# Intensive language-action therapy in virtual reality for a rehabilitation gaming system

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## ABSTRACT

One third of stroke patients suffer from language disorders. These disorders severely impair individuals' communication abilities, which impacts on their quality of life. Recently, the Intensive Language Action Therapy (ILAT) emerged as a novel paradigm for aphasia rehabilitation. ILAT is grounded in three main principles: intense practice, overcoming the learned non-use, and an individualized training. In the present study we designed and developed a VR based language rehabilitation tool by integrating ILAT's object request LAG in RGS, a novel paradigm for the rehabilitation of motor deficits after lesions to the central nervous system. RGS is a gaming environment that provides a multimodal, task specific training in virtual reality scenarios. Its special design consists of an intelligent motion detection system that monitors the users' movements. This allows for an active interaction as well as continuous evaluation of the affected limbs. We addressed the question whether aphasia rehabilitation designed within the VR environment of RGS can be an effective tool. The principal purpose of the initial pilot study was to validate the system and to learn whether a virtual adaptation of the ILAT into RGS can trigger positive changes in the linguistic behavior of Broca's aphasia patients. We report the results of a double-case initial pilot study where one acute and one chronic aphasic patient followed five RGS-ILAT therapy sessions. Before and after the treatment we evaluated their language skills using the Communication Activity Log (CAL) and Western Aphasia Battery (WAB) scales. Results show that the patients learnt how to interact within the VR system. The CAL performance suggests that both patients and their therapist perceived improvements in the communication skills after the therapy. Additionally, the approval and acceptance of the system were high. Based on this initial outcome we will further provide the present RGS-ILAT with substantive technological advancements and evaluate the system to reliably replicate the original ILAT, in order to better understand the potential of the virtual reality based language rehabilitation therapies.

## 1. INTRODUCTION

Stroke is a neurological disease which causes the most common disabling neurological damages (Carter et al, 2012). 35-40% of stroke patients suffer serious language deficits, such as aphasias, which are often accompanied by anxiety, depression or social withdrawal (Elman et al, 2000). Traditional aphasia therapies focus mostly on repeating words, where the complexity of the practiced language gradually changes from less to more frequent. These methods usually do not put emphasis on the importance of an intense practice of language adapted to the personal needs of each patient, within a meaningful context. Alternative treatment and rehabilitation methods are therefore required in order to achieve successful recovery.

Recently, the relation between language, cognition and its neural substrate has shed light onto the composite structure of the language processing and production systems as well as the effective rehabilitation of language deficits caused by stroke (Ozyürek et al, 2007; Pulvermuller, 2005; Gubailovskii et al, 2008). The brain comprises a set of interconnected neural circuits where linguistic, or any other, motor, perceptual or attentional abilities cannot be separated into discrete modules (Carter et al, 2012). Therefore, for a therapy to be effective, in the brain there must be an interaction between linguistic neural system, motor and sensory circuits, memory, planning and monitoring (Kurland et al, 2012). It has been shown that both words and complex sentences, which are semantically related to actions that involve different parts of the body, activate the sensorimotor cortex (Pulvermuller, 2005; Berthier and Pulvermüller, 2011). This observation has led to the hypothesis that sensorimotor circuits provide the cortical basis for language (Pulvermuller, 2005). Accordingly, language processing, both comprehension and production, is physically linked to the action systems. This is consistent with the general view on the tight coupling of sensing and action in the brain (Verschure et al, 2003). Being embedded within the sensorimotor system, language processing is coupled to one's bodily experience, which suggests a novel route for the rehabilitation of language deficits. Indeed, it has been reported that a specific action oriented language training can result in considerable improvements in both language performance and its underlying cerebral activity related to language, in both Wernicke's and Broca's aphasia patients (Pulvermuller, 2005). The research on the reorganization of language related brain areas, which follows rehabilitation, suggests that neural plasticity and reorganization can even result in shifts in language lateralization (Neville et al, 1998). These findings have changed the approach towards the language rehabilitation reinforcing the stimulation of multiple brain regions creating conditions for recovery (Carter et al, 2012). The range and types of language rehabilitation techniques have been further amplified by using a range of technologies including virtual reality tools, which have shown to be successful in treating deficits resulting from stroke (Abad et al, 2013; Cameirão et al, 2007; Cameirão et al, 2010; Cameirão, 2012). In particular, we have shown previously that an approach, which combines mirroring through VR with specific brain-theory based training protocols, or the Rehabilitation Gaming System (RGS), can be highly effective in the rehabilitation of the upper extremities in acute and chronic stroke patients (Cameirão et al, 2007; Cameirão et al, 2010; Cameirão, 2012). Here, we further extend this RGS approach by augmenting it with a VR based version of ILAT. In particular we investigate the question whether RGS-ILAT is effective in treating stroke induced Broca's aphasics (Difrancesco et al, 2012).

