [14]. The primary objective of serious games is not for entertainment, enjoyment or fun [15]. In neurorehabilitation, the primary purpose of a serious game is for the improvement of motor and/or cognitive function. To this end, serious games allow for continuous adaptation of the exercise difficulty according to the patients' abilities [16]. Indeed, the rate of success is a key factor of rehabilitation. If the exercise is too difficult, the patients will always fail, and they will not regain new skill. On the other hand, if the exercise is too easy, the patients will always succeed, without regaining any ability [17]. According to [17] and [18], the success rate should remain between 50% and 70% to maximize the patient's improvements. In addition to facilitating learning, serious games can also be highly engaging and motivating, which facilitates involvement of the patient in the prolonged and intensive rehabilitation process [13]. Research in the literature has already shown various potential benefits of serious games in stroke rehabilitation. For example, the single case study of [19] demonstrated that the use of a video-game designed for hemineglect rehabilitation was positively accepted by the patient, and showed improved performance, both on standardized tests (e.g. line bisection), but also and in everyday life activities. Moreover, these improvements remained at the follow-up assessment five months after the rehabilitation session. In a second example, it was also shown in [20] that hemineglect patients included in an interactive virtual street crossing training improved their visuo-spatial performance, and in their ability to cross real streets. The patients paid more attention to the contralesional side of space, compared to hemineglect patients following a computer based visual scanning task. Similar results have also been reported for games tailored to rehabilitate motor deficits. A recent randomized control study [17] of a rehabilitation gaming system used over twelve weeks showed that patients compared to controls presented significant improvements in the arm subpart of the Fugl Meyer Assessment Test, and the Chedoke Arm and Hand Activity Inventory. The patients also showed increased performance in their paretic arm velocity movement. Moreover, this study [17], and [13] showed that motor rehabilitation games were highly accepted by patients.

Currently, post-stroke rehabilitation sessions in clinical routine or using a serious game are frequently specific to one type of disorder, either cognitive or motor. Consequently, patients have to undergo a lot of rehabilitation sessions in order to recover from both motor and cognitive impairments. However, it can be highly beneficial for the patient's rehabilitation to consider a combined approach to rehabilitate different impairments simultaneously [21]. Therefore, the aim of the present ROB*i*GAME project was the development of a serious game for combined motor (hemiparesis) and cognitive (hemineglect) rehabilitation following stroke, implemented on an end-effector rehabilitation robot, that complements existing clinical therapy. The advantage of the ROB*i*GAME rehabilitation robot and serious game is to provide additional rehabilitation possibilities to the patient, without the need of added therapists, thereby providing supplementary treatment support to the patient's current rehabilitation program. In this paper, after giving details on the chosen type of rehabilitation robots in Section II, Section III describes the selected method for game development and difficulty adaptation based on individual real-time performance assessment. Section IV focuses on the created serious game, features and parameters. Then, Section V presents the results of a first feasibility study that was conducted in order to validate the game characteristics. Finally, Section VI gives details of a motivation assessment module which is currently under development and will be integrated to the game in future steps.

II. UPPER-LIMB REHABILITATION ROBOTS

Planar end-effector robots such as MIT-Manus [22] and REAplan (Axinesis®) (Fig. 1) [23] are usually composed of (i) a handle movable on the horizontal plane, allowing movements of the shoulder and the elbow, (ii) force and position sensors, (iii) motors to assist or disturb the movement of the handle, (iv) a screen equipped with speakers and placed in front of the participant for the presentation of visual and auditory information, and (v) a monitor for the therapist to configure the exercise, and see the results of the patient's performance. These types of robotic devices are increasingly being used for upper-limb rehabilitation as they can fulfill the needs of intensive therapy, as well as provide a configurable amount of assistance, in coordination with combined haptic, visual and auditory feedback. For example, recent reviews showed an improvement of upper limb motor control and daily living activity after robotic assisted therapy [2], [11]. These robots also provide a quantitative assessment tool for measuring movement kinematics and kinetics [23]. These characteristics make such robots suitable for the development of post-stroke rehabilitation of both motor and cognitive impairments, and for the inclusion of serious game development.

During robot-assisted therapy for motor rehabilitation, the robot can provide motor assistance that consists in applying a given force on the end-effector to help the patient successfully complete the desired movement. Similarly, the participant's

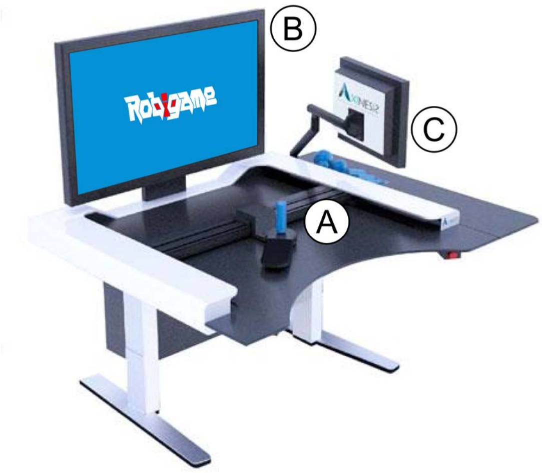

Fig.1. Illustration of the REAplan upper-limb robotic rehabilitation device (adapted from [24]). The REAplan is composed of: (A) a handle equipped with position and force sensors that is actuated by two motors, (B) a screen and loudspeakers for the participant and (C) a monitor for the therapist.

movement can be disturbed by applying a resistive force on the end-effector to increase the task difficulty. If this resistive force is in the opposite direction of the movement, it allows training the participant's force; if it is in another direction, it disturbs the participant's movement and obligates him to adapt his trajectory.

