Traumatic brain injury memory training: a virtual reality online solution

P Gamito[1,3], J Oliveira[1], J Pacheco[2], D Morais[1], T Saraiva[1], R Lacerda[2], A Baptista[1], N Santos[1], F Soares[1], L Gamito[1,3], P Rosa[1,4]

[1]Faculty of Psychology, University Lusófona of Humanities and Technologies, Campo Grande, 378, Lisbon, PORTUGAL

[2]Centre of Medical Rehabilitation of Alcoitão, Rua Conde Barão, Alcoitão, PORTUGAL

[3]Clinic of São João de Deus, Rua António Patrício, 29, Lisbon, PORTUGAL

[4]CIS, ISCTE/IUL, Avenida das Forças Armadas, Lisbon, PORTUGAL

pedro.gamito@gmail.com

[1]*www.ulusofona.pt,* [2]*www.scml.pt,* [3]*www.saojoaodedeus.pt,* [4]*iscte.pt*

ABSTRACT

This study aims at assessing an online portal where patients with traumatic brain injury (TBI) can carry on memory and attention exercises outside clinic premises. The training took place in a VR setup where one TBI patient had to complete a set of 10 online VR sessions. The neuropsychological evaluation was carried out with the PASAT (Paced Auditory Serial Addition Task) at pre, during and after treatment assessments. The results showed an increase in working memory and attention levels from the first to the final assessment, which can suggest that VR applications may promote the autonomy and increase in overall quality of life of these patients. The average time for task conclusion was of 5 minutes.

1. INTRODUCTION

Patients suffering from Traumatic Brian Injuries (TBI) need, in most cases, to relearn almost all daily life activities (Wang et al, 2004). The consequences of TBI can be very severe and range from motor disability to cognitive impairment or attention/concentration deficits (Bäumer et al, 2001). The cognitive impairment is defined by Cooper et al (2008) as a limitation in capacity for mental tasks and is often associated with deficit on executive functions. The cognitive recovery after TBI is slow and difficult and, in most cases, involves training daily life activities (Wang et al, 2004).

Concerning the application of the new technologies on rehabilitation, the most promising advance may reside on the use of virtual reality in combination with Internet wideband in order to provide and support rehabilitation training. The use of 3D (3 dimensions) virtual environments offers the possibility of real-time feedback of subject's position and progression (Sveistrup, 2004). Concerning rehabilitation, its three core pillars: repetition, feedback and motivation may gain from the use of virtual reality (VR) (Holden, 2003). In rehabilitation, one of the most common procedures is the repeated and systematic training of the impaired functions (Allred et al, 2005). In agreement to the review from Sveistrup (2004), VR can provide training environments where repetition, visual and auditory feedback can be systematically manipulated according to individual differences. For Levin et al (2005) the use of VR applications in rehabilitation can be effective because of the 3D spatial correspondence between movements in the real world and movements in the virtual worlds which, in turn, may facilitate real-time performance feedback. Other studies (Cirstea & Levin, 2007), referred that performance feedback can provide information regarding impaired motor movements and according to Sveistrup (2004), the improvement of functional capabilities is better achieved with verbal or physical guidance actions for the patients.

The repetitive practice is also an important aspect in motor and cognitive training as it improves performance in disabled patients (Chen et al, 2004). These authors used VR environments in children with cerebral palsy and observed that the repetitive practice of a particular motor aspect enables the coordination of a specific muscular system. While, repeating the exercises, patients' senses are provided with feedback about the accomplishments achieved. For example, Feintuch et al (2006) developed a haptic-tactile feedback

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system that, when integrated on video-capture-based VR environment, enables patients to feel a vibration on their fingers whenever they “touch” a ball on the VR world. Viau et al (2004) 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.

And because VR is usually presented on a multimodal platform with several sorts of immersive cues, such as images and sounds, patients are more willing to engage and pursue with the exercise. Bryanton et al (2006) found that when compared to conventional exercise, children with cerebral palsy had more fun and tended to repeat more often at home ankle dorsiflexion chair and long-sitting VR exercises.

