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RESEARCH PAPER

Cognitive training on stroke patients via virtual reality-based serious games

Pedro Gamito[1,2], Jorge Oliveira[1,2], Carla Coelho[1], Diogo Morais[1,2], Paulo Lopes[1,2], José Pacheco[3], Rodrigo Brito[1,2], Fabio Soares[1], Nuno Santos[1], and Ana Filipa Barata[1]

[1]*School of Psychology and Life Sciences, Lusophone University of Humanities and Technologies, Lisbon, Portugal,* [2]*COPELABS – Cognition and People-centric Computing Laboratories, Lisbon, Portugal, and* [3]*CMRA – Centro de Medicina de Reabilitação de Alcoitão, Sintra, Portugal*

Abstract

Purpose: Use of virtual reality environments in cognitive rehabilitation offers cost benefits and other advantages. In order to test the effectiveness of a virtual reality application for neuropsychological rehabilitation, a cognitive training program using virtual reality was applied to stroke patients. *Methods*: A virtual reality-based serious games application for cognitive training was developed, with attention and memory tasks consisting of daily life activities. Twenty stroke patients were randomly assigned to two conditions: exposure to the intervention, and waiting list control. *Results*: The results showed significant improvements in attention and memory functions in the intervention group, but not in the controls. *Conclusions*: Overall findings provide further support for the use of VR cognitive training applications in neuropsychological rehabilitation.

Keywords

Cognitive training, neuropsychological rehabilitation, stroke, virtual reality

History

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➤ Implications for Rehabilitation

- Improvements in memory and attention functions following a virtual reality-based serious games intervention.
- Training of daily-life activities using a virtual reality application.
- Accessibility to training contents.

Introduction

Stroke is a major global health problem that affects millions of people every year; it is the third main cause of death and the most common reason for disability worldwide [1]. Stroke is responsible for cognitive impairments and motor deficits resulting from brain damage, which affects more frequently the parietal, frontal, midbrain or brainstem structures and may reflect in language, attention, memory and executive dysfunctions with a significant impact on daily life activities [2].

A growing body of research suggests that information and communication technologies (ICT) have an increasingly important role in the neuropsychological rehabilitation of patients with acquired brain injury. One technology has made a particularly relevant contribution: virtual reality (VR). The use of VR applications in health care has been progressing steadily and is now a well-established reality. Research on VR-based interventions on patients with mental or physical dysfunctions date from the late 90 s, and its overall results suggest that this technology improves the quality of physical and mental health care while reducing its cost, and is thus both a viable and valuable option to consider when treating mental or other physical conditions that lead to disability [3].

One of the areas that have shown the most positive effects of VR technology is that of neuropsychological rehabilitation in patients with acquired brain injury [4–7]. Traditional methods for neuropsychological rehabilitation of particular cognitive functions that have become impaired as a result of stroke usually consist of paper and pencil exercises and tests. Some authors have argued that the use of VR in the contexts of treatment and evaluation is at least as sensitive as traditional methods of cognitive assessment and overcomes several of their limitations [8]. Likewise, other studies [4] have pointed out that VR-based rehabilitation methods have several important benefits when compared to traditional methods: VR settings, although involving controlled environments, are more ecologically valid; patients receive immediate dynamic feedback; training involves progressive learning, repetition, and setting and task customization according to users' requirements; and there are no physical consequences from errors.

The first of these aspects of VR-based interventions in particular must be highlighted. Brain injuries often lead to a reduced functionality of daily life activities. It is possible through the application of a VR setup not only to offer a cognitive training within a restorative approach, but also one with a relevant contribution to overcome constraints in the daily life activities. This is achieved mainly because the VR environments replicate real-life situations, thus producing more ecologically valid

Address for correspondence: Pedro Gamito, PhD, COPELABS/ULHT, Campo Grande, 376, Lisbon 1749024, Portugal. Tel: +35 1217577006. Fax: +35 1217577006. E-mail: pedro.gamito@ulusofona.pt

exercises, which, unlike traditional pen-and-paper exercises, promote the generalization of learning strategies to the real world that they simulate [4]. Indeed, VR allows the creation of a fully multimodal stimulation that simulates real life or imaginary situations, offering a greater sense of involvement during the exposure to the VR environments, and thus offering a dynamic and ecologically more valid training and assessment of patients' functionality.

