# New Developments in the Gesture Therapy Platform
## *Past, Present and Future of our Research*

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Abstract: Gesture Therapy (GT) is a virtual rehabilitation tool for the upper arm that has been in the making since 2008, and by now has successfully demonstrated therapeutic validity in two small clinical trials for stroke survivors. During this time, our group has published a number of contributions regarding different aspects of this platform ranging from hardware controllers to artificial intelligence algorithms guiding different aspects of the serious games behaviour, and clinical trial data from observable improvements in dexterity to changes in functional neuroreorganization. As we continue our research efforts in virtual rehabilitation and realising this knowledge in the GT platform, this paper presents an overview of the latest developments as well as a roadmap for future research.

## 1 INTRODUCTION

Virtual rehabilitation (VR) (Levin, 2011) is becoming an accepted alternative therapy, as evidence slowly piles up suggesting benefits comparable to traditional alternatives (Parsons et al., 2009; Snider et al., 2010; Sucar et al., 2013). Yet, the full potential has not been unleashed and evidence is still insufficient to draw conclusions (Laver et al., 2011). Although by now a few dozens of VR platforms exist most of them are still confined to research labs. In most if not all cases, VR is administered by means of serious games, which are used for proposing, delivering, monitoring and evaluating the therapeutic exercises in an engaging and safe virtual environment.

VR platforms capable of assisting rehabilitation must support rehabilitation principles: promote repetition, task oriented training, appropriate feedback and a motivating environment (Holden, 2005). As such, development of these platforms is an artcraft requiring to harmonize complex elements and processes. Work in this area is highly multidisciplinary involving both technical input including hardware and electronics, software engineering, human-computer interaction and virtual reality, and of course, clinical input; rehabilitatory, neurological and psychological. Figure 1 illustrates this multidisciplinary environment.

Since 2008, our group has been proposing contributions in VR research across the many subdomains

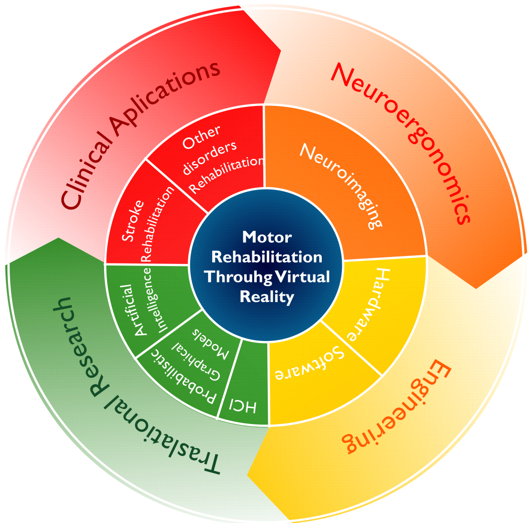


Figure 1: Developing a VR platform requires a multidisciplinary work.


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of the field. From engineering to clinical applications, and from traslational research to neuroergonomics; we have contributed with controllers for arm and finger exercising (Sucar et al., 2013), different artificial intelligence based adaptation algorithms to make the therapy adjusts to the changing needs of the patient as well as learning instructions from the therapist (Ávila-Sansores et al., 2013), a compensation detection algorithm that can ensure trunk compensation is avoided (Sucar et al., 2009), an initial set of necessary design criteria for serious games development in VR (Oropeza Salas, 2012), a set of serious games formulated capitalizing on these design principles (Oropeza Salas, 2012; Sucar et al., 2013), clinical evidence of the validity of the technique as compared to occupational therapy (Sucar et al., 2010), and an initial picture of how the brain responds to VR in terms of functional reorganization strategies (Orihuela-Espina et al., 2013). In parallel to this research efforts, we have been developing the platform Gesture Therapy (GT) (Sucar et al., 2010; Sucar et al., 2013), the practical realization of all the knowledge we have been gathering. Of course, the field of neurorehabilitation is still in its infancy with rehabilitation treatments having a disappointingly modest effect on impairment (Krakauer et al., 2012) and thus the journey has just begun.