VR seems, during hospitalization, to promote a more intensive and program supportive approach to the execution of the 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 & Katz, 2004). VR is a promising response to shorter hospitalization and foster homecare (Giorgino et al, 2008).

Studies on VR rehabilitation are usually focused on motor rehabilitation following brain damage and on training people with intellectual disabilities (Attree et al, 2005). However, VR has been also applied to rehabilitate patients that had suffered traumatic brain injuries (TBI). Slobounov et al (2006) found VR to be useful as a tool to assess brain concussion. A VR system was developed to inspect the temporal restoration of the effect of visual field motion on TBI’s subjects with short term and long term balance anomalies. The study of memory and attentional problems is important for many patients with a history of TBI, even when they are not a primary problem. Wilson et al (2006) stresses that the automaticity of basic movement skills are often learned in controlled environments. Once the patient is required to apply skills in real-world settings, demands on attention and on working memory often exceed their processing and response capabilities. Also, skills’ compliance in the previous stages of rehabilitation is inhibited by disruptions to attention and working memory processes. Patients with acquired brain injuries may find it tricky to train both a primary task (e.g. walking) and a simultaneous secondary task (e.g. signal detection). During the skill learning phase, the function of attention and memory can be supported by visual and verbal cues that can signal attention to obstacles and forthcoming events. Nevertheless, the use of attention and memory training with therapeutic purposes using VR, with TBI patients, is not yet clear (Sveistrup, 2004).

The wideband technology provides mobile and remote application of the 3D virtual environments brought about a new area of application: telerehabilitation. Due to the disability characteristics or to the distance from the rehabilitation clinic, or both, an important part of the patients neglect training sessions (Sugarman et al, 2006). Telerehabilitation may take the exercises to the patients. Lewis et al (2006) developed a telerehabilitation application that enables therapist to communicate, control and monitoring patients’ exercises remotely. This system comprises rehabilitation devices such as gloves and HMD on the patient’s side and a web camera and headphones on the remote therapist side. However, it requires the effective participation of the therapist. This may be overcome by the replacement with an avatar. This synthetic person, armed with artificial intelligence, can coach the patient throughout the rehabilitation exercises dismissing therapist’s involvement. Despite the increasing studies on this subject there are not many controlled studies that prove the efficiency of VR when it comes to rehabilitation (Holden, 2003). However, on all of them (Todorov et al; Rose et al; Brooks et al; Webster et al, cit in Holden, 2003), subjects performed better on VR set-ups than on real life exercises

Furthermore, there is lack of information regarding to the effectiveness of this approach on web based systems. Actually, there are several studies that are evaluating the effectiveness of offline virtual environments on rehabilitation training (Liebermann et al, 2006). However, and to our best knowledge, studies on the use of VR over an online platform for telerehabilitation and TBI purposes are still missing.

2. METHOD

2.1 Participant

One 20 years old male patient with memory and attention deficits resulting from TBI was recruited at the rehabilitation hospital Centro de Medicina da Reabilitação do Alcoitão. Neuropsychological screening was performed using the Wechsler Memory Scale-III (WMS). On the other hand, TBI severity was estimated with the Glasgow Coma Scale (GCS) that revealed a severe TBI level within 48 hours after injury.

The inclusion criteria were as follows: a) diagnosed with TBI between three and twelve months after the injury; b) clinical deficit in memory and attention; c) from both genders between 18 and 60 years old. Exclusion criteria: patients with previous psychiatric disorders that may have an impact on memory and attention, such as drug addiction behaviors or severe depression, as well as neurological diseases, namely dementia in its possible various forms.

2.2 Measures

Neuropsychological deficits were diagnosed through the WMS-III (Wechsler, 1997) based on working memory subscale.

TBI severity was classified according to the GCS (Teasdale, Jennett, 1974). The GCS is the most widely used instrument for neurological assessment after TBI. This instrument is divided into three subtests, for eye opening response, verbal response and motor response. TBI severity is classified in a score that range from 3 to 15, where 3 corresponds to deep coma and 15 to fully awake and conscious subject.

