Virtual environments in cognitive rehabilitation of executive functions

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ABSTRACT

The V.E.Ne.Re. Project (Virtual Executive NEuropsychological REhabilitation) consists in the constuction and validation of artificial environments based on Virtual Reality (VR) technologies, aimed for cognitive rehabilitation of executive functions (frontal lobe dysfunction; dysexecutive syndrome). Damasio (1994) pointed at the discrepancy between non immersive artificial lab tests and real life situations to explain the frequent diagnostic and therapeutic failures that occur when traditional cognitive tools are used with frontal patients. In this perspective, VR environments which are capable to generate a better subjective perception of presence and immersivity, become a very promising alternative to enhance cognitive neuropsychology of executive functions. On these premises, we will describe the current three components of V.E.Ne.Re., with special regard to the V-Store software, which consists in a set of tasks aimed to empower executive functions, attention, short term memory, behaviour control and metacognition. V-Store is planned to offer a high level of interaction and to induce time pressure, eliciting subjective managing strategies. The same environment will be used to implement also the virtual versions of two well-known cognitive tests: V-ToL (VR version of Shallice's Tower of London); V-WCST (VR version of the Wisconsin Card Sorting Test). We are currently starting to test our environments, with regards to their clinical efficacy, cost/benefit effectiveness, subjective experience and usability.

1. TARGET: DYSEXECUTIVE SYNDROMES

In the field of disabilities, the category of cognitive dysfunctions can be classified making a distinction between the loss (partial or complete) of the basic *instrumental* cognitive functions (such as attention, memory, language, visuo-spatial abilities, etc.) and the loss of *executive* functions (also called *central* or *control* functions). These are generally referred to a group of behavioural skills that includes: the ability of planning a sequence of actions, the ability of maintaining attention in time, the ability of avoiding the interfering stimuli and using the feedback provided by others, the capability of coordinating more activities together at the same time, the cognitive and behavioural flexibility and the other abilities used to cope new situations and stimuli (Crawford, 1998).

Many terms have been used to define this syndrome: *Disorders of Executive Functions*; *Dysexecutive Syndrome*; *Strategy Application Disorder* (SAD); *(Pre)Frontal Syndrome*. Loss of executive functions is primarily a consequence of brain injury located in the prefrontal cortex area, but many different categories of subjects can be characterized by the same syndrome and by similar symptoms, with different levels of severity and various forms of resulting behaviour: patients suffering of different forms of dementia (Alzheimer Disease, Frontal or Fronto-Temporal Dementia, etc.), patients with attention disorders and hyperactivity (i.e. ADD-H), subjects suffering of Schizophrenia or Psychopathy.

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Usually the problems related with cognitive disabilities are not evident: Thimble (1990) noted that the pathological conditions due to a frontal dysfunction very often usually are not recognized in the clinical practice. This happens because in the case of frontal lobe disease, cognitive performance of subjects may not be severely reduced and because many traditional neuropsychological test may fail to show significant dysfunctions in the patients' answers (Damasio, 1994; Gourlay et al, 2000; Riva, 1998). As Damasio brilliantly pointed out, in the complex tasks of everyday life, the same patients may show great limits, decisional problems and inhabilities connected with high levels of psychosocial suffering. It has been demonstrated that traditional tests of frontal lobes function may fail to document abnormality: this "diagnostic insensitivity" may cause problems between patients and health care services and can determine incapacity to predict the outcome of treatment.

Damasio's famous patient Elliot not only had normal performances in the standard "frontal" cognitive tests, but in the lab he was also able to elicit normal responses to the proposed social situations, he planned strategies and he demostrated to be able to evaluate correctly the consequences of actions in social situations. The same patient showed a severe decisional impairment and emotional disregulation in his real life environment, especially related to social situations. Elliot is described as the prototype of the hi-functioning frontal patient who experiments severe problems in his daily life.

From the point of view of cognitive rehabilitation, if we consider that the traditional protocols used in treatment are centered mainly to protect or recover the basic instrumental cognitive functions, we can understand why, in a clinical or lab setting, superior executive cognitive disabilities are today particularly hard to treat and thus receive a very reduced attention in relation to their dramatic real-life consequences.

From a theoretical point of view, we can try to explain the strinking differences in performance and behaviour between lab and life as result of four main failures of the artificial situations to mimic reality: a) choices and decisions are only to be evoked, not to be really performed; b) lack of the normal cascade of events as actions and reactions; c) compressed temporal frame; d) situations are not really presented, but only described through language (Damasio, 1994). In other words, our diagnostic and rehabilitative tools, built to be used in clinical or laboratory settings, fail their goal with executive functions because they cannot adequately reproduce real situations and the perception of the subject to be really *present* in them. Cognitive assessment and rehabilitation of executive functions faces us with the necessity to transfer our work in real life situations or, as a valid alternative, to be able to build artificial environments who can offer to the subjects similar conditions and the same sense of presence.

