Neuro-physical rehabilitation by means of novel touch technologies

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Abstract. In this work we show the results of a collaboration between an engineering department and a rehabilitation hospital in using innovative touch interfaces properly designed for both neuro-cognitive and physical rehabilitation. The novel touch interface measures also force so as to enable dexterity training through ‘direct’ manipulation of virtual objects in 3D. Two dimensions via the touch screen, the third by the force channel. We believe that this tool could increase the degree of effectiveness of traditional rehabilitation treatments thanks to its capability to merge physical and cognitive rehabilitation. Furthermore the exergames implemented allow an easy personalization of the exercise structure and difficulty level. The rehabilitator has at disposal tools to design the interface and the exercise structure personalised to the patient kind and level of disability. The effectiveness of the FP technology compared to more traditional methods of rehabilitation will be measured according to specific parameters observed in an experimental group, compared with a control group.

Keywords. Serious games, touch systems, cognitive rehabilitation, physical rehabilitation.

Introduction

In recent years there has been a significant increase in the research for new means of evaluation and neuropsychological rehabilitation [25]. The primary objective of neurocognitive rehabilitation is the recovery of autonomy in the performance of daily activities (social and work), interpersonal relationships, and more generally in increasing the quality of life of the patient. It then becomes crucial to develop new trainings and rehabilitation tools for clinical practice, counting on the help of new technologies. For this purpose serious games for health were developed including psychological therapy, cognitive training, physical rehabilitation, as well as exergaming - games used as a form of exercise. The benefits of using VR technology for rehabilitation have been the subject of many studies [1]. Several outcomes demonstrate that people with disabilities are capable of motor learning within virtual environments and movements learned in VR transfer to real world equivalent motor tasks, and can even generalize to other untrained tasks [2]. There is evidence that
proprioceptive and exteroceptive feedback, associated with the execution of skilled tasks, induces brain changes at cellular and synaptic level [15,23]. Learning new skills is associated with structural changes in specific cortical areas involved [16]. Motor skills and cognitive skills can be seen as complementary [14]. For a patient with severe brain injury, the increased levels of autonomy must in fact provide for a modification of the architecture of the cerebral structures of both the cognitive and the physical channel [17]. It must be considered that the increase in cognitive skills increases the ability to develop motor strategies. On the other hand, the improvement of motor skills increases the Brain Derived Neurotrophic Factor (BDNF), a neurotrophin in the hippocampus and frontal cortex which plays a fundamental role in the growth, differentiation, and maintenance of neuronal matter. It is a fact that energy homeostasis is fundamental for the survival of both the cell and the organism [20,21].

Accumulated evidence indicates that mechanisms of energy metabolism play a key role in mediating aspects of higher order cognitive function. Physical activity, an event that intrinsically impacts energy management, has repeatedly been demonstrated to enhance cognitive function in both animal and human studies [8, 9, 10]. Physical training has beneficial effects not only on physical functions but also on brain functioning, including memory [12], increased capillarisation [7, 18], brain plasticity [6,24], proteasome activation and up-regulation of the antioxidant system [11].

The development of specific skills through the use of both motor, and cognitive rehabilitation could thus result in a more significative user recovery [19,22].

Touch sensing interfaces have rapidly increased their technological level. 3M MicroTouch™ provides tactile feedback effects for on-screen video buttons to make users actually "feel" like they are depressing mechanical buttons. Apple Multi-Touch™ technology enables to detect click, scroll, swipe and rotate independently. The Korean Institute of Science and Technology developed a touch that measure normal and tangential forces [3]. This, overtaking the actual limitations of touch screens that currently fail to properly distinguish force intensity, will certainly open new possibilities for serious games in the field of dexterity rehabilitation. We believe touch technology has not yet been completely exploited and, following the path of its huge improvements, clinical applications will certainly benefit. On this track we developed a custom instrument, the Force Panel - FP, in the framework of the VERITAS FP7 project with the aim to quantify the dexterity of different categories of impaired peoples. The same instrument is currently used for serious games in clinical settings. The novel touch interface measures also force thus enabling dexterity training through ‘direct’ manipulation of virtual objects in 3D: two dimensions via the touch screen, the third along the (vertical) force channel [4, 5]. In summary touch interface stimulate the physical rehabilitation the visual interaction can exploit cognitive exergames.

