Virtual exercises to promote cognitive recovery in stroke patients: the comparison between head mounted displays versus screen exposure methods

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ABSTRACT

Stroke can be considered as a major cause of death and the consequences are associated with different syndromes of the impaired physical, cognitive, behavioral and emotional domains. The cognitive rehabilitation is often related to improvement on executive functioning through repeated and systematic training in memory and attention exercises, in which virtual reality has proven to be a valid approach. Several devices have been used as visual outputs. Head mounted displays (HMD) and desktop screens displays are amongst them. HMD is usually perceived has being more immersive than screens. However, it presents several shortcomings if a widespread use is the objective. In this way, this study aims at assessing the prospect of opting for screen displays as an alternative to HMD within virtual reality (VR) based applications to rehabilitate memory and attention impairments in stroke patients. A sample of 17 patients with memory and attention deficits resulting from stroke were recruited from the hospital Centro de Medicina da Reabilitação do Alcoitão. The patients were randomly assigned to two different groups: (1) HMD based VR; and (2) desktop screen based VR. The patients in the experimental groups underwent a virtual reality (VR) training programme with 12 sessions regarding memory and attention exercises. These patients were assessed before and after the VR training sessions with the Wechsler Memory Scale for memory and the Toulouse Pieron for attention functioning. The results showed increased working memory and sustained attention from initial to final assessment regardless of the VR device used. These data may suggest better functional independence following VR-based intervention and support the use of non-expensive displays as an alternative to high-end setups commonly used in VR applications devised for rehabilitation purposes.

1. INTRODUCTION

Stroke is a major cause of death in the developed countries and can give way to severe cerebral lesions that are accountable for motor disabilities and cognitive impairments, resulting in personal, professional and social dysfunctioning (Wang et al, 2004). Most of the impairments reveal themselves in the form of attention and memory deficits that, more often than not, may compromise patients’ daily life activities. Being so, a recurrent approach devised to rehabilitate these functions should rely on exercising daily life activities through systematic and regular training (Baumer et al, 2001).

In this context, several studies are in development in order to assess the role of neuropsychological rehabilitation in cognitive and motor recovery. The scientific literature is in agreement with respect to the development of neuropsychological approaches, that they have to gather the scientific knowledge from different areas of psychology. The most widely known approaches for cognitive rehabilitation are function based approaches for neuro-rehabilitation since this are focused on a specific cognitive or motor domain.
(Sohlberg and Mateer, 2001). The repetitive practice is also an important aspect in motor and cognitive training as it improves performance in disabled patients (Chen et al, 2004).

The exercises devised to rehabilitate motor disabilities or cognitive impairments should observe rehabilitation’s trinity: repetition, feedback and motivation (Holden, 2005; Allred et al, 2005; Cirstea and Levin, 2007). As an attempt to boost these entities, virtual reality (VR) exercises are now considered a sound option. VR offers the possibility of an endless repetition, providing visual, auditory and haptic feedback; and, because VR platforms are usually perceived as a game, patients are engaged, driven and, as a result, motivated by the exercise (Allred et al, 2005). In fact, according to Cirstea and Levin (2007) in a virtual environment, training exercises can be considered as more engaging and motivating than the traditional approach.

Also, some authors (Levin et al, 2005) argued that using VR applications in rehabilitation may benefit training purposes, mainly through the 3D spatial correspondence between movements in the real world and movements in the virtual worlds, which may facilitate real-time performance feedback. While repeating the exercises, patients’ senses are provided with feedback about the accomplishments achieved, which may improve performance in disabled patients.

VR seems, during hospitalization, to promote a more intensive and program supportive approach to the execution of exercise, providing appropriate feedback to the patient. Also, exercises may be displayed with an adapting degree of difficulty, making possible the use of non-invasive forms of physiological monitoring. VR, in addition, gives therapist the ability to individualize treatment needs, while providing the opportunity for repeated learning trials and offer the capacity to gradually increase the complexity tasks while decreasing therapist support and feedback (Weiss and Katz, 2004). VR is a promising response to shorter hospitalization and foster homecare (Giorgino et al, 2008).