In both cases, the computation of this force (direction and amplitude) can be configured so that the amount of provided assistance or resistance adapts to the patient's performances continuously. More details on the force computation are given in section IV.

On the other hand, robot-assisted therapy for cognitive rehabilitation can combine (i) visual cues (e.g. highlighting a target on the screen), (ii) auditory cues (e.g. recorded spoken instructions), and particularly (iii) haptic cues (e.g. initializing the movement of the handle towards the target to be selected). Activation of lateralized cues help hemineglect patients re-orientate their attention to the contralesional space, the contralesional side of stimuli, or to activate the contralesional limb that may be underutilized. The type of provided help associated with trigger conditions (e.g. delays) can be configured and adapted to the patient's cognitive performance.

The serious game presented in the following sections (ROB*i*GAME) is implemented on the REAplan but is meant to be adaptable to other similar devices.

III. PRESENTATION OF ROB*i*GAME

Developing a serious game for post-stroke rehabilitation to improve both motor and cognitive skills simultaneously highlights numerous challenges. One can name the task specifications and the regulation of the task difficulty, including the amount of motor assistance, in accordance to the patient's performances which vary during a rehabilitation session, and from one rehabilitation session to another. Indeed, in order to optimize the patient's rehabilitation, the game difficulty has to be continuously adapted to the motor and cognitive performances of the patient. The schematic representation of ROB*i*GAME (Fig. 2) shows the proposed method for this regulation, independent of the type of task. In the proposed structure, the ROB*i*GAME can include several types of tasks such as target pointing, geometrical shape drawing, itinerary following, isometric force, etc. The planned tasks are single player tasks.

In order to initialize the game difficulty, the patient's performance can be evaluated through the various motor and cognitive assessment protocols presented in [25] and [26] respectively, before the first rehabilitation session. These results are stored (**s**) (Fig. 2) so that they can be used to determine the difficulty level. The patient is also continuously assessed during the game, in order to update constantly the game difficulty to his evolution (e.g. improved performance or tiredness). The evaluation results include for example the patient's range of motion, as shown in Fig. 3 in case of a left hemiparetic patient. In this figure, the dark blue area represents the "active" workspace that is reachable by the patient without assistance, whereas the light blue area is the "passive" workspace that he can reach with the help of a therapist. The game will never take the patient outside the passive workspace. The active workspace is expected to extend while the patient improves his motor skill, thus it will be updated continuously during the game.

Then, during the game, the desired difficulty is determined within a single regulator based on the patient's performance during the previous exercises and/or his assessment results. Indeed, the regulator computes a set of difficulty indicators (**y**) that are characterized in the exercise (e.g. an area indicator for the workspace or an assistance indicator for the amount of motor assistance). These indicators are common to all the types of task. However, each type of task is associated with a set of