1. Material and Methods

The device is composed of a resistive touch-screen, an embedded system, a 15”LCD and three load cell with their relative amplification and filtration modules. The figure below shows the instrument. Two planes compose the resistive touchscreen. One rigid glass plane, the second plane is flexible and is in PET material that interfaces with the user. The measure of x and y position of the touch is separately detected alternately powering the two surfaces. The LCD is mounted onto the base by means of three load cells that measure the contact force modulus and position. The instrument is made of a
structure based on harmonic wires that constrain the movement along the plane of the
touch screen while allowing the upper part to move along the perpendicular direction.
In this way the device orientation does not affect (or at least compensates for) the
orthogonal pressure exerted by the user measurement. The electronic drivers of the
LCD and the force transducers conditioning system are hosted under the screen. The
embedded system drives the touch and reads the force and position values. The
elaboration and graphical interface is achieved by an external computer that receives
position and force data from the embedded system and generates the visual interface by
its graphics processing unit.

The Force Panel has a spatial resolution of 0.4 mm with an accuracy of ±1.8 mm.
The system composed by the force transducers operates with a resolution of 0.05 N
while its accuracy is ±0.1 N. The maximum working frequency is 100 Hz, limited by
capacitive effects of the resistive touch panel.

![Figure 1. A photo of the Force-Panel instrument and functional connections between the principal modules.](image)

To be used by peoples affected by cognitive and physical disabilities we realized a
reclining table in which we inserted the instrument. The instrument in this way can also
be used by wheelchair users.

The software application is written using Processing 1.5.1, an open source
programming language and environment for people who want to program images,
animation, and sound. It is used by students, artists, designers, architects, researchers,
and hobbyists for learning, prototyping, and production. It is created to teach
fundamentals of computer programming within a visual context and to serve as a
software sketchbook and professional production tool.

2. Serious games for cognitive and physical rehabilitation

Some recent scientific studies emphasize the importance of integration between
physical and cognitive rehabilitation in severe brain injury [13]. Cognitive
rehabilitation seems to be more effective when combined with physical stimuli and a
well sensorial challenging. Physical stimuli can facilitate cognitive recovery through
the modulation of neurotrophic factor. The neurotrophic factors are proteins important
both during development of the central nervous system that in the processes of
neuronal survival, with a fundamental role in the phenomena of synaptic plasticity that
are the basis of a central transmission normally functioning. Recently, attention has
focused in particular on Brain Derived Neurotrophic Factor (BDNF), a particularly
neurotrophin present in the hippocampus and frontal cortex, which also plays an
important role in the processes of learning and memory, has a fundamental role in the
growth, differentiation, and maintenance of neuronal survival [21]. It has been
demonstrated, first in animals and then in humans, that the physical stimulation
produces a specific increase of cerebral blood volume of the dentate gyrus, the only subregion of the hippocampal formation that supports neurogenesis (formation of new nerve cells) in adulthood [17]. This change correlates selectively with an improvement of cardiopulmonary and cognitive functions. According to these studies, the physical activity would also be able to increase the mood and reduce depressive symptoms. It can therefore be assumed that the physical stimulation promotes the growth of neural precursors [15,25]. The other side of the cognitive activity, learning and adequate environmental stimulation, allow the activation and the survival of the new cells. In conclusion, it can be argued that in the cognitive rehabilitation of patients with acquired brain injury (traumatic brain injury or ischemia), the integration of neuropsychological rehabilitation paths with motor stimulation and physiotherapy can allow the achievement of better and faster results [24].

In neurocognitive rehabilitation, use of computer programs is gaining more and more interest [25]. These tools allow various benefits, such as greater flexibility, the ability to be programmed depending on the condition of the patient, a greater motivation by patients in their use, a greater effectiveness in the measurement of the variations of performance, the possibility to be also used by patients at home. In this study identified some software developed for the rehabilitation of specific cognitive functions. Have been defined and organized functions target on which to develop and modify individual computer exercises, in order to identify precisely the rehabilitative purpose-specific training offered to patients. Were defined levels of complexity gradual, appropriate to the degree of severity of the outcome in individual patients.

