Applications of virtual reality for the assessment and treatment of topographical disorientation: a project

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ABSTRACT

The traditional tools afforded by neuropsychology have proved to be of considerable service not only for the description of the clinical course of illnesses, but also for their nosographic and diagnostic contextualization. Virtual reality technology appears to be able to take on a valued rôle within the variety of diagnostic tools that are necessary for an adequate assessment of impairments of executive function. Development of diagnostic tools based on virtual reality may be cost-effective, particularly with respect to old but still widely used paper-and-pencil tests. The aim of the project presented in this paper is the creation and validation of various VEs to improve the assessment and rehabilitation of topographical disorientation, a disease present in various cerebral pathologies.

1. INTRODUCTION

Topographical orientation disorders may be the expression of memory or attention deficits, unilateral spatial neglect, or elementary visuo-perceptive disorders. In a minority of cases, topographical disorientation presents as an isolated disorder and is the expression of a focal brain lesion (Cammalleri *et al.*, 1996; Nichelli, 1996). Some authors observe that topographical disorientation may also be seen in a variety of brain disorders, including developmental conditions (Fine et al, 1980), progressive demential diseases (Passini et al., 1995), epilepsy and traumatic brain injuries (Whiteley & Warrington, 1978).

Most information regarding neuro-anathomic correlates have been reports of more than 200 patients developing relatively selective defects in topographical functioning following the onset of focal lesions due to stroke, penetrating missile wounds, or surgical resection for treatment of epilepsy or tumour (Barrash, 1998).

Most environmental representation is predicated upon the ability to recognise specific locations where navigational decisions are executed (Aguirre & D'Esposito, 1999). This perceptual ability is termed *landmark* (or place) recognition and is thought to be the first "topographic" ability acquired in developing infants (Piaget et al., 1960). Subjects improve in their ability to successfully identify environmental features with developmental age.

Route knowledge describes the information that encodes a sequential record of steps that lead from a starting point, through landmarks and finally to a destination. This representation is essentially linear, in that each landmark is coupled to a given instruction (i.e. go right at the bank), that leads to another landmark and another instruction, repeated until the goal is reached. While more information can be stored along with a learned route, there is evidence that subjects often encode only the minimal representation that is necessary (Byrne, 1982).

Descriptions of route learning also emphasise its grounding in an *egocentric* co-ordinate frame. Egocentric (or body-centred) space is the domain of spatial concepts such as left and right. Orientation is maintained within a learned route by representing egocentric position with respective landmarks (i.e. pass to the left of supermarket, then turn right).

Whereas route-learning is conducted within egocentric space, map-like representations are located within the domain of *exocentric* space, in which spatial relations between objects within the environment, including those observed, are emphasised (Taylor & Tversky, 1992). A developmental dissociation between egocentric and exocentric spatial representation has been demonstrated in a series of experiments indicating that these two co-ordinate frame representations are utilised by adult subjects (Acredolo, 1977). In order to generate a representation of exocentric space, exocentric spatial decisions must be combined with an integrated measure of one's motion in the environment. Drawing on recent research it appears that topographical disorientation is not a unitary construct but rather that it dissociates into several sub-types, depending on the underlying cognitive and perceptual processes that have been compromised.

The literature suggests that two different specific mechanisms may lie at the origin of the topographical orientation disorder; according to some authors (Paterson & Zangwill, 1945; De Renzi, 1982a), it is possible to distinguish a *topographical agnosia* and a *topographical amnesia.*

In *topographical agnosia* the patient is unable to recognise the characteristic elements of places that ought to be known to him. It is hypothesised (Thorndyke & Hayes, 1982; Kosslyn, 1990) that the deficit is due to a failure to analyse the specific aspects of visual stimuli (the "what" system; Ungerleider & Mishkin, 1982); the capacity to re-visualise mentally, refer verbally and sketch out the path that ought to be taken to go from one place to another remains, instead, intact.

Topographical amnesia is the condition in which the conspicuous points of the environment evoke a sense of familiarity and are easily recognised without, however, the subject being able to assign a spatial value to these points. According to the authors cited above, the deficit is due to the lack of functioning of the process responsible for identifying the spatial relationships between elements that are expressible according to topological notions of the type below/above, at the end of ..., on the right of ..., etc. (the "where" system; Ungerleider & Mishkin, 1982).

The anatomical correlates of the two systems involved in perceptive processing of the visual and spatial components ("what" and "where" systems) have been identified in two distinct cortical pathways, the first of which starts from the retina, passes through the lateral geniculate body, and proceeds up to the level of the occipito-temporal associative area (ventral pathway – "what" system), whilst the second terminates in the occipito-parietal associative area (dorsal pathway – "where" system) (see also Aguirre & D'Esposito, 1997).