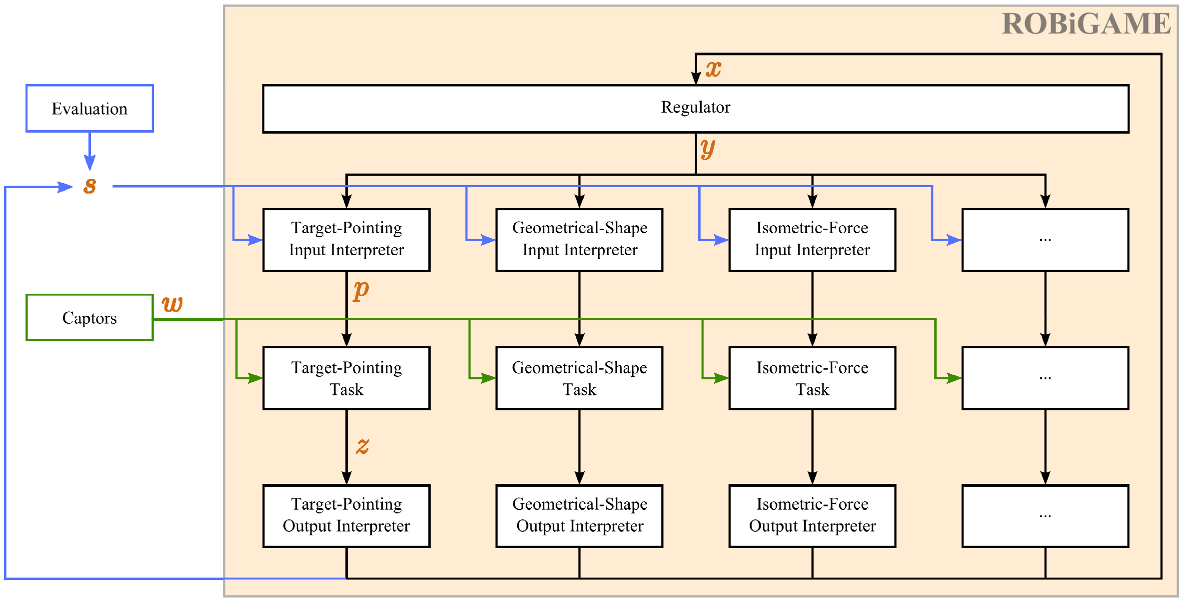

Fig. 2. Schematic representation of the ROB*i*GAME regulation. The aim is to adapt the game difficulty to the patient's performance. The ROB*i*GAME can include several different types of task, with each one being associated with a set of task-specific parameters characterizing the task difficulty (***p***). The desired task difficulty is determined within a single regulator, which computes a set of difficulty indicators (***y***) that are common to all the types of task. An input interpreter translates these indicators into the task parameters, based on the patient's evaluation (***s***). Then, during the task performance, the game receives information from captors (***w***) and reacts in function of the captured data. When the task is completed, all the information that was measured during the task (***z***) is sent to the output interpreter, which translates it into performance indicators (***x***). The performance indicators are finally sent to the regulator, which computes the difficulty indicators of the next task.

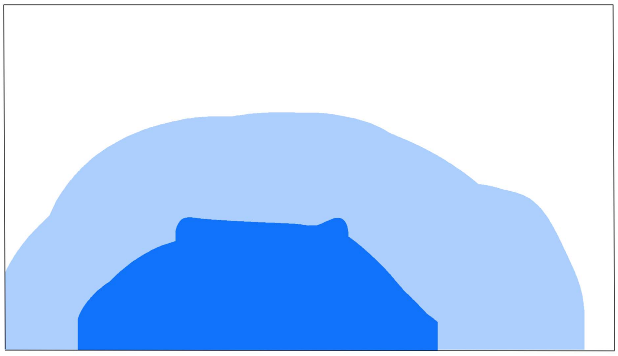

Fig. 3. Illustration of the patient's range of motion obtained during the assessment protocol: typical trace of an actively reachable workspace (dark blue) and passively reachable one (light blue) of a left hemiparetic patient

task-specific parameters (**p**) that characterizes its difficulty (e.g. the target position or the geometrical shape complexity). As a consequence, the difficulty indicators need to be translated into the task parameters within an input interpreter, which takes into account the results of the patient's evaluation (**s**).

During the exercise, real-time information is received from captors (e.g. the robot) such as position and force measurements (**w**) and the game reacts in function of the captured data (e.g., by increasing the amount of motor assistance or triggering cues). When the exercise is completed, all the information that was captured by the robot and the game (**z**) is sent to an output interpreter that transforms the information into performance indicators (**x**). These performance indicators characterize the motor and cognitive performance, and the motivation of the patient during the exercise he/she just realized (e.g., characterized by the amount of provided motor assistance, visual help or the patient's emotional state). Finally, these indicators are sent to the regulator, which then computes the difficulty indicators characterizing the next exercise.

In addition, during the exercise realization, images of the participant will be recorded and sent to a motivation extraction module that is currently under development. This module will analyze the patient's motivation through his attention and emotional state. Results will be used for two different purposes: (i) assessing to what extent the ROB*i*GAME achieves keeping the patient motivated, (ii) influencing the game scenario and difficulty level within the regulator. More details on this motivation extraction module are given in section VI.

Although the ROB*i*GAME structure allows the inclusion of several types of tasks, it was chosen to start the development with a target-pointing task, which is discussed in the next section.

IV. THE TARGET POINTING GAME

In the target-pointing game, a set of targets are displayed simultaneously on the screen. The participant has to reach some of them with the handle of the robot, and bring the target object to the starting point, one by one, and in a particular order. In order to select the theme for the scenery design of the game, a questionnaire survey evaluated the user preferences. Results showed that, in general, adults preferred games that were related to real life compared to fantasy games. Moreover, challenge and precise goals seemed to be the most two important features of the game preferred by the participants. Therefore, the theme selected for the scenery design was a sandwich store, where the participant was asked by the sandwich store manager to prepare sandwich orders for clients. However, the engine is generic enough to be adapted for other category of people (e.g. children) or scenarios, with the same game functionalities.

The target-pointing game was developed using the Unity Technologies, which is a popular 2D/3D multiplatform game engine of games and interactive experiences. It is object-oriented and provides a wide range of tutorials and excellent documentation. All the programming was made in C#.

A. Gameplay

When the game begins, the screen shows a client arriving at the sandwich shop and placing an order. The message of the client is personalized and mentions the name of the player. An example is shown in Fig. 4. The list of ingredients that the participant has to find is displayed on a white board next to the client.