This paper presents some of the latest features added to the GT platform; two more new games, a brand new interface inspired in the *home paradigm* that serious games should reflect functional tasks of daily living, and the new user profiling capabilities. The goal pursued by the incorporation of these features is facilitating translational research e.g. making possible point-of-care patient application, as well as enabling more ecological testing environments e.g. the patient's home. This paper also presents preliminary steps taken to demonstrate (i) that the same platform can be shared across different medical conditions responsible of upper limb impairment, in particular from stroke to cerebral palsy, and (ii) that serious games originally developed for VR can also be useful beyond their original intended domain and can further help to ease cognitive decline. Finally, we also want to use this paper to sketch some of the work ahead.

# 2 GESTURE THERAPY (GT)

GT is a VR platform for the motor rehabilitation of the impaired upper limb. GT was conceived for home usage and consequently exhibits low cost. The platform has two major hardware elements pictured in Figure 2; a computer with a webcam and a controller

Figure 2: The Gesture Therapy platform. The user interacts with the games by means of the gripper.

or gripper. This specifically designed controller facilitates arm and hand tracking and incorporates a pressure sensor for flexion of fingers. The solution mixes hardware and software elements in an integrated platform with five major modules schematically depicted in Figure 3.

- The **physical system** encompasses the hardware platform incorporating a computer, a webcam for tracking and specifically designed controllers e.g. a handgrip.
- The monocular **tracking system** is the software responsible for tracking the arm surrogated by the controller's ball. Tracking is based on a particle filter using colour and texture and is capable of estimating depth.
- The **simulated environment** presents the games and interacts with the user. It is also responsible for providing visual and auditory feedback.
- The **trunk compensation detector** controls the platform response to detected compensatory movements with the trunk by the patients. It capitalizes on Haar features and a cascade of classifiers.
- Finally, the **adaptation module** adjusts the 3D space in which the exercise occurs intra-game in real time tailoring the challenge to the progress of the patient. The underlying algorithm exploits sophisticated artificial intelligence decision models.

Further details of the platform status *before* this publication can be found in (Sucar et al., 2013). This paper presents the *new* modifications and enhancements made to the platform since then.

## 2.1 Clinical Trials

So far, we have carried out two clinical trials, both in Mexico at the National Institute of Neurology and Neurosurgery and focused on stroke patients.

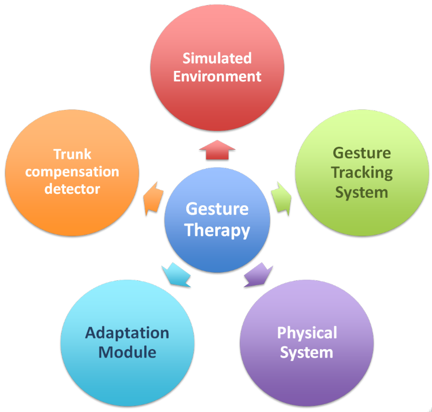


Figure 3: Conceptual modules of the GT platform.

- **Clinical Trial I.** 42 patients were randomised to two groups; a control group of 22 patients received 21 sessions of 60 minutes of occupational therapy, and the intervention group received an equal amount of virtual reality based rehabilitation therapy with Gesture Therapy. Both groups presented a significant improvement in terms of motor recovery assessed using Fugl-Meyer (Fugl-Meyer et al., 1975) and Motricity Index (Demeurisse et al., 1980) scales (Wilcoxon; $p < 0.05$). Differences in improvement between the therapies were not significant. Motivation as evaluated with the Intrinsic Motivation Inventory (IMI) (McAuley et al., 1989) was stronger among patients treated with Gesture Therapy. Patients treated with GT demonstrated greater interest and claimed higher importance and utility. Full details can be found in (Sucar et al., 2010).
- **Clinical Trial II.** 28 subjects were allocated to 3 groups; group one received 20 sessions of 45 minutes of occupational therapy, whilst groups 2 and 3 received equal amount of Gesture Therapy, with the third group further undergoing neuroscans for exploration of the neural underpinnings responsible for behavioural improvements. Both therapies exhibited significant motor improvements as evaluated with Fugl-Meyer and Motricity Index (Mann-Whitney U; $p < 0.05$), and differences in improvements between them were not significant. GT matched the control improvements for hand, wrist and elbow. Prefrontal cortex and cerebellar activity were found to be the driving forces of the recovery associated with Gesture Therapy. We found that those with stronger disabilities appear to benefit the most from this paradigm (Orihuela-Espina et al., 2013).