2. VIRTUAL REALITY AND THE SENSE OF PRESENCE IN CLINICAL APPLICATIONS

Virtual Reality (VR) is considered as the most advanced evolution of the relationship between man and computers (Vincelli et al., 2001). VR is different from other technologies because it offers to users the chance to experience psychological states of *immersion* and *involvement* (Rizzo et al., 1998) due to the combination of hardware and software tools with particular interactive interfaces (such as *head-mounted display* and *tracker*). So one of the possible added values of Virtual Reality (with respect to traditional electronic systems of representation and interaction) seems to be the particular level of *presence* that subjects can experience in virtual environments (VEs). With the present and future development of technologies, synthetic environments will be able to re-create situations more and more similar to the ones we experiment in everyday life, therefore we can easily imagine that the possibility to feel presence in virtual environments and to use this technology in many fields will always increase.

Virtual Reality is a technology used in many applications, from health care to arts, from e-learning to entertainment. Focusing on the health care field, VR finds a role in many areas such as psychotherapy (assessment and treatment of pathologies such as social phobias, eating disorders, sexual disorders, depression, autism, etc.), cognitive rehabilitation (about memory, attention, spatial abilities and superior cognitive functions), motor rehabilitation (about paraplegia, tetraplegia, parkinsonism and other disabilities). In particular, in the field of rehabilitation, the possibility to use new technologies has been studied (Gordon et al., 1989) and the potential of virtual reality based applications has been recognized (Pugnetti et al., 1998; Rizzo & Buckwalter, 1997a).

According to Rizzo et al. (1998), it is necessary to carry on a realistic cost/benefit analysis to evaluate which is the added value of VR in different applications comparing with traditional approaches. A key question is "does the objective that is being pursued require the expense and complexity of a VE approach, or can it be done as effectively and efficiently using simpler, less expensive, and currently more available means?".

There are different issues to consider in order to evaluate the real costs and benefits of Virtual Reality in mental health applications. One of these important issues, in order to ensure high benefits in the use of VR, is represented by production of functional and useful environments. Traditionally, as indicated by Waterworth & Waterworth (2001) "VR designers typically aim to create a convincing, engaging, environment in which users feel present". The focus for VR developers seems to be "presence" and all the systems to improve it.

But the concept of presence is very complex because this psychological state is characterized by many factors and so a key issue becomes the choice of the presence factors that have to be considered in the use of VEs in mental health applications. Riva (2000) notes that the substantial challenge for the designers and users of VR is *how* to use immersive environments to support clinical practice. It becomes clear that a VE built for entertainment has to be different from a one use in psychotherapy or cognitive rehabilitation. So which are the core characteristics of a virtual environment in order to ensure a kind of presence that is functional and useful for mental health applications?

In Riva's opinion two key characteristics of VR as a clinical oriented tool have to be the *perceptual illusion of non-mediation* and the *sense of community*: in mental health applications reproducing physical aspects of virtual environments may be less important than the possibility of interaction that a VE could allow. According to Riva, in clinical oriented environments "the criterion of the validity of presence does not consist of simply reproducing the conditions of physical presence but in constructing environments in which actors may function in an ecologically valid way" (p. 356). Thus the level of presence, connected with the functional use of VEs in clinical applications, depends also on the level of interaction and possible interactivity (Riva, 2000; Smets et al., 1994).

3. OUR REASONS FOR A VR CHOICE

Cognitive rehabilitation has to allow patients to recover their planning, executing and controlling skills by implementing sequences of actions and complex behavioural patterns that are requested in everyday life (Rizzo & Buckwalter, 1997a, 1997b): with these conditions, VR can be specifically indicated to reach this goal (Rizzo et al., 2000; Grealy et al., 1999). Moreover VR allows to build realistic spatial and temporal scenarios that can be easily used to increase diagnostic sensitivity of standard paper&pencil tests (Pugnetti et al., 1995, 1998). For example, in the case of early recognition of Alzheimer's disease, VR may be the most efficient method for a systematic screening of subjects (Rizzo et al., 1998).

Due to the great flexibility of situations and tasks provided during the virtual sessions, considering both the time, difficulty, interest, and emotional engagement, this new technology allows, besides the diagnostic applications (Zhang et al., 2001), to enhance the restorative and compensatory approaches in the rehabilitating process of cognitive functions inside the traditional clinical protocol.