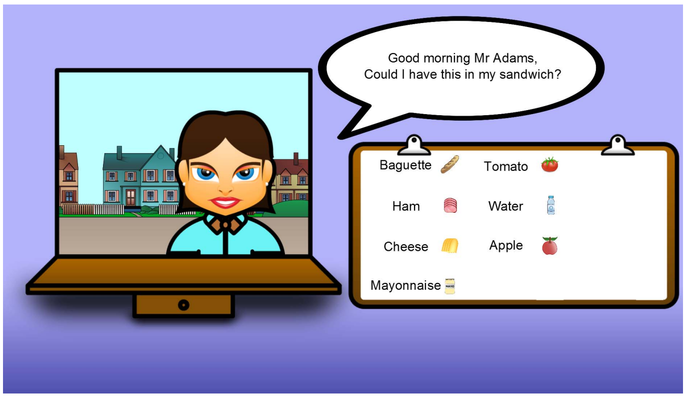

Fig. 4. Illustration of a client ordering a sandwich in the sandwich store game. This screen allows the participant to have a first overview of the exercise (e.g. the number of ingredients of the recipe).

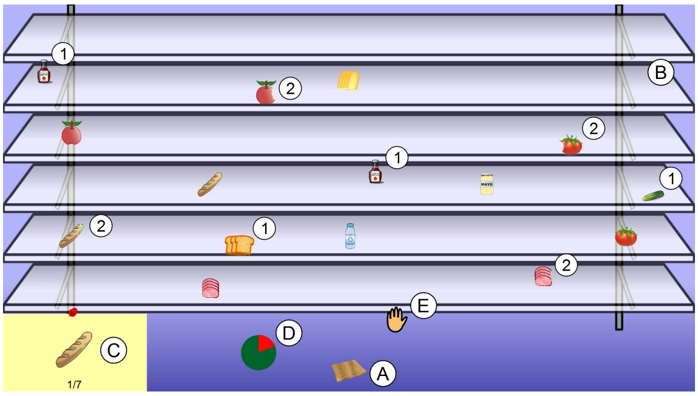

Fig. 5. Illustration of the sandwich store counter. This screen shows: (A) the starting point, (B) the workspace, (C) the next target to catch, (D) the timer and (E) the cursor controlled by the handle displacement. In addition to the targets that the participant had to reach towards, the display also included (1) additional targets that were not part of the order, and (2) targets with a defect.

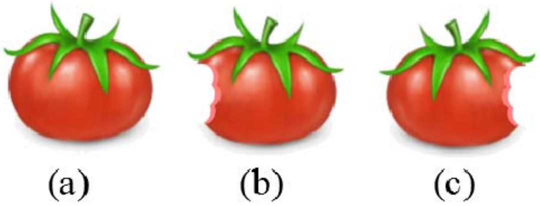

Fig. 6. Illustration of a target (tomato) present in the sandwich store game: (a) target to reach, (b) target with a defect on the left side, (c) target with a defect on the right side. Targets (b) and (c) allowed for the assessment and rehabilitation of the left and right allocentric hemineglect respectively.

Once the participant is ready, the game continues on a second screen (Fig. 5) that displays the following elements (see numbering in the figure): (A) the starting point, where the participant has to bring the targets after reaching them, (B) the workspace, where the targets are displayed, (C) the target to find, presented in the order of the recipe, and (D) the time remaining to find all the targets asked for the client. The position of (C) and (D) is bottom left by default, but both are placed on the bottom right of the screen in case of left hemineglect. The hand (E) follows the handle displacement. When the sandwich is finished, the game comes back to the first screen so that the completed order is given to the client. If the time runs out before the participant finds all of the targets, the exercise is indicated as unsuccessful and the client becomes angry and leaves without his order.

In order to influence the game complexity, two types of distracting elements can be displayed on the screen (see the corresponding numbering in Fig. 5): (1) additional targets that were not asked by the client, and (2) targets with a defect (e.g. rotten or damaged) on one side (left or right). These elements should not be reached by the patient. A defect target corresponds to one of the targets that the player has to reach in order to compile the sandwich (see Fig. 6 as an example). It is expected that patients with allocentric hemineglect might not see the defect on the contralesional side of the object, and would therefore not be able to make the difference between the real target and the defect one. Indeed, these defect targets were added to the task in order to encourage these patients to take into account the whole target in order to successfully complete the exercise.

During the game, cognitive cues can be triggered after a given period of time in order to help the patient to orient their attention towards the target. Three types of visual cues are used: targets with glowing edges, target enlargement and target rotation. Each cue has a different level of visibility in order to provide an incremental or more obvious help. Patients with weak hemineglect may require less cues, while patients with severe hemineglect may need high visibility cues or even motor help (see next paragraph) to facilitate their finding of the target object. The different levels of visibility of the cues can also allow to assess the improvement of the patient during the course of the rehabilitation programme.