### *1.1 ILAT and Broca's Aphasia*

ILAT is a Speech and Language Therapy (SLT) approach that aims at reinforcing the activation of both linguistic and its underlying motor circuits in a systematic and structured way by means of intensive practice and contextualized game scenarios (Pulvermuller, 2005). The therapy focuses on treating Broca's aphasia that results from the lesion to the left frontal cortex (Boo et al, 2011). The syndrome is characterized by disorders in the syntax of language production including motor disorders and agrammatism. Individuals who suffer this type of aphasia are typically not fluent when speaking and often cannot combine words into meaningful sentences (Marshall, 2008). Patients who suffer from Broca's aphasia therefore may benefit from rehabilitation methods that focus on the reinforcement of full sentence production as well as general fluency. Within this context, Pulvermüller et al. emphasize three main premises of ILAT (Difrancesco et al, 2012). The first one is the intensive training (e.g. 3h/week for 2 weeks). Secondly, ILAT exploits the behavioral relevance of the therapeutic context, namely, the embodiment of speech within a communicative, natural, action context. Finally, the authors suggest the use of behavioral techniques such as shaping, modeling and positive reinforcement. Indeed, recent studies show that even patients with severe Broca's aphasia and/or Apraxia of Speech (AOS) can improve when undergoing ILAT (Kurland et al, 2012). In the present study we propose a new rehabilitation scenario that combines ILAT and RGS. We believe that the original ILAT may benefit from its VR implementation, which allows for the implementation of multimodal feedback, and provides wider accessibility.

### *1.2 ILAT Scenario*

There are 3-4 players who take part in the original ILAT session. One of the players is a Speech and Language Therapist (SLT), whose role is to actively monitor the patients, keep track of utterances, model speech and adjust the velocity of the game. The rest of the participants are patients with post-stroke Broca's aphasia. The Original ILAT consists of two types of Language Action Games (LAGs): the object request LAG (see Fig. 1) and the action-planning LAG (Difrancesco et al, 2012). The object request LAG begins when all the participants are given identical sets of cards (from 6 to 12 each). The player who starts the game (player A) selects one card and holds it in his/her hand, so that the other participants cannot see its content. Next, s/he verbally requests the same card from another player (player B). The possible moves that can follow depend on whether the player B owns the requested card. Player B can therefore either follow the request and pass the corresponding card, or reject the request. Further clarification attempts can occur in case of misunderstandings between the players. The goal of the object request LAG is for the player to be the first with no cards left on the table. This can be achieved by either passing or receiving the matching card/s. In the present project we have implemented the object request LAG protocol in RGS by rigorously following its language-action structure.

### *1.3 RGS*

RGS is a novel paradigm for the rehabilitation of motor deficits after lesions to the central nervous system (Cameirão et al, 2010). It is a gaming environment that provides a multimodal, task specific training in virtual reality scenarios (see Fig. 2). Its special design consists of an intelligent motion detection system that monitors the users' movements. This allows for an active interaction as well as continuous evaluation of the affected limbs. The original purpose of the system is to provide a novel rehabilitation tool to treat motor deficits of upper limbs in post stroke patients. RGS deploys a number of scenarios which can be adjusted to the specific needs of the users. That allows for a continuous interaction with the Virtual Environment (VE). The computer-generated world is viewed form the first person's perspective, and all the events that happen within the VR are under real-time user control. RGS has proved to be successful in the number of clinical trials (Cameirão et al, 2007; Cameirão et al, 2010; Cameirão, 2012). We see RGS as an example of the novel field of science-based medicine where interventions are based on causal theories of brain and behavior. Its tracking system, individualized training and reinforced visual feedback (Cameirão et al, 2010) allow for the integration of ILAT.