The FP instrument is used within the Hospital Villa Rosa as the experimental protocol. To date has been mainly used as an aid in rehabilitation to facilitate the rehabilitation of fine motor skills with exercises based on the control of digital pressure and visuo-motor coordination. The aim of this research is to add the physical channel to the cognitive rehabilitation. In this light the FP technology only provides the rehabilitation of fine motor functions of the upper limbs, but also integrates cognitive rehabilitation and physiotherapy.

We have organized and summarized the cognitive abilities in a pattern (Table 1), in order to identify the specific functions to be rehabilitated through individual exercises.
<table>
<thead>
<tr>
<th>Macrofunction</th>
<th>Specific function</th>
<th>Specification</th>
<th>Environmental correlations</th>
<th>For example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>Spatial Orientation</td>
<td>Ability to organize the self-perception in the space and in the time</td>
<td>Orient oneself of “where and when” in specific situations</td>
<td>What time is it? Where are you?</td>
</tr>
<tr>
<td></td>
<td>Temporal Orientation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vigilance/Alertness</td>
<td>Activations level of arousal</td>
<td></td>
<td>Physiological quickness in stimulus responses</td>
<td>Athlete that wait the start in the race</td>
</tr>
<tr>
<td>Attention</td>
<td>Selection of one attention target and inhibition of distractors</td>
<td>To preserve attention in a long time</td>
<td>Ability of to take the interested stimulus out of contest and to ignore the distractors, in a span of time</td>
<td>Try to listen to a conversation while as other conversations are in progress Speak on the telephone while you are cooking</td>
</tr>
<tr>
<td></td>
<td>Sustained attention</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Divided attention</td>
<td>Division of attentive resources between many simultaneous stimulus/tasks</td>
<td>Pay attention to more informations or more tasks</td>
<td></td>
</tr>
<tr>
<td>Short Term Memory (MBT) and Working memory (WM)</td>
<td>Temporary retention system, elaboration and selection of visual-spatial information, verbal and write, finalized to make a cognitive task</td>
<td>MBT: memory and recall of just presented informations</td>
<td>WM: ability of keep in memory the informations for the all time necessary for finalize the task</td>
<td>Ability to repeat the last expression that you have hear For solve algebrical calculation, I must remember many prior changeovers</td>
</tr>
<tr>
<td>Memory</td>
<td>Permanent or part time retention system, in the memory stock</td>
<td>Capacity to organize events, situation, learnings, in order to render available this informations if necessary</td>
<td>Serf-memory, memory of events, learning knowledges</td>
<td></td>
</tr>
<tr>
<td>Executive functions</td>
<td>Planning</td>
<td>Include this capacities To planning action’s strategies To inhibit automated behaviours</td>
<td>To be able to organize own actions and behaviours, in relation of the environmental requests, social relations, even in non-ordinary situations</td>
<td>Write the shopping list: to planning what you want to buy. To find the motivation for leave home. Go in the supermarket, according to necessity, but having the flexibility to put down in the shopping trolley one economic product, for example. Go in checkout counter having patience, standing in line and having willingness to pay</td>
</tr>
<tr>
<td></td>
<td>Attention Control – To inhibit inappropriate responses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Set Shifting – Cognitive flexibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abstraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Motivation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Language</td>
<td>Verbal production</td>
<td>Ability to produce understandable verbal messages Ability to understand verbal messages</td>
<td>Ability to interact in the usual communications</td>
<td>To interact through the word and listening in a conversation between 2 or more persons</td>
</tr>
<tr>
<td></td>
<td>Oral comprehension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual perception</td>
<td>Object Space</td>
<td>Ability to recognize the objects, through the visual channel Ability to elaborate the surrounding space</td>
<td>To recognize the objects To recognize the places and environments</td>
<td>To distinguish between a pen and a pencil Distance between me and an object</td>
</tr>
<tr>
<td>Motion</td>
<td>Executive Strategical</td>
<td>Patterns of finalized motor behaviour</td>
<td>Programming of motor actions, in relation of space into take place the action</td>
<td>To climb a mountain</td>
</tr>
</tbody>
</table>
3. Some serious games implemented

3.1. Map Game

The exercise requires the user to indicate his actual position on Google Maps moving through different zoom levels. By pushing on the screen a rectangle appears around the touch position, while on the top bar it is indicated the intensity of the force. To go over the level the user needs to choose an area that includes the actual position and keep the force in the green range for a predefined time span indicated in the watch just below the force bar located on top. Time period and force span can be defined in the option menu.