Motor assistance during the game can be triggered to help the patient reach the target with the handle. The REAplan is a force controlled robotic device that allows the provision of assistive or resistive force during movement. The computation of this force is based on the definition of a reference trajectory (i.e. a trajectory that the participant should follow with the end-effector, based on the concept of virtual spring; see Fig. 7). The assistance force combines two components: a lateral force (F_{lat}) and a longitudinal force (F_{long}). The lateral force is proportional to the distance between the end-effector actuated by the patient and the reference trajectory, and to a variable stiffness coefficient (k_{lat}). The longitudinal force is proportional to the difference between a reference speed (v_{ref}) and the speed of the end-effector actuated by the subject parallel to the reference trajectory, and to a damping coefficient (c_{long}). The stiffness and damping coefficients (i.e. k_{lat} and c_{long}) are positively or negatively incremented by a predefined value (Δk_{lat} and Δc_{long} respectively) at a given frequency f, based on a statistical analysis of the values of the position error and of the speed error respectively [28].

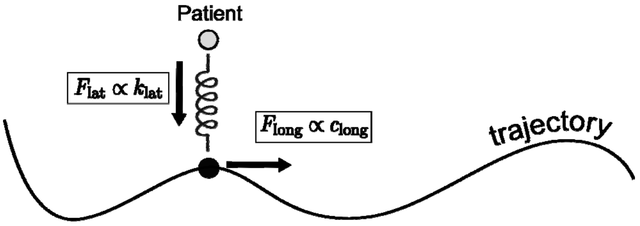

Fig. 7. Operating method for the motor assistance. The force computation is based on the definition of a reference trajectory and combines two components: a lateral force (F_{lat}) proportional to a stiffness coefficient (k_{lat}), and a longitudinal force (F_{long}) proportional to a damping coefficient (c_{long}). The black point is the orthogonal projection of the patient's position on the reference trajectory (adapted from [27])

Several different types of feedback are provided during the game. Firstly, during the order preparation, a positive sound is activated when the player reaches to the correct target, and similarly a negative sound is activated when the player reaches to a distractor or a defect target. Also, when the target is dropped off at the starting point, glowing stars are displayed to show that the ingredient has been inserted in the sandwich. Secondly, at the end of each order, the ingredients that were reached correctly are highlighted in green on the white board, but the targets that were not reached are highlighted in red. Also, the mood of the client varies if the order is correct (happy) or if there are missing ingredients (angry). Finally, at the end of the session, the game informs the player about the number of successfully achieved orders from the total number of orders made by the client.

B. Game inputs

Each client's sandwich order can be configured to adapt the game difficulty to the patient's performances. In this way, it is possible to present more targets on the contralateral side in order to rehabilitate hemineglect, provide less motor assistance in order to rehabilitate hemiparesis, decrease the total time to perform the exercise, increase the number of distractors to make the task more challenging, etc.

The motor and cognitive difficulty of the target-pointing task is defined by setting the value of the following parameters:

- the number of targets shown on the screen, their position and the order in which they must be reached;

- the number of defect targets, the defected side (left or right), their position, and the position of the associated whole target;
- the number of distractors and their position;
- the total time taken to achieve the exercise.

Then, for each target to reach, it is also possible to define:

- the list of visual cues to display and their associated triggering period;
- the motor assistance parameters (the initiation values of k_{lat} and c_{long}, the values of v_{ref}, f, Δk_{lat}, Δc_{long} and the trigger period);
- the size of the selection zone: this parameter defines an area around the center of the target in which the participant has to select the target, independent of the image size. The size of the selection zone defines the required precision of the reaching;
- the validation time: this corresponds to the period of time the participant has to stay in the selection zone in order to select the target.

These parameters correspond to the set of parameters **p** (see Fig. 2) and are adapted automatically for each exercise according to the patient's cognitive and motor performance.

C. Game outputs

The patient's motor and cognitive performances during each exercise are evaluated through the recording of a set of measured variables **z** (see Fig. 2). These variables are:

- the total time needed for the exercise;
- the position of the handle over time;
- the force applied on the handle over time;
- the motor assistance parameters over time (k_{lat}, c_{long}).

Moreover, for each target that has to be reached, the following variables are obtained from the raw data:

- the movement initiation time, the time needed to reach the target and the time needed to bring the target object to the starting point;
- the triggering time of each visual cue and of the motor assistance;
- the list of distractors and defect targets that were reached, the time needed to reach the distractor/defect target, and the time spend on the distractor/defect target.

V. FEASABILITY STUDY

In order to validate the usability, features and parameters of the target-pointing game, a feasibility study was run. The points of interest were: (i) the acceptance of the game by the patients, (ii) the enjoyment provided by the game, (iii) the graphic design, (iv) the visual cues and motor assistance, (v) information given to the patient during the game, and (vi) the effectiveness of the feedback. The second aim of the study was to determine more precisely the important features to take into account for the development of an auto-adaptive regulator.

Participants were recruited at the Cliniques universitaires Saint-Luc in Brussels. We selected two stroke patients (both with hemiparesis and one with hemineglect), and two therapists. The study was approved by the hospital ethics committee, and all participants gave their informed consent prior to participation.