The second of these aspects is that while VR technology allows users to actually interact with a multisensory simulated environment, it simultaneously provides real-time feedback on subjects' performance [9]. The third aspect is that the use of VR applications for cognitive rehabilitation during hospitalization allows for a more intensive training, which is crucial for the effectiveness of this approach [10]. It concurs with the assumptions of neuroplasticity, which proposes that the reorganization of neural circuits is achieved through the systematic repetition of training on particular tasks involving different cognitive abilities [9]. Finally, the VR setting implies that there are no physical consequences of errors, thus facilitating patients' adherence to the exercises without fear of the consequences of failure.

Besides these aspects, it is important to note that these applications have been developed in collaboration or in parallel to the videogame industry, making this technology less expensive and more accessible both for clinicians and for patients. Several of these games have also been adopted by physicians with rehabilitation purposes, despite not having been fully designed for rehabilitation goals [11].

The current study assesses the effectiveness of a VR-based intervention for the cognitive training and rehabilitation of stroke patients following these different aspects of the rationale behind this form of intervention by comparing patients submitted to the intervention to patients in waiting list control. The VR application used in this intervention was designed to reproduce general daily life situations and train functionality that is usually impaired after stroke, and following pre-specified sequences of aims and tasks. We measured general and visual cognitive abilities (due to the visual nature of the task) both before and after the intervention/ control.

Methods

Participants

Twenty-nine stroke patients were recruited from a hospital in the Lisbon region, Portugal. The exclusion criteria for this study were: (a) previous history of neurological or psychiatric disorders other than the stroke condition; (b) substance or alcohol abuse; (c) scores below the cutoff values in the Mini-Mental State Examination – MMSE [12]; (d) uncorrected visual deficiencies. Nine patients were excluded due to visual deficiencies or because they left the hospital before the end of the study. Participants gave their informed consent to the neuropsychological evaluation prior to enrolment. The final sample of 20 stroke patients (9 male) with a mean age of 55 years ($SD = 13.5$) and intermediate schooling was retained. These patients were randomly divided in 2 different conditions: (1) 10 patients (5 male) in the experimental group, consisting of intervention using VR applications; and (2) 10 patients (6 male) in the control group, consisting of a waiting list. No significant differences were found between groups for age, gender and education (all $p's > 0.05$).

Procedure

The study was run between October 2011 and July 2012 and was approved by an Ethic Committee based on the statement of ethical principles of the Declaration of Helsinki. Patients were recruited from a medical rehabilitation hospital by therapists from the research and intervention team introduced by in-house therapists, and were asked to participate in the study, explaining its benefits, duration, and demands on patients' time and commitment. During patient enrolment, exclusion criteria were assessed for each patient.

After the initial assessment with the neuropsychological measures, patients were trained to use the computer during a 1 h session, in which they were able to acquire interaction skills with the VR setup. The VR intervention program was run after this training session. Each of the patients was randomly assigned to either the intervention group or the control group based on simple randomization with random number generator. The patients were submitted to cognitive stimulation during their inpatient stay at the hospital by the same therapists involved in recruitment, who provided the mobile devices on which the application was run, fired-up the exercises, and explained how they worked to participants. The intervention consisted of 60-minutes sessions of cognitive stimulation with mobile technology using Serious Games (two to three sessions per week over the usual 4–6 week period of treatment). No institutional affiliations were presented in the e-health media. The executive training exercises performed by participants in the experimental group were selected in order to develop cognitive abilities related to executive functioning. In the assessments, another group of therapists provided, explained, and collected the assessment forms.

The cognitive training in the VR scenario comprised several daily life activities that were devised to train cognitive functions such as: working memory tasks (i.e. buying several items), visuo-spatial orientation tasks (i.e. finding the way to the minimarket), selective attention tasks (i.e. finding a virtual character dressed in yellow), recognition memory tasks (i.e. recognition of outdoor advertisements) and calculation (i.e. digit retention). These training tasks set gradually increasing demands on memory and attention abilities. This VR application for cognitive training was developed using Unity 2.5. (Unity Technologies™) and it is freely available at: http://copelabs.ulusofona.pt/scicommons/index.php/publications/show/533. Figure 1 depicts some of the tasks used during the neuropsychological intervention. The application was run on a 16'' ASUS M60V laptop with a 1GB ATI Radeon 4650 graphic board and an eMagin Z800 HMD.