The feedback is provided both in wrong and correct behavior cases. It is provided by sound and visual cues. At the end of the test the application shows the user a final score.

![Figure 2](image_url) Sequence of image of the Map Game exercise. From the left initial screen, during the test, final score.

In Table 2 it is summarized the rehabilitation cognitive and physical areas interested.

<table>
<thead>
<tr>
<th>REHABILITATION AREAS (REHABILITATIVE TARGET-NEUROCOGNITIVE FUNCTION INVOLVED)</th>
<th>CORRESPONDENCE WITH TRIAL PROPOSED BY THE STUDENTS (MODALITY OF INTERACTION WITH THE FP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial orientation</td>
<td>Capacity to collocate yourself in an interactive-map that in function of the enlargement level, give you a different point of view</td>
</tr>
<tr>
<td>Visual perception (space)</td>
<td>Capacity to recognize place and environment by observing maps and images</td>
</tr>
<tr>
<td>Motion control</td>
<td>Total time to pass each level, number of error for each level, mean distance to the objective point, standard deviation from the objective point</td>
</tr>
<tr>
<td>Force control</td>
<td>Mean force during the residence time for each level, standard deviation of the force</td>
</tr>
</tbody>
</table>
3.2. Find the Cheese

This exergame requires that the user guide the mouse through the intermediate cheeses (the ones in piece) till the final (whole) cheese avoiding the cats. The complexity of the labyrinth is function of the selected level. During the dragging operation no force is required but when the mouse reach the cheese a green circle shape appear and the user need to press since a limit set in the option menu to eat the cheese.

There are some different sound and visual feedback during the execution:

- the mouse become red and a sound is emitted if hit the wall;
- the mouse become red a sound is emitted and a screen shoot compare if hit the cat;
- if the user eat the final cheese but has not yet completed all the intermediate ones a sound is emitted;
- if the level is correctly completed a rewarding sound is emitted and a final congratulation screen appear.

One important feature in this exergame is the personalization of the level. The rehabilitator can create the labyrinth in function of the patient kind and level of disability. For example for left hemiparesis the rehabilitator could concentrate the exercise effort in the left side of the screen thus fostering the user attention in the affected side.

![Figure 5. Find The Cheese screen shoot. Initial screen with the option; start the test; during eating step.](image)

Table 3. Comparative table with respect to the pattern of neuropsychological functions.

<table>
<thead>
<tr>
<th>REHABILITATION AREAS (REHABILITATIVE TARGET-NEROCOGNITIVE FUNCTION INVOLVED)</th>
<th>CORRESPONDENCE WITH TRIAL PROPOSED BY THE STUDENTS (MODALITY OF INTERACTION WITH THE FP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual and spatial perception</td>
<td>Patient need to learn where can move the mouse and where there are limits (walls and cats). Then he need to touch the screen with accuracy to avoid the obstacle and reach the target</td>
</tr>
<tr>
<td>Pianification</td>
<td>The patient need to find the right path to reach the target (cheese)</td>
</tr>
<tr>
<td>Motion control</td>
<td>To avoid the obstacle the patient need to make movement with a certain level of accuracy. The following parameters are measured and stored: total time, path compared to the optimal one, number of collision with the wall, number of collision with cats, number of cheese eat respect to the total</td>
</tr>
<tr>
<td>Force Control</td>
<td>When the cheese is reached, the patient need to press enough to eat it. The threshold is settable. The following</td>
</tr>
</tbody>
</table>
parameters are measured and stored: mean force for each level, standard deviation of the force, time to eat each cheese

4. Discussion and Preliminary Results

The effectiveness of the rehabilitation process integrated (motor and cognitive) will be studied through an experimental design. A group of patients will be undergoing the integrated cognitive-physical rehabilitation paths, while a control group will be treated with traditional rehabilitation methods. Improvements autonomy of both groups of patients will be assessed through standardized tests and scales.

References