The neuropsychological assessment for this experiment was divided in three phases: PTA – Pre-Treatment Assessment (session 1); ITA – Intermediate Treatment Assessment (session 5) and POSTA – Post-Treatment Assessment (session 9). The assessment was conducted by the Paced Auditory Serial Addition Task (PASAT) for neuropsychological evaluation of working memory and attention. The PASAT consists of two auditory lists of single numbers with a total of 60 numbers for each trial, presented in sequence with an inter-stimulus interval of 3 and 2 seconds, respectively. The patient has to listen to consecutive numbers and to verbally respond with the sum of each number. Because the PASAT requires the ability to retain information during extended periods of time, the test can be used to assess sustained attention and working memory processing.

In order to evaluate task performance, behavioral assessment was also performed. The completion time of each task was registered and used further as an indicator of task performance speed.

2.3 Procedures

This study took place in a room of the Psychology Department of the Centro de Medicina de Reabilitação de Alcoitão, Lisbon, Portugal. The patient was selected from the Rehabilitation Ward after acquiring memory and attention deficits from a motor vehicle accident.

The VR platform consisted on a small town populated with digital robots (bots). The town comprised several buildings arranged in eight squared blocks, along with a 2 room apartment and a mini-market in the surroundings, where the participant was able to move freely around and to grab objects, if wanted. The platform was developed using Unity 2.5.

The patient interacted with the VR worlds through an eMagin Z800 HMD (Head Mounted Display), moving around by pressing the left mouse button. For grabbing the 3D objects, the patient needed to press the f key on the laptop keyboard. Patient's avatar was spawned in the apartment's bedroom, from where he accomplished each session tasks by moving towards the final goal described further on. The HMD was hooked up to a 16'' ASUS M60 V with a 1GB ATI Radeon 4650 graphic board. The therapist role was to explain sessions' procedures and to assess the session outcome.j

The VR-based tasks consisted of 10 VR online sessions, such as follows:

Session 0: training interaction;

Session 1: daily life activities such as morning hygiene and breakfast, and working memory task such as finding the way to the minimarket and buying one item) (Figure 1);

Session 2: session 1 + working memory task: finding the way to the minimarket and buying several items (Figure 2);

Session 3: visuo-spatial orientation task I: finding the way from the minimarket back home (Figure 3);

Session 4: session 1 + visuo-spatial orientation task II: finding a different way to the minimarket (Figure 4);

Session 5: session 1 + a selective attention task I: finding a yellow dressed virtual character (Figure 5);

Session 6: session 1 + a selective attention task II: finding the door number 29 (Figure 6);

Session 7: session 1 + a recognition memory task: retention of outdoor advertisements (Figure 7);

Session 8: session 1 + calculation and digit retention tasks: Mini-Mental State Examination (Folstein et al, 1975) and Short test of Mental Status (Kokmen et al, 1991) tasks along the way (Figure 8);

Session 9: visuo-spatial orientation task III: spawned on a different local of the VR world, the patient had to find his way back home with an item bought at the minimarket (Figure 9).