Measures

The neuropsychological evaluation was based on the Wechsler Memory Scale [13], Toulouse–Piéron Test [14] and the Rey Complex Figure [15]. These tests were applied both before and after neuropsychological intervention. The MMSE was used only as a screening measure of cognitive impairment during patient enrolment.

The Wechsler Memory Scale – 3rd edition (WMS-III) is an assessment tool that allows evaluation of the different components of working memory. The WMS-III consists of seven sub-tests, namely, personal and general information, orientation, mental control, logical memory, digit span, visual reproduction and associative learning. The application of this test has an average duration of 30 minutes.

The Rey Complex Figure (ROCF) is a standardized approach to assess visual memory based on drawings of visual elements. The ROCF has three drawing trials: Copy trial; 3-minute Immediate Recall trial; and 30-minute Delayed Recall trial. In this study, we focused on immediate memory processes which are believed to be impaired in drugs addicts. Thus, we have used only the 3-minute Immediate Recall trial of the test. The maximum overall score of each trial is 36 points.

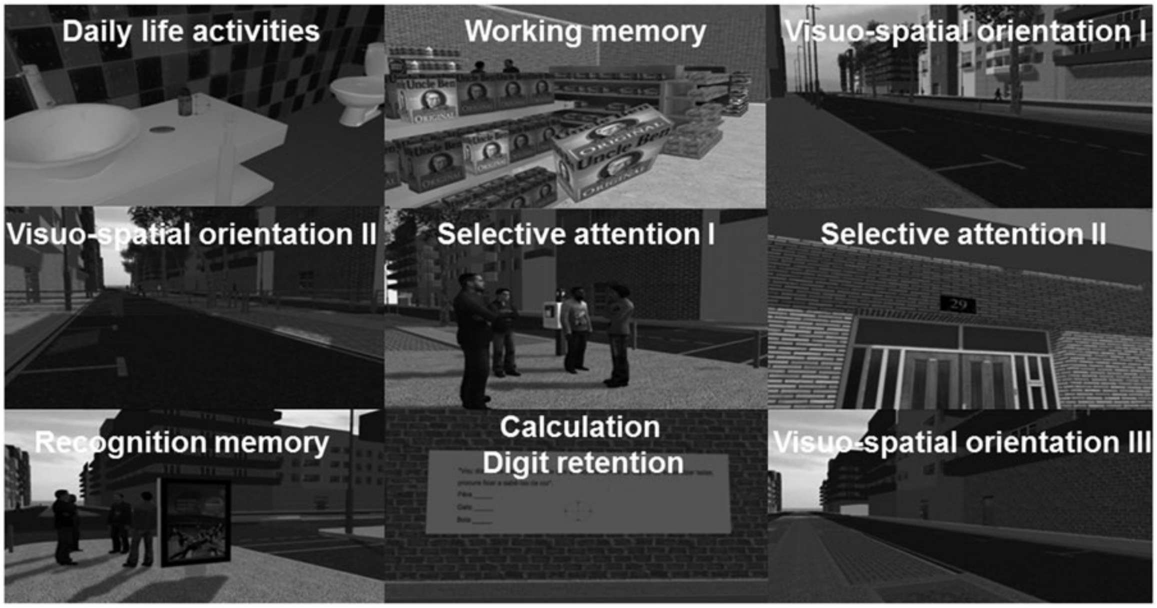

Figure 1. Virtual reality sessions during neuropsychological intervention (395 × 207mm (72 × 72 DPI)).