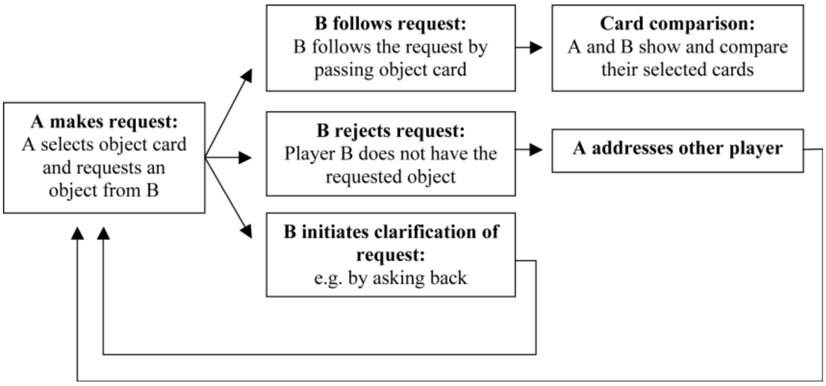


**Figure 1** *Object Request LAG. The diagram presents possible decisions that can be make during the game (Difrancesco et al, 2012).*

The aim of the present study is therefore to extend the range of the rehabilitation focus that RGS originally provides to the rehabilitation of Broca's aphasics and to learn about the potential benefits of VR based language rehabilitation techniques.

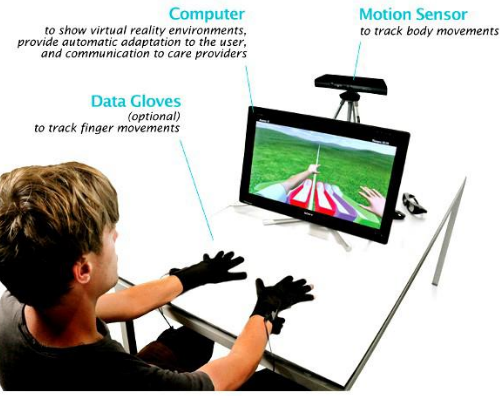


**Figure 2** *Rehabilitation Gaming System (RGS) setup. The subject works with his/her arms on a cut-out table facing a computer screen. The movements of the arms are tracked by the Kinect. The captured movements are mapped in real time to the movements of two virtual arms that mimic the movements of the user on the display.*

## 2. METHODS

In the present study we built a VR version of ILAT using the Rehabilitation Gaming System (RGS) in order to investigate the potential of VR based language rehabilitation methods. We conducted a double-case initial pilot study in order to test the system. Additionally, we evaluated the patients' language skills before and after the intervention.

### *2.1 System Description*

The software of the present system is integrated within the environment of the RGS. The experimental setup consists of two standard personal computers (Vaio L Series All-in-One PC, Tokyo, Japan) with a 24" (61cm) Full HD touch screen, two motion sensing input devices (Xbox Kinect, Seattle, USA) and a networking system.

### *2.2 Virtual Scenario*

The virtual environment was designed and developed using Unity3D game engine (Unity Technologies, San Francisco, USA). The motion tracking system (Xbox Kinect, Seattle, USA) captures and maps the movements of the users' real arms onto those of the avatars. Consequently, during every session all users can continuously observe the movements of both their virtual arms' and those of the opponent/s.

The training scenario takes place in a shared virtual room, to which the players connect via a local network. Each of the users can see three objects placed on the virtual table (see Fig. 3). In the beginning of the game one of the players is indicated to start the game. Consistent with the original request LAG scenario, his/her task is to first choose one object from those available on the table and then verbally request the same object from the opponent. In case of a successful communication the opponent should understand the request and pass the corresponding object. Such a sequence of events accounts for a successful communicative interaction, for which both players get a point.