For the purpose of the study, a scenario of ten client's orders varying in difficulty was proposed to the participants. If needed, the researcher manually modified the set of parameters **p** of each order to adapt the scenario better to the participant. Before the initiation of the scenario, the context of the game and the instructions were explained to the participant using an interactive training paradigm. After the ten client's orders, a questionnaire about the features of the game that used a 5-point Likert scale from "strongly disagree" to "strongly agree" was presented to the participant. A blank space was also provided to encourage the participant to report remarks. The duration of the session was approximatively 45 minutes per participant.

Results showed that the target pointing game had a lot of positive aspects, but also that some changes were essential. First, the patients enjoyed the game: both patients responded "strongly agree" to the playability of the game, and both indicated that they would like to play the game again. Patient A reported the desire to play the game alone, indicating that patients could be disposed to be rehabilitated by a game implemented on a robot without the presence of a therapist. Patient B particularly enjoyed the ecological aspect of the game, and noted that the clients were realistic (e.g. when showing an angry face because they didn't receive their order on time). As for the targets, therapists and patients strongly agreed that most of the target designs were realistic, except for the grated carrots and grilled aubergines that they indicated should be redesigned. Some target proportions should also be revised in order to be more consistent. The therapists suggested to increase the size of the targets in order to make them more easily perceived. However, both patients reported that the target size was adequate (indicating "strongly agree" on the questionnaire). A further study is required with more patients in order to be able to draw a firmer conclusion on the adequacy of the target size in the game, but we could consider adapting this parameter to the patient's performance, and to his visual acuity: greater targets for patients with a low performance level and smaller targets for patients with a high performance level. Therapists were sceptical that patients would be able to distinguish the defect target from the other targets. However, both patients succeeded to identify correctly the defect part of most targets. Patient B reported that the defect part of the slice of bread could be more pronounced, and therapist B found that the defect part of drinks was not sufficiently distinct to differentiate. In a future study, the defect targets design should be tested by patients with allocentric hemineglect. Patient B was not hemineglect, and yet he appreciated the inclusion of defect targets because it increased the diversity aspect of the game.

The visual cues aiming to help the patients find the target were not perceived during the game, except if the therapist showed the cue to the patients. Therefore, the cognitive help strategy should be reviewed. An idea could be to present only one visual cue to the patients, and if they still do not perceive the target, an oral cue could be given to encourage the patients to examine all of the workspace. Patient B reported that the target enlargement was the most visible cue. However, these observations should be confirmed in a future study by including more patients. For motor assistance, once triggered, the amount of assistance seemed to be well adapted to the patient's performance. However, the triggering conditions of this assistance should be reviewed. Currently, the motor assistance starts after the appearance of the visual cues. Consequently, patients need to wait a few seconds before receiving assistance to reach the target, although they had already perceived it. This aspect could frustrate the patient. Therefore, the triggering conditions of the assistance must be changed to detect when the patient perceives the target.

During the study, we noticed that patients seemed to receive too much information at the beginning of the game. This shows that the training of the game was essential to explain all the gaming features (e.g. the timer showing the remaining time to make the sandwich or the paper showing the target to catch and its order in the recipe). Note that, patients did not pay attention to the timer during the game, and this could be due to the design or position of the timer. One solution could be to increase the size of the timer and move it to the top of the screen. A sound could also ring out during the last seconds.

Finally, regarding the feedback, patients and therapists reported that the auditory feedback was appropriate. Patient B was willing to receive more feedback on his performance, in particular on the time he took to complete the sandwiches, as he was asked to do the exercise as fast as possible. Therapist B noted that the amount of feedback should be increased when failing a sandwich. He suggested that the game could show the patient which targets he failed to reach and its location. He also suggested to display the already reached targets near the counter during the exercise. Finally, patients and therapists appreciated the client change of mood when he didn't receive his order.

VI. DEVELOPMENT OF A MOTIVATION ASSESSMENT MODULE

Recovering from post-stroke cognitive and motor impairments requires a prolonged and intensive rehabilitation, which can discourage the patient. Therefore, ensuring that the patient remains involved and motivated is a goal pursued by the ROB*i*GAME project. Towards this goal, it seems interesting to assess the patient's motivation during the serious game. The objective of this measure is twofold: firstly, it would allow to assess to what extend ROB*i*GAME achieves the goal of keeping the patient motivated during the game, and confirm that the developed game is appropriate for stroke patients; secondly, the extracted motivation could be used during the game regulation to influence the difficulty level, together with the motor and cognitive information that has been already captured.