# 3 NEW TECHNICAL FEATURES FOR GT

## 3.1 New Games

Two new games have been added to the game set of GT that until now had 3 games. The new games attend the obvious necessity for a larger variety of tasks to reduce boredom caused by excessive repetition of games in a game set. Also by diversifying the tasks the enlarged game set might appeal to other patients. Screenshots of the games are pictured in Figure 4.

- **Spiders on the Wall.** In this game the patient armed with a hammer as an unlikely tool for killing spiders has to combat these annoying creatures creeping up the wall. The distance at which the next spider appears is dictated by the challenge level at play which in turn is governed by the adaptation policy, optimally designed to ensure matching user progress. The game favours bidirectional movements including elevation/depression and abduction/adduction.
- **Fungi in the Sink.** Cleaning time. The sink is dirty and the patient has to clean the mold stains. Similarly, the distance at which the next mold stain appears is dictated by the challenge level again ruled by the adaptation module. The game also favours bidirectional movements including elevation/depression and abduction/adduction.

Similarly to previous games in GT, these have been developed using the Torque game engine and communicate with the rest of the platform by means of a shared memory address. They both incorporate visual and audio feedback and this is given in the two classical flavours; *knowledge of performance* and *knowledge of results* (Deutsch et al., 2008). These games still have to face clinical trialling.

## 3.2 New Interface

The *home paradigm* is our conceptualization that exercises promoted by the serious games should mimic natural movements inspired in functional tasks of daily living mostly occurring in the home environment, thus stressing the rehabilitation goal of making the patient self-sufficient (at home). Although the paradigm has been integral to GT for a while now (Oropeza Salas, 2012), it has not been until recently that we have developed a brand new interface that really exploits this paradigm. The new interface integrates the menus to be navigated by the patient within different views of a house from outside and from the inside as illustrated in Figure 5. A lighting effect

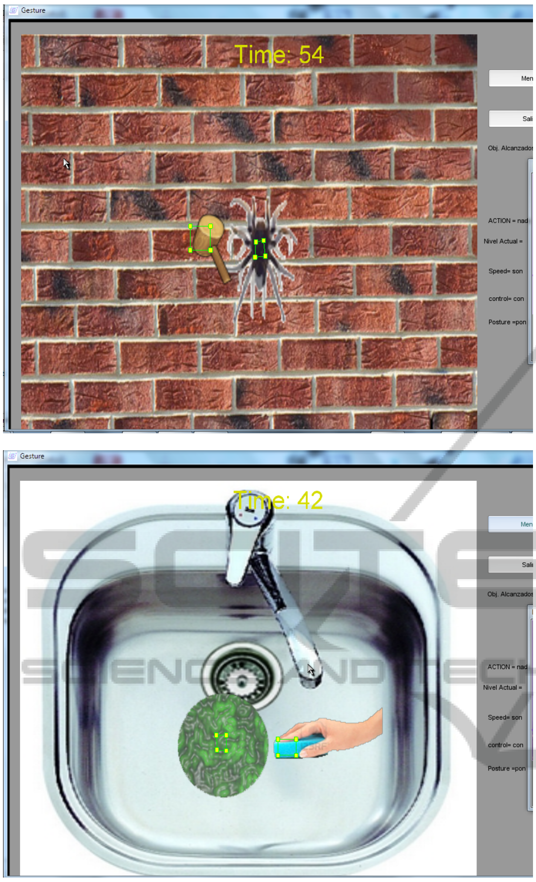


Figure 4: Screenshots of the two new games added to GT's game set.

highlights buttons as the user crosses above them with the cursor. Currently, navigation through the interface is made by means of the mouse, but we expect the GT gripper to be also an optional input device for the interface very soon, thus further facilitating the use by the impaired person without help from thirds.

### 3.3 User Profiling Capabilities

User profiling refers to all the managerial capabilities to track patients and physicians use of the system, as well as the therapy compliance of the former and the clinical annotations of the latter. We have now enriched GT with user profiling capabilities, a necessary addition for regular use whether at home or in health institutions. The user profiling capabilities of GT conform a new module (to add to those in Figure 3) that tracks all activity occurring in an instance of GT.