The interaction with the virtual objects is based on delays. Thus in order to select or to pass an object, depending on the turn, players needs to place one hand over that object for 2-3 seconds. If the passed object matches the requested object they both appear in the basket which belongs to the player who started the round. At the same time the patients' scores increase, two new objects appear on the table, and the turn changes. After such sequence of events, the second player is required to choose and request an object. The selection of objects is indicated by a short animation and a corresponding sound (e.g. a piano melody, in case of the piano; heartbeat in case of the heart; or footsteps in case of a shoe). We decided to incorporate sounds in order to provide additional associative cues assisting in recall and to help the patients in retrieving the words. All the objects light up whenever they are being pointed to. The purpose of the visual feedback is to enhance the salience of relevant objects and to ease the interaction with the system. Additionally, during the period of object selection an animated wall appears in the middle of the table. This prevents the opponent from seeing not only what object is being selected, but also possible indicative gestures. As soon as an object is selected, the wall disappears and the players can see the opponent's virtual avatar. Instructive headings such as "It's Your Turn", "Well Done", "Try Again", or "Game Over" are displayed every time an event in the game changes (change of turn, collection of an object, failure, end of the game etc.). Since the system was tested in the Hospital Esperanza in Barcelona, Spain, the User Interface (UI) is written in Spanish.


**Figure 3** *The virtual scenario of Intensive Language Action Therapy in Virtual Reality from the first person perspective. The virtual objects are placed on the virtual table as well as in the baskets on the sides. The opponent is sitting at the other side of the table.*

### *2.3 Setup*

All the phases of the study took place in the Hospital de la Esperanza, in Barcelona, Spain. In a speech therapy ward, two computers were placed in front of each other so that the players could be close enough to efficiently communicate with one another. The seats were placed so that the patients could not see the opponent's real hands while selecting the virtual objects.

### *2.4 Protocol*

Each of the patients participated in three phases of the study: a system evaluation phase, a training phase and an intervention phase. Both patients completed excerpts from Western Aphasia Battery (WAB) before and after the intervention, to be later analyzed. WAB is a standardized measure commonly used to assess the function of language which includes: Spontaneous speech, Auditory verbal comprehension and recognition, Sequential commands, Repetitions, Object naming, Word fluency Sentence completion Responsive speech andReading comprehension of sentences and commands. After completing the evaluation, patients participated in twentyminutes training phase. During this phase a healthy player and a speech therapist were performing the virtual task. Meanwhile, the crucial parts of the game were being explained: system's startup, gaming rules and objectives. The next day the training phase took place (20 minutes). Two patients were asked to play against each other, and later they were interviewed about the usability of the system. Based on the foregoing evaluation slight changes were immediately incorporated with regards to the objects displacement within the VE. As the pre-phase period was completed the patients started the intervention which lasted for five days. Each of the patients played against the healthy player in the presence of a speech therapist. The role of both the healthy player and the therapist was to actively monitor the patients, keep track of their utterances, and adjust the velocity of the game, while the record of patients' successes and failures was stored by the system (RGS). Date, the session number, time, utterance type, quantity of failures, as well as scores from every session were continuously registered for further analysis. Moreover, all the sessions were recorded to extract Reaction Times (RTs) and to later analyze the data gathered from every session as suggested by the original study (Difrancesco et al, 2012). RTs were measured from the moment when the patient selected the object to be requested from his/her opponent to when s/he fully uttered the correct name of the corresponding object. The game events, which included failures, names of the indicated objects, points, and the acts of selecting and passing the objects were continuously logged and stored after every session.

In order to further measure the potential change on a communication rating scale, the two patients as well as the speech therapist completed the Communicative Activity Log (CAL) before and after the intervention (Pulvermuller, 2005). CAL is a qualitative tool to measure patients' amount and quality of communication in everyday life. CALs' questions regarded the frequency with which patients would communicate in everyday life situations such as shopping, talking on the phone, answering/asking questions, and more. The questionnaire consisted of 18 questions to be answered on a 6-point Likert scale. The scale ranged from 'never' to 'very frequently'. Additionally, after the period of the intervention, both patients were asked to complete a 16-item System Validation Questionnaire (SVQ) presented on a 7-point Likert scale.