In our opinion, in general cognitive rehabilitation, the added value of VR compared to the traditional treatment can be summarized according to the following points:

- possibility to programme: each virtual environment can be produced in a specific way focusing on the patient's characteristics and demands;
- possibility to graduate: each virtual environment can be modified and enriched with more and more difficult and motivating stimuli and tasks. This last issue shall not be underestimated, because many subjects with cognitive dysfunctions have a low level of motivation and compliance about the traditional rehabilitating iter that is usually repetitive and not stimulating;
- high level of control: the possibility of controlling the rehabilitating process in its development is very high. This issue allows to professionals to monitor the level of affordability and complexity of the tasks that can be provided to patients;
- ecological validity: a virtual environment allows to stimulate in the subjects emotional and cognitive experiences like in the real life. So the tasks executed during the immersion in the VR can induce the patient to reproduce complex cognitive procedures (such as planning and organizing practical patterns of actions, attentional shift, etc…) that are similar in all the aspects to the ones used in the situations of everyday life;

Table 1. *Possible issues to consider in designing Virtual Environments in clinical applications.*

Key questions	**Possible answers**	**Applications and indications for VR designers**
1. Are VEs useful, effective and efficient in clinical applications?	Evaluation of possible advantages and limits Cost/benefit analysis	Development of VEs that have to ensure only the level (and quality) of presence requested by each application.
2. Do VEs reproduce the physical and perceptual characteristics of real environments?	Attention on graphics and technical characteristics. Focus on realism and technical issues	Development of VEs that have to ensure realism and a level of presence as non-mediation and immersion.
3. Do VEs allow users to function in an ecologically valid way?	Attention on cultural and social aspects. Focus on interaction, interactivity Importance of relationships and context	Development of VEs that have to ensure ecological situations of interaction, interactivity

Table 2. *Synthetic description of the three components of V.E.Ne.Re..*

Name	*Goal*	*Brief description*
V-Store *Virtual Store*	▪ rehabilitative	Virtual environment (internal store) in which the subject (clinical or experimental) has to solve a series of tasks ordered in six levels of increasing complexity. Tasks are designed to stress executive functions, behavioural control and programming, categorial abstaction, short-term memory and attention. A series of distracting elements are present, aimed to generate time-pressure and to elicit managing strategies. The examiner has full control on all variables, to enhance usability and to increase the number of sessions that a single patient will be administered
V-ToL *Virtual Tower of London*	▪ rehabilitative ▪ diagnostic	A virtual version of the notorious Tower of London Test by Shallice, using the same environment as V-Store. The test is meant to evaluate the executive ability to program behaviour in time. The original paradigm and trial sequence is carefully respected, to grant the clinical and scientific equivalence of results. The task can be used as a one-time assessing test or repeated as a rehabilitative tool (the examiner can intervene on all variables implied).
V-Wcst *Virtual Wisconsin Card Sorting Test*	▪ rehabilitative ▪ diagnostic	A virtual version of the notorious Wisconsin Card Sorting Test (Heaton, 1981), using the same environment as V-Store. The test is meant to evaluate the executive abilities of categorization, abstraction and behavioural flexibility. The original paradigm and trial sequence is carefully respected, to grant the clinical and scientific equivalence of results. The task can be used as a one-time assessing test or repeated as a rehabilitative tool (the examiner can intervene on all variables implied).

- economical advantage: rehabilitation with VR can be cheaper than the traditional one, mostly when it comes to the reconstruction of complex scenarios, also of very complex ones (such as presence of more persons in the same time, particular environmental conditions), which avoids the need to leave the rehabilitation office or building.

Nevertheless, when it comes to the specific needs of rehabilation of dysexecutive symptoms and frontal lobe syndrome, the employment of virtual environments appear to have another fundamental advantage with respect to traditional non-immersive means. According to Damasio (1994; see 1st par.) diagnostic and rehabilitative tools used in labs and clinics often fail to assess and treat the frontal patients because they operate within artificial situations, which are far from reproducing the real situations. In this view, immersive virtual environments appear to be the best solution to make lab situations become closer to the natural setting in the subject's perception.

For these reasons, in our work we decided not only to use and implement immersive virtual environments, but also to assess very carefully the key variables that support such choice: subjective sense of presence; qualitative evaluation of virtual experiences; usability level.

4. DESCRIPTION OF THE V.E.Ne.Re. PROJECT

This project aims at planning, developing and testing a rehabilitating protocol with virtual environments for high-level cognitive dysfunctions that affect patients with brain injures, cerebral diseases, degenerative pathologies and in particular subjects who can be evaluated as "frontal patients" in scientific literature. Even if the focus of this project will be overall centered on this last syndrome, we suppose that the applications which will be developed could be useful in a broad spectrum of rehabilitative opportunities.