Motor aspects of using VR environments were also studied (Viau et al, 2004). They analyzed movements performed by participants with hemiparesis with virtual objects in VR and real objects in real environments. These authors found no differences between the movements performed in VR and real environments and suggested that this VR technique can be an effective training for rehabilitation. Other studies (Edmans et al, 2006) aimed at training a specific function (making a hot drink) in stroke patients in a real and virtual world conditions. Data suggested that virtual applications can be used for rehabilitation of stroke, but the neural mechanisms underlying performance in a virtual world can be different than real life situations. For example, real world performance was associated only with motor planning, whereas in a virtual world performance was more associated with praxis. Moreover, Knaut and collaborators (2009) studied arm and trunk movements with kinematics in a sample of stroke patients with hemiparesis. Results were in line with previous studies and can suggest that VR can be used for clinical interventions with these patients.

Typically VR may be experienced using one of following types of settings: (a) desktop personnel computer (PC); (b) workbench; (c) CAVE (CAVE Automatic Virtual Environment), (d) HMD (Head Mounted Display) and (e) screens. PC, workbench and CAVE are usually neglected on rehab studies. On the workbench, immersion and presence levels are reduced and the CAVE represents a financial investment difficult to attain by the majority of the research groups. Consequently, HMD and screens are the most currently used. The HMD, when associated to a tracking system, allows a 360 degree field of view and 3D stereoscopy, which is considered to be responsible for its effectiveness on immersion. On the other hand, most HMD are heavy, expensive and, when used for long time, may cause retinal strain. Screens allow more than one subject at a time and are not as much intrusive as HMD are. Nevertheless, and because field of view is limited to projection area and as tracking system is missing, screens are usually considered to be less immersive.

Although the use of VR devised to rehabilitate motor and cognitive impairments is being studied intensively, there is no agreement regarding the best way to provide VR exercises to brain lesion patients. Given the previous literature on this topic, the main purpose of this study was to test the use of a VR training environment to promote cognitive recovery of memory and attention deficits in stroke patients, but also to compare memory and attention outcomes between two groups of stroke patients using, each, HMD or PC screen displays.

### 2. METHODOLOGY

#### 2.1 Sample

A sample, consisted of 17 patients (M= 51 years old; SD = 14 years), in which 58% were males and 42% were females with memory and attention deficits as a consequence of stroke was collected from the
rehabilitation hospital Centro de Medicina da Reabilitação do Alcoitão. All patients had more than 12 years of formal education.

Exclusion criteria were as follows:
- More than 6 months after stroke episode (Figure 1);
- Comorbidity of language disorders;
- Dementia;
- Other previous psychiatric disorders that may have an impact on memory and attention, such as drug addiction behaviors or severe depression.

![Figure 1. Time since injury.](image)

From the initial sample, 9 patients (M = 55 years; SD = 9 years) were assigned to the desktop VR experimental group, whereas the remaining 8 patients (M = 45 years; SD = 16 years) to the HMD experimental group.

There were no significant differences in age and years of education and time since injury between the patients assigned to desktop VR and HMD (p > 0.05). Moreover, gender was also equally distributed between the two experimental groups (p > 0.05).

2.2 Measures

Given that cognitive impairment after a stroke is frequently associated memory and attention impairments, each patient was assessed through a brief screening test, the Mini Mental Examination Test (Folstein et al., 1975) that was previously validated to the Portuguese population by Guerreiro and collaborators (1994). Memory and attention deficits were considered when Z scores in memory and attention subscales were 2 SD (standard deviation) below the normative data.