### *2.5 Subjects*

Two post- left hemispheric stroke patients (See Table. 1), C.G.G. (man, aged 75, right- handed) and T.H. (woman, aged 52, left- handed) participated in the three experimental phases. Both subjects had normal vision and suffered from post stroke Broca's aphasia. For the purpose of the present pilot study the exclusion criteria only partially followed the protocol introduced by Pulvermüller (Difrancesco et al, 2012). We therefore first made sure that the two subjects did not suffer chronic heart disease or any related illnesses which makes the participation difficult. Secondly, the subjects could not suffer from any disease which would prevent from understanding the instructions of both the scenario of the LAGs and the interaction with the system itself. Therefore, the presence of impairments which affect perception as well as motor and neuropsychological functions such as deficits in motor planning (apraxia), vision, learning, memory or attention were accordingly evaluated and excluded.

**Table 1**. *Clinical data about the patients who participated in the study (C.G.G. and T.H.)*

| Patient | Native language | Months after onset | Origin of the stroke | Lesion Site | Type of aphasia | Severity of aphasia |
|---|---|---|---|---|---|---|
| C.G.G. | Spanish | 15 | Hemorrh-agic | Left frontote-mporal | Non-fluent | Very severe |
| T.H. | Bengali/ English | 1 | Atheroth-rombotic ischemic | Left middle cerebral artery | Non-fluent | Moderate |

## 3. RESULTS

The present study was designed to investigate whether VR based language rehabilitation systems can trigger positive changes in the communicative behavior of post stroke Broca's aphasia patients. We approach our aim by designing and testing ILAT in RGS system. Together the results presented here reinforce the notion that such novel techniques should be further investigated to better understand their efficiency and usability.

### *3.1 Clinical evaluations: CAL and WAB*

Results from CAL show improvements in all the evaluations in both patients (see Fig. 4). From the overall score of 90 points, the speech therapist assigned 43 points before and 47 points after the intervention to C.G.G. which means that the score increased by 9.3%. An increase was also reported in case of T.H. The score given by the therapist to T.H. prior to the intervention equaled to 19 points, and increased to 32 points after the treatment. The score increased by 68.4% after the intervention. Improved results from CAL were also observed in patients' self-ratings after the intervention. The score of C.G.G. increased by 14.7%, and the score of increased by T.H. by 27.9%.

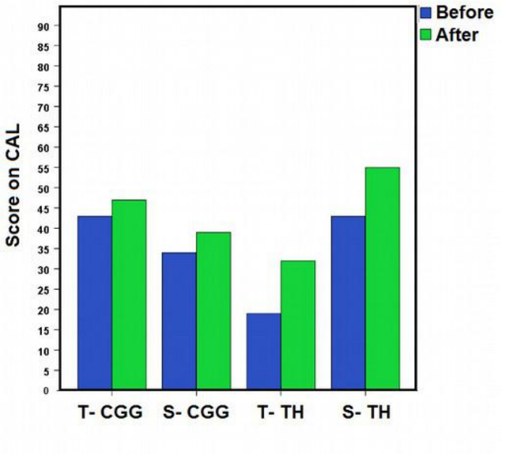


**Figure 4.** *Pre- and post- results from CAL for CGG and TH. Blue bar: results from the pre-evaluation, green bar: post-evaluation. T-CGG: therapist's evaluation of CGG T-T.H.: therapist's evaluation of T.H., S-CGG: self-evaluation of CGG, T-TH: self-evaluation of TH.*

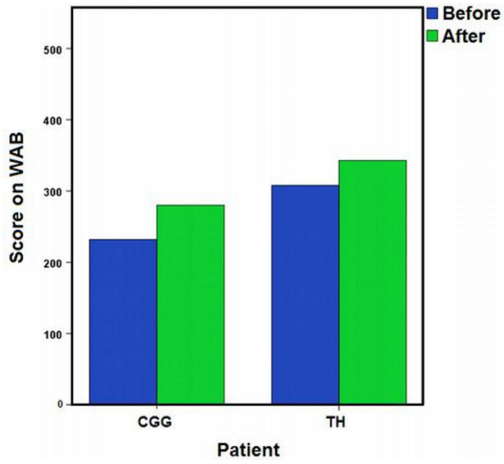


**Figure 5.** *Results from pre- and post- WAB for C.G.G. and T.H. Blue bar: pre-evaluation score, green bar: post-evaluation score.*