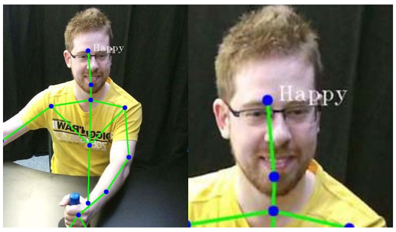

Fig. 8. Illustration of body tracking with a happy face detection

A motivation extraction module is therefore under development for integration into a future version of the ROB*i*GAME. This module requires the use of a 3D camera: the Kinect V2 sensor with Microsoft Kinect SDK [29]. The compatibility of this material with the REAplan robot and the conditions of use (e.g. the luminosity) has been previously pre-tested. The camera will be positioned on the top of the screen, in front of the participant. The captured patient's behavior will be used to extract two features: (i) the patient's gaze (based on the head direction) [30], and (ii) his emotional state. The patient's gaze reflects his attention during the game. If the patient pays attention, his gaze will focus on the screen. Given the technical limitations of the camera position (i.e. the distance from the participant), it is not possible to access the participant's eyes orientation. However, according to [31], we can consider that the gaze direction is closely matched to the head direction, as validated by [29] and [32] in healthy participants. This hypothesis will however be verified during a clinical trial with stroke patients in future stages of the project. Therefore, in the current project, head direction will be obtained from the Kinect user skeleton tracking and used to determine the patient's attention. Furthermore, for emotional state, it is possible to extract expressive parameters from the patient's face, such as "FACS" [33] which are basic units related to the facial expressions. These parameters will be used to determine positive, neutral or negative expressions (e.g. pronounced involvement or fatigue). The proposed method has been validated with healthy patients, as shown in Fig. 8 for the detection of a happy face. Again, the proposed method will be validated during a clinical trial with stroke patients.

VII. CONCLUSION AND PERSPECTIVES

In this study, we implemented a target-pointing game on an end-effector robotic device, the REAplan. Our goal is to create a robot assisted serious game to rehabilitate both cognitive and motor impairments following stroke. The structure of the game allows to assess the patient's performance, and to adapt the game level accordingly, during the rehabilitation session and from one session to another. A set of input parameters of the game were identified and tested during a feasibility study. This study showed that patients and therapists enjoyed the game, and that patients would like to play the game again. The game was reported to be entertaining because of the large number of targets, the variety of challenge and distracting elements. However, the cognitive help strategy, and the triggering conditions of the motor assistance need to be reviewed. The game should also give more feedback on the patient performances during the game. Future steps include testing the sandwich store game with more therapists and patients, in particular with allocentric hemineglect disorder. Indeed, more data should be collected to highlight other possible issues of the proposed game and modify the required characteristics.

Then, the new version of the game should be tested in a clinical trial with stroke patients. Finally, the motivation assessment module extracts the patient's gaze and emotional state to evaluate the patient attention and motivation during the game. This module is currently under development, and will be integrated into the serious game.

ACKNOWLEDGMENT

This work was supported by the Région Wallonne, the Fondation Saint-Luc and the Fondation Motrice. The authors would like to thank Axinesis for the development of the rehabilitation robot REAplan and Martin Vanderwegen for his collaboration. Finally, the authors would also like to thank all the patients and the therapists for their participation in this study.

REFERENCES

[1] J. Mackay and G. Mensah, "The atlas of heart disease and stroke", World Health Organization, editor, World Health Organization, pp. 1-112, 2004.

[2] A. Pollock, S. Farmer, M. Brady, P. Langhorne, G. Mead, J. Mehrholz, and F. van Wijck, "Interventions for improving upper limb function after stroke", Cochrane database Syst Rev., vol. 11, pp. 1-161, 2014.

[3] A. Jaillard, B. Naegele, S. Trabucco-Miguel, J. F. LeBas and M. Hommel, "Hidden dysfunctioning in subacute stroke", Stroke, vol. 40 (7), pp. 2473-2479, 2009.

[4] K. M. Heilman, R. T. Watson and E. Valenstein, "Neglect and related disorders", Clinical neuropsychology, vol. 3, pp. 279-336, 1993.

[5] G. Rode and L. Pisella, "De la négligence aux négligences : sémiologie – dissociations", in De la négligence aux négligences, P. Azouvi, Y. Martin & G. Rode, Eds. Marseille : Solal, 2011, pp.23-43.

[6] P. Pradat-Diehl, F. Poncet, H. Migeot and C. Taillefer, "Conséquences dans la vie quotidienne des troubles de la représentation corporelle", Revue de neuropsychologie, vol. 2(3), pp. 231-234, 2010.

[7] M. Jehkonen, J. P. Ahonen, P. Dastidar, A. M. Koivisto, P. Laippala, J. Vilkki, and G. Molnar, "Visual neglect as a predictor of functional outcome one year after stroke", Acta Neurologica Scandinavica, vol. 101(3), pp. 195-201, 2000.

[8] H.O Karnath, J. Rennig, L. Johannsen and C. Rorden, "The anatomy underlying acute versus chronic spatial neglect: a longitudinal study", Brain, pp. 355, 2010.

[9] J.M. Geddes, J. Fear, A. Tennant, A. Pickering, M. Hillman and M.A. Chamberlain, "Prevalence of self reported stroke in a population in northern England", J. Epidemiol. Community Health, vol. 50, pp. 140-143, 1996.

[10] T. Kitago and J. Krakauer, "Motor learning principles for neurorehabilitation", Neurol Rehabil, vol. 110, pp. 93-103, 2013.

[11] J. Mehrholz, M. Pohl, T. Platz, J. Kugler and B. Elsner, "Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke", Cochrane Database Syst Rev., vol. 11, 2015.