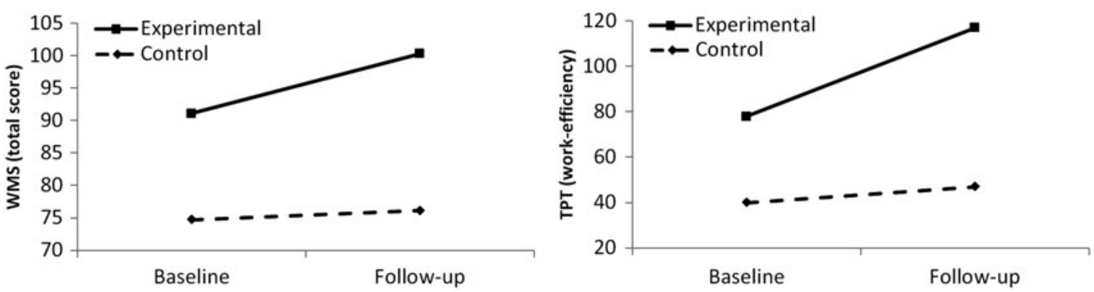

Figure 2. Estimated Marginal Means for total scores on the Wechsler Memory Scale (WMS) and work-efficiency of the Toulouse Pierón Test (TPT).

The Toulouse–Pieron Test (TPT) consists of a standard cancellation test involving symbols. The TPT is a test to assess sustained attention. Its main outcome measures are based on 2 different indexes: (1) work-efficiency, which is related mainly to processing speed; and (2) the dispersion index, which involves the resistance to distraction.

Results

Statistical analyses were performed using repeated measures ANOVAs with a within-subjects factor (assessment: baseline versus follow-up) and a between-subjects factor (treatment: experimental versus control). Separate ANOVAs were performed for the total score of the WMS, for work-efficiency and dispersion-index of the TPT, and for the Immediate Recall trial of the ROCF. The mean scores for each of the dependent variables under study are shown in Figure 2.

The results for the WMS showed a significant interaction effect between factors ($F(1,18) = 4.745$, $p = 0.043$). This interaction effect was decomposed into simple effects, with *Bonferroni* adjustment, which showed a significant improvement in scores of patients in the experimental condition at follow-up ($p < 0.05$), but no significant improvements in WMS scores of patients in the control group.

The same procedure was followed for the TPT-related variables. A significant interaction effect was also found on work-efficiency of sustained attention ($F(1,17) = 4.719$, $p = 0.044$). Simple effects analysis with *Bonferroni* adjustment revealed a similar pattern to that of working memory ability: there was a significant increase in work-efficiency in patients in the intervention group at follow-up ($p < 0.05$), but no significant effect in controls. Regarding dispersion index in sustained attention assessed with the TPT, there was only a marginally significant interaction effect between factors ($F(1,17) = 3.988$, $p = 0.062$), which was not further explored. In contrast to the results on the other measures, there were no significant simple or interaction effects of the intervention on the ROCF test, although simple tests in the intervention group did indicate an improvement.

Discussion

The current study was designed to test the use of VR applications in neuropsychological rehabilitation. For this purpose, we tested the effect on stroke patients of a VR rehabilitation program with exercises developed specifically to train attention and memory abilities. Overall results suggest that there is a beneficial role of this approach in memory and attention functions, although, given the lack of power, we did not find significant results on visual memory assessed with the ROCF. It is worth noting that even in this case, results did improve in the experimental group at follow-up, but we found no interaction effects.

In any case, the comparisons between the experimental group and controls revealed a difference between those groups in attention and general memory ability assessed with the WMS. These results provide further support for previous findings reported in the field. For example, some studies suggest that VR used as rehabilitation technique may be important to restore attention, memory and spatial orientation [16]. Other results indicate that rehabilitation of memory using VR promotes procedural learning in subjects with memory deficits [17].

To conclude, these results support the effectiveness of VR-based training for cognitive rehabilitation of memory and attention functions in stroke patients. According to some studies, in order to occur the transfer of impaired cognitive functions to intact brain regions, training of these cognitive functions should be challenging, repetitive, motivating and intensive [17]. Our results suggest that VR achieves these goals.

Further research is needed, however, to clarify if it does this more effectively than traditional forms of cognitive training. Additionally, we usually assume that there is a greater adherence to training process due to the gaming characteristics of the process, but this assumption has not yet been tested. Other assumed advantages of VR-based cognitive therapy, such as shorter periods of training required for rehabilitation, also need to be tested. On the other hand, some advantages are obvious and are part and parcel of its technological possibilities, such as the greater ease of access to the training contents and protocols, as they are available online and can be run almost anywhere outside the lab.

Declaration of interest

The authors report no declarations of interest.

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