The patients were asked to complete excerpts from the Western Aphasia Battery (WAB) before and after the intervention (see Protocol). The excerpts included the evaluation of "Spontaneous Speech" (20 points), "Auditory Verbal Comprehension" (200 points), "Repetition" (100 points), "Naming" (110 points) and "Reading" (100 points). Accordingly, the maximum score which could be achieved equaled 530 points. Both patients scored higher in the post evaluation than in the pre-test (see Fig. 5). Results from WAB prior to the intervention show an increase for C.G.G. and T.H. by 20.7% and 11.4% respectively. C.G.G. scored 232 points and his result increased to 280 points after the intervention sessions. T.H. had 308 and 343 points before and after the intervention.

### *3.2 Data from the System*

The mean RTs from every session was reported and compared throughout the five days of the intervention for C.G.G and T.H. (see Fig. 6). The reported data shows that the RT of C.G.G. decreased from 22 seconds (first day) to 10.75 seconds (fifth day), that is, by 51.1%. Similarly, in case of T.H. the RT also decreased from 22 (first day) seconds to 6.3 seconds (fifth day), that is, in 71.4%.

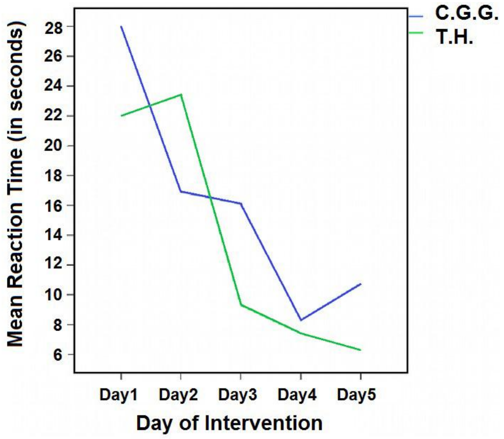


**Figure 7.** *The total scores obtained during every session by the two patients. Green: the score of T.H.; blue: the score of C.G.G.*

We define a failure as an event when a patient passes an object different than the one which was requested by the opponent. We believe that such behavior is caused by either confluent interaction with the system or a misunderstanding of the requested object. Over the period of the intervention the number of FTs in case of C.G.G. decreased by 62.5% and in case of T.H. it decreased by 55% (see Fig. 8).

We considered the amount of objects selected representative for the fluent interaction with the system. In both patients the quantity of objects selected per session increased. C.G.G. selected 24 objects during the last session which was 3.8 times more than during the first day (see Fig. 9). The number of selected objects in case of T.H. was 2.2 times higher on the last day of the intervention. The patient selected 9 objects during the first and 20 objects during the last session.

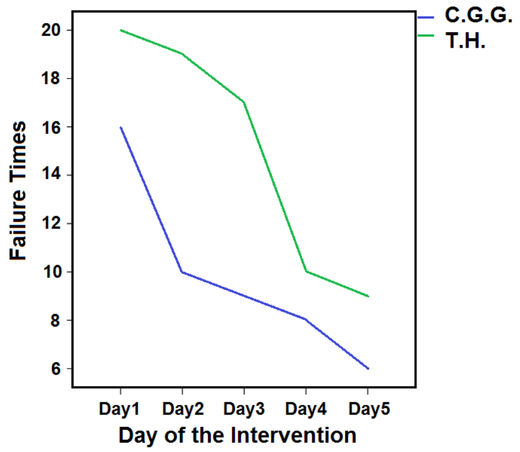


**Figure 8.** *The number of Failure Times in every day of the intervention for the two patients.Failure times: the times when a patient gave an object different the one requested. Green: the number of FTs for T.H.; blue: the number of FTs for C.G.G.*