[12] R. S. Marshall, R. S., "Rehabilitation approaches to hemineglect" The neurologist, vol. 15(4), pp. 185-192, 2009.

[13] J. W. Burke, M. D. J. McNeill, D. K. Charles, P. J. Morrow, J. H. Crosbie and S. M. McDonough, "Optimising engagement for stroke rehabilitation using serious games", The Visual Computer, vol. 25(12), pp. 1085-1099, 2009.

[14] R. M. Tomé, J. M. Pereira and M. Oliveira, M., "Using Serious Games for Cognitive Disabilities", Springer International Publishing, pp. 34-47, 2014, [In International Conference on Serious Games Development and Applications].

[15] D. Michael and S. Chen, "Serious games: Games that educate, train and inform" MA: Thomson, 2006.

[16] N.A. Borghese, M. Pirovano, P.L. Lanzi, S. Wüest and E.D. de Bruin, "Computational Intelligence and Game Design for Effective At-Home Stroke Rehabilitation", Games Health J. vol. 2(2), pp. 81–8, 2013.

[17] M. Da Silva Cameiro, I. Bermúdez Badia, E. Duarte and P.F.M.J Verschure, "Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke: A randomized controlled pilot study in the acute phase of stroke using the Rehabilitation Gaming System", Restor Neurol Neurosci., vol.29(5), pp. 287–98, 2011.

[18] J. Perry and J. Andureu, "Effective game use in neurorehabilitation: user-centered perspectives", Handb Res Improv Learn Motiv through Educ Games Multidiscip Approaches pp. 1–44, 2011.

[19] R. Mainetti, A. Sedda, M. Ronchetti, G. Bottini and N.A. Borghese, "Duckneglect: video-games based neglect rehabilitation", Technology and Health Care, vol. 21(2), pp. 97-111, 2013.

[20] N. Katz, H. Ring, Y. Naveh, R. Kizony, U. Feintuch and P.L. Weiss, "Interactive virtual environment training for safe street crossing of right hemisphere stroke patients with unilateral spatial neglect", Disability and rehabilitation, vol. 27(20), pp. 1235-1244, 2005.

[21] M.S. Cameirão, A.L. Faria, T. Paulino, J. Alves and S. Bermúdez, "The impact of positive , negative and neutral stimuli in a virtual reality cognitive- motor rehabilitation task : a pilot study with stroke patients", J Neuroeng Rehabil., 2016

[22] H. Igo Krebs, N. Hogan, M.L. Aisen and B.T. Volpe, "Robot-aided neurorehabilitation", IEEE Trans Rehabil Eng., vol. 6(1), pp. 75–87, 1998.

[23] M. Gilliaux, T.M. Lejeune, C. Detrembleur, J. Sapin, B. Dehez, C. Selves et al, "Using the robotic device reaplan as a valid, reliable, and sensitive tool to quantify upper limb impairments in stroke patients". J Rehabil Med, vol. 46, pp. 117-125, 2014.

[24] Axinesis SA, Axinesis rehabilitation technologies, available on : <http://www.axinesis.com/> (consulted on October 28th 2016).

[25] S. Dehem, V. Montedoro, M. Edwards, D. Galinski, S. Heins, B. Dehez, G. Stoquart I. Brouwers & T. Lejeune, "Assessment of motor impairments in children with cerebral palsy using a rehabilitation robot and serious game exercise", unpublished

[26] V. Montedoro, S. Dehem, M. Alsamour, D. Galinski, S. Heins, G. Stoquart, B. Dehez, T. Lejeune & M. Edwards "Hemineglect assessment and rehabilitation using a robotic serious game", unpublished

[27] D. Galinski, "Conception et optimisation d'un robot de rééducation neuromotrice du membre supérieur avec compensation active de la gravité", PhD thesis, Université catholique de Louvain, Louvain-La-Neuve, 2014.

[28] J. Sapin and D. Galinski, "Rehabilitation system and method", patent application PCT/EP2016/072676, September 23rd 2016.

[29] F. Rocca, P. H. De Deken, F. Grisard, M. Mancas and B. Gosselin, "Real-time marker-less implicit behavior tracking for user profiling in a TV context. in 28th International Conference on Computer Animation and Social Agents (CASA 2015)", Singapour, 2015.

[30] F. Rocca, M. Mancas, and B. Gosselin, "Head pose estimation by perspective-n-point solution based on 2d markerless face tracking", Intelligent Technologies for Interactive Entertainment, Springer, pp. 67-76, 2014.

[31] E. Murphy-Chutorian and M. M. Trivedi, "Head pose estimation in computer vision: a survey", IEEE transactions on pattern analysis and machine intelligence, 2009.

[32] K. Abe and M. Makikawa, "Spatial setting of visual attention and its appearance in head-movement", IFMBE Proceedings, 2010.

[33] P. Ekman and W. Friesen, "Facial Action Coding System: A technique for the measurement of facial movement", Palo Alto, U.S.: CA: Consulting Psychologists Press, 1978.