The database is implemented in postgreSQL and permits tracking of user activity. From the patient point of view it tracks times spent on the therapy, and in each particular game individually. It further keeps track of the traces of the user avatar at all times

Figure 5: The new interface inspired in the *home paradigm*. Top: Different elements of the facade of the house (i.e. windows) disguise the main menu. Bottom: The house interior permits access to the different games in different rooms highlighting the relation between the exercise and the functional task associated.



and records timestamps and performances associated. Therapies can be delivered following game selection by the therapist or a pre-dictated plan. The therapist can add clinical annotations to every session played by the patient. The Entity-Relation diagram of the database is shown in Figure 6.

## 4 CLINICAL EXPLORATION BEYOND STROKE

### 4.1 Extension to other Motor Impairing Conditions: Cerebral Palsy

Because of the large prevalence and incidence of stroke (Roger et al., 2012), GT was originally developed focused on these patients. However, as the main principles of motor rehabilitation are shared with other motor impairing medical conditions, it is likely that a platform developed for stroke would also be suitable for treating the rehabilitation process of these other conditions. In this sense, we have already started a clinical trial to test the feasibility of using GT in children with cerebral palsy. However, as the game set of GT was thought for adults, we have temporally borrowed games from the Armeo system (Hocoma, 2013); an strategy that we already used in the past before GT had its initial game set.