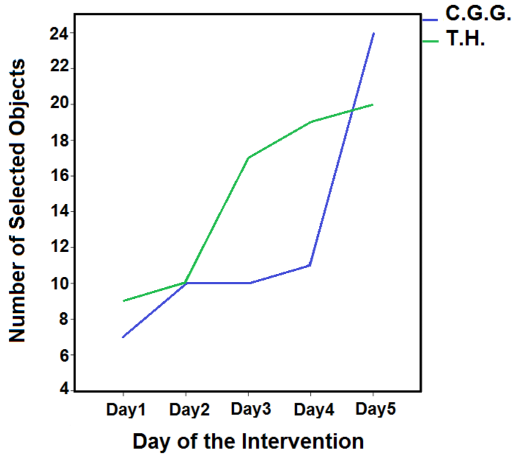


**Figure 9.** *The number of objects selected during every session by the two patients. Green the number of objects selected by T.H; blue: the number of objects selected by C.G.G.*

The System Evaluation Questionnaire was distributed after the period of the intervention. It consisted of 16 questions which regarded patients' opinion on the system, its usability, functionality, design. The patients were to declare to which extend they agreed with a given statement on a 7-point Likert scale (see Protocol). The maximum score was 112 points from which C.G.G. scored 89 (79.5%) and T.H. 109 points (97.3%) respectively.

## 4. CONCLUSIONS AND DISCUSSION

In the present study we designed and developed a VR based language rehabilitation tool by integrating ILAT's request LAG to the RGS, and tested the system. The principal purpose of the initial pilot study was to validate the system and to learn whether a virtual adaptation of the Intensive Language Action Therapy into RGS can trigger positive changes in the linguistic behavior of Broca's aphasia patients. The gathered results suggest that both subjects learnt how to interact with the initial model of RGS-ILAT and they were satisfied with the system. Since Broca's aphasia patients do not suffer comprehension deficits (LaPointe, 1990), FTs were mainly associated with the fluency and facility with which the users interacted with the system. After the intervention, the FTs in case of both C.G.G. and T.H. decreased. These results show that both patients got gradually acquainted with the system. The patients could interact more easily within the VR scenario, manipulate the objects and, as a consequence, play with more fluency. Additionally, the results from the SEQ were highly promising. C.G.G. and T.H. evaluated the system for 89 (79.5%) and 109 points (97.3%) respectively. The assessed attributes included facility, comprehensibility, fluency, effectiveness, the range of practiced vocabulary, entertainment and more. The questionnaire was also testing whether the patients felt entertained, motivated and satisfied while interacting with the system. To the statement "I would like to have the system at home" both patients strongly agreed. No further improvements were suggested by the participants. After having analyzed the overall results from the study, it can be argued that the approval and acceptance of the system was high. The reported positive changes in pre and post both WAB and LAG suggest that C.G.G. and T.H. improved their core language skills as well as communication skills. Since the RTs decreased in case of both patients over the period of the therapy, it may be concluded that both patients improved their language behavior within the 5-day intervention. Moreover, in both patients, the number of scored points in the game rose or remained unchanged through the sessions, which accounts for the increase in fluency.

One of the limitations of the present study was the lack of implementation of a precise hand-tracking system, which would allow for the simultaneous use of language and motor actions (e.g. holding the card while requesting the represented object), highly encouraged by ILAT. Moreover, we have not yet implemented the action-planning LAG, as suggested by the original protocol (Difrancesco et al, 2012). To reliably compare the RGS-ILAT with the original therapy we need to include increasing number of objects that would amplify the range of the lexicon used, by introducing words of different frequency, minimal pairs, semantic categories, and multi-feature objects. Although present results might have been additionally influenced by other factors than the intervention, such as the natural recovery processes, motivation, or personal attitude, the positive outcome encourages us to further develop and test the system. Since only two subjects participated in the study and the period of the intervention was limited to five days, we are not yet able to compare our results to those of the original therapy To fully validate the RGS-ILAT system we will therefore conduct a follow-up study with an increased number of subjects and a higher intensity of the intervention, to be able to compare our results with those of a similar non-VR, and investigate whether the present system is more, less or equally effective. This will also shed the light on whether the positive rating of the proposed therapy is influenced by the novelty effect. Based on previously discussed results, the gathered feedback, as well as limitations we will provide the present ILAT-RGS with substantive technological advancements and evaluate the system in order to better understand the potential of the virtual reality based language rehabilitation therapies. The reason for proceeding with the enhancements of the RGS-ILAT system is to provide aphasia patients with an effective language rehabilitation tool which could be utilized as an additional reinforcement to the conventional therapy, or its continuation.

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