While most authors agree that the posterior right hemisphere (cortical and subcortical) is involved, a variety of sites therein have been implicated, for example, posteromedial regions (Landis et al., 1986), the posterior parietal and adjacent lateral occipital and temporal cortices (De Renzi, 1982), the right paraippocampal gyrus (Habib & Sirigu, 1987), the posterior limb of the right internal capsule with secondary hypoperfusion in the right parietal region (Hublet & Demeurisse, 1992), the anterior commissure, right foramen of Monro, right fornix (Botez-Marquard & Botex, 1992), and the splenium of the corpus callosum (Bottini et al., 1990).

The cases of spatial disorientation present in the literature indicate an anatomical-functional correlation prevalently at the level of the right hemisphere, even though a bilateral involvement is not excluded (Goeffry *et al.*, 1997).

2. VIRTUAL REALITY IN THE ASSESSMENT AND TREATMENT OF THE TOPOGRAPHICAL ORIENTATION DISORDER

In the field of clinical neuro-psychology, virtual reality will probably change some of the diagnostic procedures that, decades after their introduction, are still used (Pugnetti et al., 1998).

Starting from the traditional tools afforded by neuropsychology, which have proved to be of considerable service not only for the description of the clinical course of illnesses, but also for their nosographic and diagnostic contextualization, the aid of virtual reality proves to be of major interest both as a complementary tool and to increase the possibilities of management of the patients from a rehabilitative point of view (Rizzo *et al.*, 1997).

The *immersion in the image* enabled by VR makes it possible to re-propose to the subject the "natural" features of the environment in which he lives and acts *as if* they were real. Recent research shown that training in virtual environments is comparable to training in the real world (Koh et al., 1999).

In particular, with reference to the assessment and treatment of topographical disorientation, virtual reality offers new possibilities to the clinician:

a) *Controlling and manipulating in a precise and objective manner the presentation to the subject of different variables that are implicated in the subject's capacity to orient himself topographically.*

On account of their intrinsic characteristics (for example, abstractness of the task) traditional pencil-and-paper tests are not able to assess the subject's orientation skills directly "*in vivo*". The tests proposed using virtual reality enable the subject to place himself in a "familiar" environment and to understand the task more easily. It is hypothesised that the direct connection between the nature of the task and the skills necessary for carrying it out may, on the one hand, increase diagnostic accuracy and, on the other hand, increase the subject's compliance to the assessment process.

b) *Using for assessment and rehabilitation a tool that reflects the life situations that are indispensable for the autonomy of the person.*

Current research conducted in a neuropsychology and rehabilitation setting suggests the importance of studying the topographical orientation disorder in view of the direct repercussions on the autonomy of the person. Of particular consideration is the presence of this deficit in various forms of brain disease and the consequent burden in terms of health assistance that this implies.

In particular, in a rehabilitation framework, the virtual environment presents itself as a highly ductile tool, in so far as it may be adapted, by the clinician, to the needs of the individual patient, of his deficits, and of his residual skills.

c) *Once the virtual environment has been created, the construction and use of immersion in this environment and the simulation of everyday situations, quickly and at a low cost.*

A complete and innovative assessment of the patient's topographical orientation capacities requires the performance of a number of tasks in the real environment. In the majority of cases, this procedure cannot be followed in so far as it is very costly in terms of time and the are additional problems for the patient admitted to a hospital structure.

The virtual environment makes it possible for the clinician to avail himself of all the advantages of a test that reproduces the features and stimulation typical of the natural environment, at the same time maintaining safety, objectiveness and serenity, both for the clinician and for the patient, whether from a psychological standpoint or from a health standpoint.

Virtual reality technology appears to be able to take on a valued rôle within the variety of diagnostic tools that are necessary for an adequate assessment of impairments of executive function. Development of diagnostic tools based on virtual reality may be cost-effective, particularly with respect to old but still widely used paper-and-pencil tests. If compared to other instruments which are less structured - such as in-the-field tests and direct naturalistic observation - virtual reality may not be as cost-effective, flexible and comprehensive, but may still be able to produce the kind of objective information that the former approaches generally lack (Pugnetti et al., 1998).

Our project will also use the theoretical model of 'wayfinding' in virtual environments, recently proposed by Chen and Stanney (1999). This model suggests that wayfinders generally commence by directly perceiving the environment or by working from a cognitive map. In terms of direct perception of the environment, landmark knowledge is acquired by directly viewing indirect representation such as photographs. In terms of cognitive mapping, procedure/route knowledge is acquired to through direct experience or through simulated experience and stored in memory. In addition, survey/configuration knowledge may be acquired from direct perception of the environment or from map use and also stored in memory.