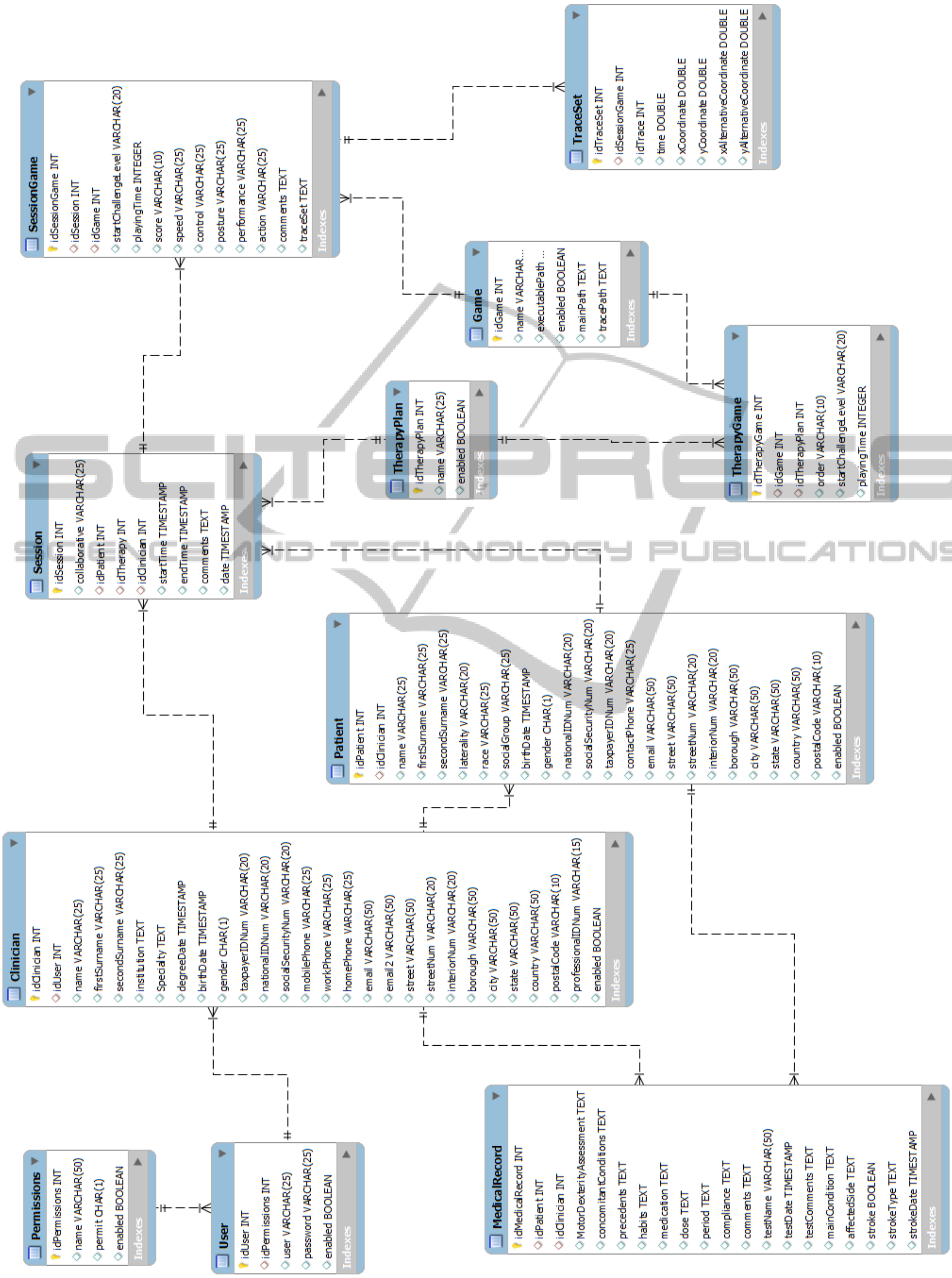


Figure 6: The diagram representing the database supporting the user profiling capabilities.

So far data from 14 patients of palsy have been collected from two groups following a between groups pre-post design; a control group following an occupational therapy and an intervention group that has been administered Gesture Therapy. Motor dexterity improvements have been measured by means of Fugl-Meyer scale (Fugl-Meyer et al., 1975) measured prior to therapy onset and after therapy ends. Intermediate results so far are illustrated in Figure 7. A patient of palsy using GT during the most recent trial is shown in Figure 8.

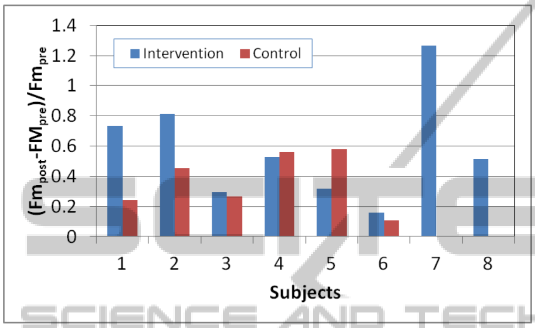


Figure 7: Normalised improvement achieved by the patients in the ongoing clinical trial. Pairing of bars is only for illustrative purposes, but it is not meant to represent the experimental design (between groups). Large benefits can be appreciated in those patients allocated to the intervention group.

Figure 8: A patient of palsy using GT during the most recent trial.

### 4.2 Extension to other Medical Domains: Cognitive Decline

A current trend in VR is exploiting commercially available platforms such as the Wii, the Xbox, the PlayStation or the Kinect to reduce costs and afford faster developing times. Off-the-shelf game sets for these platforms hardly ever are suited for rehabilitation and may lack essential components for ensuring therapeutic effectiveness. An unconventional alternative might be to bridge domains, and reutilize serious games out of their original intended context. The hypothesis is that serious games specifically designed for a certain purpose can escape their realm to be used in other more or less related purposes.

In this sense, we are evaluating the appealing of virtual games originally developed for motor rehabilitation in GT, to be used for enhancing cognitive stimulation of older adults (Morán et al., 2013).

We have chosen cognitive stimulation as a target application for exporting virtual rehabilitation games because the population affected by cognitive decline, i.e. elders, is also the population most affected by stroke; the original target population of GT. The selection of this sufficiently close domain can boost the chances of the exported games to be successful in their new domain; yet, the new functional requirements in the new domain (cognitive stimulation) are different enough from the original domain (virtual rehabilitation) to represent a considerable challenge in the migration.



Towards this end we conducted a usability evaluation of GT as a cognitive stimulation tool with 32 elders from a local municipal third-age support group. Participants were exposed to a subset of the games currently available from the GT platform (steak cooking, window cleaning and fly killer). The elderly were asked to evaluate the platform in terms of perceived usefulness, ease of use and user experience. The main goal was to assess GT's usability aspects as a borrowed platform from the rehabilitation domain.