The project will use the technology of VR systems. Due to the use of VR, the project aims at offering new solutions to reorganize the cognitive abilities in the subjects with disabilities in order to improve life quality, in the sense of a better control of behaviour and information processing.

The three components that are currently planned for programming and testing are described in Table 2.

The project will follow 5 steps:

1) *collecting of the real needs and demands of subjects with frontal syndrome using focus group and discussion group*. It will not be possible to use only a user-centered approach because of the possible distortion of the subjective judgment typical in patients with frontal deficits; so it will be necessary to create situations where to compare different points of view and to think over these issues between the professionals involved in the rehabilitation (neuropsychologists, neurologists, nurses, assistants, etc…). Using the focus and discussion group methodology, it will be possible to point out the different types and levels of cognitive disability and the most common psychological reactions in front of the suffering in order to define the application fields of VR. In particular a key issue will be the rehabilitation of the most complex cognitive functions (planning an action in all its different steps, distribution of attention towards more information in the same time, etc…), that are traditionally not considered in the standard rehabilitating iter;
2) p*lanning and realization of the virtual environments*. During this step of the project, it will be realized the planning and realization of new virtual scenarios and the tuning and functional adaptation of virtual environments already used in other applications (such as psychotherapy and motor rehabilitation). The goal of this step will be the construction of virtual environments where the subjects can carry out cognitive tasks similar to the ones that they already develop in different situations of everyday life. These environments will be characterized by gradual levels of complexity, control and feedback;
3) a*nalysis of the usability of virtual environments to simulate real tasks using normal subjects*. In this step, through the reports provided by normal subjects, it will be possible to evaluate the level of immersion, engagement and realism produced by the software that has been realized in the previous step. To have a measure of the subjective aspects of virtual experience, it will be used the Sense of Presence Inventory, which is going to obtain a validation also in Italy;
4) *use of virtual environment sessions within the traditional rehabilitating iter*. In this step the traditional protocol followed in the cognitive rehabilitation will be integrated with a session of interaction with virtual environments. It will be realized a comparison between the experimental group performances

(group composed by patients with frontal syndrome and VR enhanced treatment) and control group performances (group composed by patients with frontal syndrome and classical treatment without VR sessions). Two controlled clinical trials will be planned: the first one regards a small sample whereas the second one involves a large sample. The possibility to have results from the first small sample will allow to modify and tune the virtual environments for the second and lager clinical trial;

5) e*valuation of the efficacy of virtual environments in the rehabilitating iter*. This step aims at verifying the qualitative and subjective aspects of virtual experiences in the disabled patients. Moreover it will be evaluated the reached degree of rehabilitating efficacy and the perceived level of motivation related to the virtual experience. The qualitative evaluation of virtual experiences in the rehabilitating iter will be realized using a subjective questionnaire (in particular the QUEST, *Quebec User Evaluation of Satisfaction with Assistive Technology*). The data collected with this questionnaire will be necessary compared with other evaluations provided by the professionals involved in the rehabilitation (neuropsychologists, neurologists, nurses, assistants, etc.).

5. V-STORE: A REHABILITATIVE TOOL

The virtual environment consists of a fruit store internal room: the subject (or more correctly his "avatar", his representation within the virtual world) is set in front of a conveyor belt on which some baskets (from one to three) cross the room. The subjects' task is to fill up the baskets with pieces of fruit that can be found in four shelves located on the other walls of the room.

At the beginning of each trial, a verbal command is communicated through a loudspeaker, located on the front wall, by which the subject is instructed about what to do: how to fill the baskets and with what kind of fruit. The task has to be completed accurately before the baskets run out of the room on the belt, or else the trial will be repeated from the beginning. It is possible to fix a maximum limit in how many "moves" the subject can execute to solve the trial, forcing him to follow the most efficient and quick strategy.

The tasks are ordered according to their complexity, starting from very quick trials that need few fruit moves, up to trials that start with a long and verbally complex command and request special strategies in moving the available fruits from one basket to another. The trials are currently divided in six levels of ten tasks each.

Other elements which are present in the environment are a waste basket, the light switch and a wall telephone, located on the rear wall, through which the subject can receive supplemental orders that integrate the initial verbal command in the most difficult level. The subject can intervene on some additional commands, by which he can stop the belt, end the trial, freeze time.

The supervising examiner can introduce a series of distracting events which increase difficulty and are meant to generate time pressure (Fasotti et al., 2000): room light fainting or progressive dimming, telephone ring, belt speed modification. In these situations, the most interesting focus of performance and rehabilitation consists in the managing steps that the subject will operate and his strategic approach.

For each trial, the system records the following data about the subject's performance for further analisys or research: accuracy, execution time, moves and strategical planning, and furthermore the managing steps taken to face distractors or difficulties, which often constitute the gratest limit for frontal patients.

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