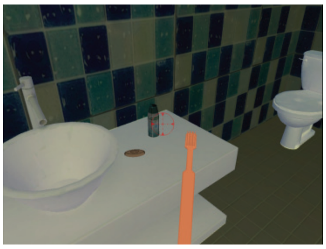

Figure 1. *Daily life activities.*

Figure 2. *Working memory task.*

Figure 3. *Visuo-spatial orientation task I.*

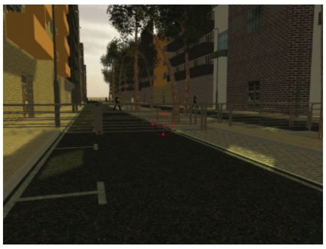

Figure 4. *Visuo-spatial orientation task II.*

Figure 5. *Selective attention task I.*

Figure 6. *Selective attention task II.*

Figure 7. *Recognition memory task.*

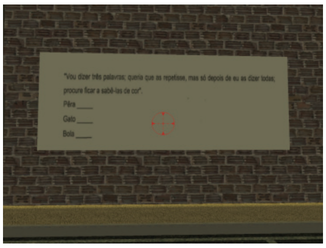

Figure 8. *Calculation and digit retention tasks.*

Figure 9. *Visuo-spatial orientation task III.*

3. RESULTS

PASAT data were analyzed for the corrected responses on each assessment (PTA, ITA, POSTA) for both trials – PASAT 3s and PASAT 2s. Values were considered significant for $p<0,05$.

Non-parametric pairwise comparisons were carried out by the χ^2 adjustment statistic to analyze the percentage of correct responses between assessments for both PASAT trials (3 and 2 seconds inter-stimulus intervals). For the first trial (Figure 10), data showed a significant increase in the percentage of correct responses between PTA and ITA ($\chi^2(1, 59) = 23{,}438$; $p < 0{,}001$), and between ITA and POSTA ($\chi^2(1, 59) = 41{,}667$; $p < 0{,}001$).

Regarding the second trial (Figure 11), data also revealed a significant increase in the percentage of correct responses between PTA and ITA ($\chi^2(1, 59) = 4{,}356$; $p < 0{,}05$), and between ITA and POSTA ($\chi^2(1, 59) = 5{,}689$; $p < 0{,}05$).

This means that the memory and attention exercises conducted on the VR world led to an improvement of the working memory and attention of this patient.

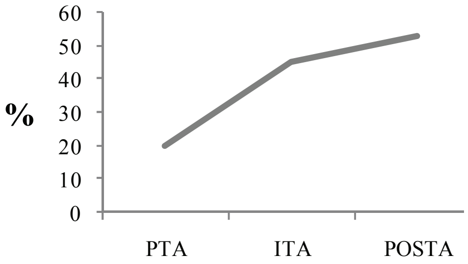

Figure 10. *Percentage of correct responses between assessments for the first PASAT trial (3s)*

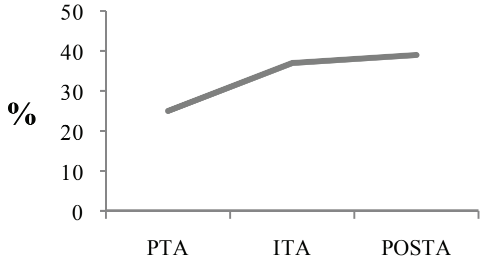

Figure 11. *Percentage of correct responses between assessments for the second PASAT trial (2s)*

Descriptive analyzes showed that the average completion time for each task was approximately of 5 minutes.

4. CONCLUSION

The main goal of this study was to assess an online VR platform for cognitive telerehabilitation of TBI patients. A preliminary VR session was conducted in order to evaluate possible navigation and interaction issues with the environment. The patient was able to achieve a satisfactory level of performance after some practice, with an average time for each task of 5 minutes. These data revealed a significant increase in working memory and attention levels, suggesting an improvement on patient cognitive function, which is in line with other studies that used VR platforms to increase memory and attention (Liebermann et al, 2006).

The importance of an online rehabilitation rests upon the ability to enable home training for patients that are far from the rehabilitation clinic or, for patients that still need to go to the clinic for training purposes. Other advantage resides on the ecologically validity of the training set. Being an immersive and interactive training, the fastidious repetition of traditional training is reduced. On a VR set, training 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 (Stansfield, Dennis & Suma, 2005).

However, only with a larger sample it would be possible to fully assess and understand the impact of training memory and attention on TBI patients over a VR online setting. Also, the dissemination of game platforms such as Wii®, Xbox®, Playstation 3®, may contribute to a enhanced and more user-friendly training environments. And one should not forget that for future generations, the PC and its peripherals will be no longer a strange element. Most of the resistance of this type of intervention may result on the suspicion, of both patients and therapists, in using information technologies.

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