Elders were introduced to the use of the tool (2-minute demo), later they were allowed to freely explore its use to familiarize with it and solve any doubts regarding its use (3-minute training session), and then they were allowed to play a complete session with each of the three games (15-minute play session in total). Finally, the elders answered an on-exit questionnaire regarding their perception on the use of the tool using a set of TAM-based items (Venkatesh and Davis, 2000) and open questions.

Results from the analysis of the TAM-based items support that elders perceived the GT platform as a useful (93.75/100), easy to use (93.75/100) and pleasurable to use (91.66/100) cognitive stimulation tool. However, results from the open questions data provide evidence about elders considering the proposed activities (games) as being entry level cognitive stimulation activities, and recommended to include additional more challenging activities such as puzzles, memory games or simple math problems.

These results suggest that the transfer of games across realms could be, in some cases, a feasible enterprise but their effectiveness and usability may be compromised, thus demanding small adaptations. This is encouraging as small adaptations might be less costly and faster to perform than starting new games from scratch.

# 5 ROADMAP FOR RESEARCH ASSOCIATED WITH GT

During this journey GT has become a solid piece of research in virtual rehabilitation with contributions in many aspects of the domain. Yet, research continues at our laboratory. These are a few of the efforts we plan to make in the near future:

- **Games Design Criteria.** The design criteria taxonomy in (Oropeza Salas, 2012) is a naive effort. Encompassing the rehabilitation goals is arduous, but a few game design criteria are already springing for facilitating the development of rehabilitatory serious games e.g. (Flores et al., 2008), an effort which is so far uncoordinated. It is desirable to establish a framework of serious game design criteria and guidelines for virtual reality rehabilitation, and identifying critical elements that make a game an effective tool for rehabilitation. We aim to demonstrate that by better understanding the necessities of rehabilitation games, specific aspects of the development process of serious games for rehabilitation can be streamlined, thus speeding up the development of platforms for supporting virtual reality based therapies.
- **Transfer of Knowledge.** The question of how virtual practice translates to the real world is not new (Holden, 2005), yet remains largely unexplored. The overlap between the real and the virtual task must be understood to optimize or facilitate transfer. It is not sufficient simply to demonstrate that training does transfer in a given situation; rather, it is crucial to identify whether a specific skill is being transferred (Sveistrup, 2004). We believe it is critical to investigate indispensable elements that make a serious game an effective tool for rehabilitation, with special emphasis on transfer of knowledge from the virtual to the real world and identifying game elements that increase adherence to the games and by extension to the therapy. Additionally, this may reduce the excessive reliance on premature clinical trials.
- **Functional Reorganization of the Brain.** Krakauker got it right (Krakauer et al., 2012); training of compensatory strategies have minimal impact on impairment. Current understanding of motor learning and brain plasticity has to be a primary research direction. Our only study so far in this direction (Orihuela-Espina et al., 2013) was just an initial step, and was limited by the enforced imagery-based task imposed by the fMRI neuroimaging modality. We believe that employing other neuroimaging techniques such as diffuse optical neuroimaging (Villringer and Chance, 1997) will permit us to interrogate the brain with higher ecological validity, even if that means sacrificing some spatial resolution.

# 6 CONCLUSIONS

This paper has summarised our current research efforts in the different areas of VR, and in particular how these efforts are being coordinated around the GT platform. By enlarging our gameset, the new games will give patients more variability and we expect this to result in higher motivation and adherence to therapy. The new interface makes the platform more user friendly, dropping the need for a researcher or therapist trained in the platform to be present at all times. In this sense, installation and application launch are now trivial, software is all integrated in a single executable (previously the tracking and games have to be launched separately), and menu navigation is expected to be more natural. Also, the new user profiling capabilities was a necessary step before more ecologically aggressive trials could be attempted opening the door for releasing the platform to more rehabilitation wards and ultimately, the patient's home without direct or on-site clinical supervision. Efforts are being also made to extrapolate the virtual paradigm of GT beyond stroke. First steps involve extension to other motor impairing conditions (e.g. palsy) and other less similar medical domains (e.g. cognitive decline). Preliminary results in both directions are promising. Finally, we have also reflected about near future research that we think might make an impact on VR. We look forward to keep advancing knowledge that can consolidate VR as a cutting edge alternative for motor rehabilitation and recovery from impairment.

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