3. DEVELOPMENT AND VALIDATION OF THE VIRTUAL ENVIRONMENT FOR THE ASSESSMENT OF TOPOGRAPHICAL ORIENTATION DISORDER

Compared to traditional pencil-and-paper neuropsychological tests, assessment via VR makes it possible to investigate in greater depth the functionality of the higher cognitive skills (attention, memory, planning) and to infer the degree of integrity of the underlying neural processes involved in the tasks of topographical orientation (perceptive analysis and identification of the shapes of objects – "what" component; perceptive analysis of the spatial relationships between the objects and execution of movements towards these objects – "where" component).

The virtual environment will be developed in such a way as to reproduce the peculiar characteristics of a typical quarter of a medium-sized town. Elements such as roads, streets, avenues will thus be used, in which reference targets and reference points will be placed, such as buildings, shops, offices, urban amenities, etc.

The validation of the assessment tool will be carried out on the results of the performance of 200 subjects who, on the basis of pencil-and-paper neuropsychological assessment, have proven to be in possession of unimpaired cognitive skills. The subjects' performance in VR will be compared with that obtained using traditional pencil-and-paper neuropsychological tests.

The development of the assessment tool suggests the creation of three sub-tests:

1. The first sub-test will be aimed at assessing *topographical agnosia* – the tool will assess the capacity of the subjects to recognise objects functioning as reference points inside the virtual environment.
2. The second sub-test will be aimed at assessing *topographical amnesia* – the tool will assess the capacity of the subjects to describe topographical relationships of which they have had experience within the virtual environment.
3. The third sub-test will be aimed at assessing *topographical orientation skill* – the tool will assess the capacity of the subjects to autonomously reach a target place within the virtual environment following a phase of getting to know the environment.

The assessment proposed for the subjects may thus be divided into four different interconnected tasks:

Type of task	***Variables assessed***
1 – *Getting to know the virtual environment*: the subject will be guided for a few minutes inside the virtual environment; he will be asked to observe the environment because, in a subsequent phase, he will be asked to move around autonomously inside it.	
2 – *Assessment of topographical agnosia*: the subject will be presented with certain target stimuli, some of which coincide with the reference points of the virtual environment which the subject has had the opportunity to encounter in task 1; other target stimuli will be new. The test will assess recognition.	Number of mistakes made by the subject
3 – *Assessment of topographical amnesia*: the subject will be asked to recognise spatial relationships (below/above, at the end of ..., on the right of ..., etc.) existing between some stimuli that he has encountered in task 1.	Number of mistakes made by the subject
4 – *Assessment of orientation skill*: the subject will be asked to reach a target stimulus inside the virtual environment in the shortest time possible and taking the shortest path.	Time taken to complete the task Distance covered Number of mistakes (compared to the shortest path) Target reached/not reached

The validation of the virtual environment for the assessment of the topographical orientation disorder will foresee the following actions:

1. Choice of the subjects that will be included in the validation study according to one basic criterion. The subjects must have achieved scores within the norm at a neuropsychological assessment in which, after a general assessment (Mini Mental State Examination - MMSE), the following areas will be further investigated: capacities of memory (Wechsler Memory Scale-Revised, Corsi Test, Verbal Span); capacities of attention (Attention matrices, Toulouse Test); and visuo-spatial skills (Cancellation of Gauthier bells, Benton Visual Retention Test, Elithorn Test);
2. Test on the 200 normal subjects;
3. Analysis of the psychometric characteristics of the tool.

4. DEVELOPMENT AND STUDY OF THE EFFECTIVENESS OF THE VIRTUAL ENVIRONMENT FOR THE REHABILITATION OF SUBJECTS AFFECTED BY TOPOGRAPHICAL ORIENTATION DISORDER

The virtual environment with which the subjects will interact in the course of rehabilitation will be organised hierarchically with respect to the difficulty of the tasks that will be proposed and will make precise reference to the theoretical cognitive model of the topographical orientation disorder.

Each rehabilitation treatment will focus on the specific areas of strength and weakness of each individual patient in terms of topographical orientation skill. The virtual town within which the subject will move around and perform specific tasks envisaged by the rehabilitation protocol will constitute the basic tool for:

a) re-training the patient in the specific cognitive functions that are deficient with respect to the task;
b) overcoming the deficit through the creation of compensatory mechanisms;
c) implementing alternative strategies for dealing with the orientation deficit.

The tasks proposed will tend to be moulded to the everyday tasks that the subject is normally used to performing.