During the neuropsychological intervention, our main concern was to stimulate memory and attention abilities since these are important components of executive functioning. In this way, each patient was assessed in two different moments (before and after training) with the Wechsler Memory Scale – WMS-III (Wechsler, 1954) and the copy of Rey Complex Figure – RCF (Osterieth, 1994) for neuropsychological evaluation of memory, and the Toulouse Piéron – TP (Piéron, 1955) for attention and concentration abilities.

2.3 Procedures

This study was carried out at the Psychology Department of the Centro de Medicina da Reabilitação de Alcoitão, Lisbon, Portugal.

This study leaned on different types of cognitive exercises that were performed by 9 patients in a HP Intel® Core™2 Quad Processor Q6600 PC equipped with a GeForce GT 220 and a 21” Asus VE228D screen display (1680 X 1050 pixels of screen resolution); and by 8 patients in the same PC but, in this case, plugged to a HiRES eMagin Z800 HMD.

The VR environment was developed using Unity 2.5 (Unity TechnologiesTM) and consisted of a small town with a 2 room apartment and a minimarket in the vicinity. The interaction with the VR environment was performed using left mouse button to move forward and the right to move backwards. The space key on the keyboard was configured as an action button, to grab the objects and interact with virtual objects. Patient’s avatar was spawned in the apartment’s bedroom, from where they accomplished each session tasks by moving towards the final goal described bellow. The therapist role was to explain sessions’ procedures and to assess the session outcome.

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The study design unfolded throughout 12 sessions (one session per week). On first session, memory and attention tests (WMS-III, RCF and TP) were applied. On second and third session patients acquired computer interaction skills on a training platform. The next nine sittings were used for cognitive training by VR.

Cognitive training comprised personal orientation tasks, such as the execution of daily living activities of morning hygiene, meal preparation and dressing (i.e., choosing the right clothes to wear); working memory (i.e., buying several items with a certain amount of money) and recognition memory tasks (i.e., recognition of outdoor advertisements); visuospatial orientation tasks (i.e., finding a different way to the minimarket) and selective attention tasks (i.e., finding a yellow dressed virtual character). In the last session were applied again memory and attention tests. An example of these tasks can be found below (Figure 2).

![Example of VR training tasks](image)

**Figure 2.** Example of the VR training tasks. The top panel shows personal orientation tasks, the mid panel is for working memory, whereas visuospatial orientation and selective attention tasks are illustrated at the bottom panel.

### 3. RESULTS

The statistical procedures were carried out through repeated measures ANOVA with one within-subjects factor (before intervention vs. after intervention) and a between-subjects factor (HMD vs. desktop screen).

As regards to memory, the ANOVA performed to WMS total scores and to RCF scores showed a main effect of evaluation in the WMS (F(1, 16) = 12.491; MSE = 117.813; p < 0.01) and the and the RCF (F(1, 16) = 8.676; MSE = 19.709; p < 0.05).

These data revealed a significant increase in WMS scores (M = 85.71; SD = 3.89 vs. M = 98.94; SD = 3.99) and RCF score (M = 11.41; SD = 1.83 vs. M = 15.77; SD = 2.49) from initial to final assessment. However, no significant interaction effects were reported between factors (p > 0.05) in the WMS and RCF assessments (Figure 3).

Also, data indicated a main effect of evaluation in the TP test (F(1, 16) = 15.935; MSE = 542.598; p < 0.01), suggesting that sustained attention increased from initial (M = 75.69; SD = 10.83) to final assessment (M = 108.56; SD = 16.23) when assessed with the TP test. There were no significant interaction effects (p > 0.05) between evaluation and VR device (Figure 4).

These data also suggest that the use of VR environments might be a valid alternative for cognitive training in stroke patients. A control sample is, however, missing. Enhanced working memory and attention
and concentration abilities may also imply better functional independence in brain injured patients, which is one of the major goals of neuropsychological rehabilitation.