The main aim is the development of a virtual environment which:

- is a reproduction of the peculiar characteristics of a typical quarter of a medium-sized town; elements such as roads, streets, avenues will thus be used, in which reference targets and reference points will be placed, such as buildings, shops, offices, urban amenities, etc.; and
- envisages the use of tasks organised in a hierarchical fashion as regards their difficulty and which reflect the theoretical model of the topographical orientation disorder.

In the creation of the virtual environment, which will form the basis of the cognitive rehabilitation of subjects affected by topographical orientation disorder, particular attention will be paid to the choice of:

a) types of target stimuli (e.g., bank, post office, pharmacy, food stores, etc.), so that they reflect reality faithfully;
b) tasks that have a particular interest for the subject and his autonomy, thus reflecting his day-to-day reality – the aim is to find tasks that motivate the subject to perform and that are meaningful for personal autonomy);
c) difficulty of the tasks – the tool will be built in such a way as to present a gradually increasing complexity of the stimuli proposed to the subject; and
d) tasks that are consistent with the theoretical reference model.

The first trial will be conducted to verify the effectiveness of the tool and for the subsequent definition of:

- the virtual environment created as a basis for cognitive rehabilitation of subjects affected by topographical orientation disorder; and
- the rehabilitation protocol used.

4.1 Recruitment of subjects

All the subjects will undergo a neuropsychological assessment (pencil-and-paper test). Criteria for exclusion are: a score of less than 16 at the MMSE; serious aphasia; serious behaviour disorders; serious reduction in hearing or eyesight.

The sample will include 10 subjects who have presented topographical orientation deficits in the assessment phase in the virtual environment and who will take part in the effectiveness study.

4.2 Methodology

According to a randomisation procedure, the subjects will be assigned to the clinical-rehabilitation group (5 subjects) or to the control group (5 subjects).

4.3 *Rehabilitative intervention*

The subjects assigned to the clinical group will undergo 15 cognitive-rehabilitation sessions with a three-weekly frequency, each session having a duration of 40–50 minutes (15–25 minutes in the virtual environment).

In the rehabilitation phase, the same tasks (stimuli) will be proposed to all the subjects in the same sequence. Each patient will be stimulated to perform the task successfully following cognitive rehabilitation techniques that take into account his deficits and his residual skills.

The rehabilitation protocol will contemplate the use of the virtual environment according to a growing complexity (the same for all subjects), with the aim of gradually retraining the patient to overcome his deficit, where possible, or propose to him compensatory strategies or aids that take into account his residual faculties and his specific deficits.

4.4 Assessment of effectiveness

The effectiveness of cognitive rehabilitation with the use of virtual reality will be assessed by comparing the results obtained at neuropsychological assessment (pencil-and-paper tools, assessment in VR) before and after treatment (within one week before start of treatment and one week after end of treatment) and by a person other than the rehabilitator.

The analysis of the results will be carried out both within each individual group (whether clinical or control) and by comparing the two groups.

5. CONCLUSIONS

Virtual reality technology could have a strong impact on neuropsychological assessment and rehabilitation. The key characteristic of VEs is the high level of control of the interaction with the tool without the constraints usually found in computer systems. VEs are highly flexible and programmable. They enable the therapist to present a wide variety of controlled stimuli and to measure and monitor a wide variety of responses made by the user.

However, at this stage, a number of obstacles exist which have impeded the development of active research specifically testing persons with cognitive impairments. These obstacles include problems with acquiring funding for an almost untested new treatment modality, the lack of reference standards, the non-interoperability of the VR systems and, last but not least, the relative lack of familiarity with the technology of researchers working in these areas.

The aim of this project is the creation and validation of various VEs to improve the assessment and rehabilitation of topographical disorientation, a disease present in various cerebral pathologies.

Our project will also use the theoretical model of wayfinding in virtual environments, recently proposed by Chen and Stanney (1999). This model suggests that wayfinders generally commence by directly perceiving the environment or working from a cognitive map. In terms of direct perception of the environment, landmark knowledge is acquired by directly viewing indirect representation such as photographs. In terms of cognitive mapping, procedure/route knowledge is acquired to through direct experience or through simulated experience and stored in memory. In addition, survey/configuration knowledge may be acquired from direct perception of the environment or from map use and also stored in memory. The result of the integration of these three types of spatial knowledge is a cognitive map. Beyond spatial knowledge, cognitive maps may also contain wayfinding decision and plans.

Our hypothesis is that the study of spatial orientation through specific tasks, both in a normal sample and in subjects affected by topographical disorientation, can bring greater comprehension and validation of cognitive models of spatial orientation than that currently available.

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