**Figure 3.** WMS mean scores (left figure) and RCF mean scores (right figure) to each experimental condition.

**Figure 4.** TP mean scores to each experimental condition.

On the other hand, results revealed no interaction effects between factors (p > 0.05), suggesting that these improvements did not interact with display method of exposure. These outcomes may indicate that training cognitive functions in VR settings is, probably, an option to traditional training procedures and that non-expensive displays, like PC screens, are an alternative to posh setups such as the HMD.

### 4. CONCLUSIONS

VR applications have long been applied for rehabilitation purposes. Its use to train cognitive functions it is now common. VR applications carry out several advantages when compared to the traditional counterparts. They are immersive, enable a certain amount of free will and they are ecological sounded. One entity that has been working as a propeller is the videogame industry. There are now available off-the-shelf graphic engines that are relatively easy to use and that produce realistic and interactive synthetic worlds. Also, on the hardware side, computer components like CPUs and graphic boards are giving a hand. So are the associated output devices such as screens, HMD (head mounted devices), or CAVE (CAVE Automatic Virtual Environments).

Screens and HMDs are usually therapists’ choice (CAVE are expensive and require extra manpower). HMD are immersive and, more often than not, are coupled with a head tracker that emulates one’s head movement in the virtual world. On account of that they should be “today’s special”. However, they are not. They are more expensive than screens, they can cause visual discomfort and, above all, they are a stand-alone extra difficult to justify for lay users such are common patients and therapists. Furthermore, the evolution of screen based displays has placed screens competing shoulder to shoulder with HMD technology. The quality of both general purpose TVs and computer displays, allied to first-rate and rather cheap sound systems, enable a decent immersive experience that could only be obtained, a few years ago, by HMD.

This apparent similitude is, however, in need to be challenged by scientific data. Accordingly, this paper aimed at comparing two samples of stroke patients that had each trained memory and attention functions with
a HMD and a PC screen display. The results showed that the observed improvement on those functions was independent from the device that was in use. This may indicate that screen based displays are a sounded option to HMD.

As in western countries the elderly population is increasing and the average age of stroke is decreasing, combined with reduced hospitalization periods, the need for rehab applications that can be handled outside health institutions facilities is paramount. Without the direct support of well-trained caregivers, exercises should be devised to be as much straightforwardly as possible. And so is the gear used for the VR experience. Under the same circumstances, i.e. producing equivalent therapeutic outcomes, the choice should go towards cheaper and easy to handle device such are screens.

In addition, this study also points towards the prospect of using VR exercises aimed at training memory and attention functions in stroke patients.

The cognitive rehabilitation exercises used in our programme were developed according to a cognitive retraining rationale with focus on memory and attention functions (Sohlberg and Mateer, 2001). In agreement with these authors the repetitive training of specific cognitive skills can help to recover disrupted functions leading to better adjustment in personal and social domains.

Indeed, despite the aim of the each intervention programme, meaningful improvement in patient’s everyday living activities must be the major goal of rehabilitation. One suggestion for further studies is that evaluation should focus also on the level of activity and engagement in activities of everyday living (ADLs). For example, level of performance in ADLs could be assessed through the caregivers’ opinions that could allow the understanding of personal, professional and social adjustment of these patients in basic and instrumental ADLs.

Also, controlled trials should be carried out in further studies to enable the comparison of VR based interventions with other conventional approaches or even with a waiting list group.

Although there is lack of support regarding the effectiveness of VR-based applications in cognitive rehabilitation, motor aspects of using VR environments were studied (Viau et al, 2004; Edmans et al, 2006; Knaut et al, 2009). These studies have suggested that the 3D spatial correspondence between movements in the real world and movements in the virtual worlds can benefit training purposes with VR applications. Another important issue with rehabilitation is the patient’s motivation to perform the predetermined exercises. In agreement to some authors training in a VR setup is perceived more as a game and less than a task and can be considered as more engaging and more stimulating than the conventional methods of rehabilitation.

5. REFERENCES


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