Convergent validation of a virtual reality-based street crossing with neuropsychological tests in neglected and non-neglected stroke patients

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ABSTRACT

Unilateral spatial neglect is one of the most common and disabling impairments of stroke. The assessment of this deficit is carried out with paper and pencil tasks that can lack correspondence to everyday activities. Virtual reality can recreate realistic but safe environments that allow the therapists to study how the patients would react in real life situations. This paper presents a virtual street-crossing system that immerses the participants in a recreated street where they are asked to navigate safely. The presented study with chronic stroke patients showed remarkable correlations of the performing variables of the system with standard cognitive scales, which suggests that virtual reality systems can evidence alterations in cognitive skills, such as neglect.

1. INTRODUCTION

Unilateral spatial neglect (USN) is a common consequence of brain injury. It is one of the most disabling impairments since it affects the perception of the stimuli of part of the environment, which directly interferes on the performance of the activities of daily living (ADL) (Allegri, 2000). However, USN is traditionally diagnosed through paper and pencil tasks that are rarely associated with functional activities.

The use of virtual reality (VR) technology in the rehabilitation domain has given rise to several systems related with USN (Tsirlin et al, 2009). VR can immerse patients in realistic scenarios and monitor their performance, and therefore allow therapists to discern how they would react under real circumstances. Most of the VR systems are oriented to help the therapists in the assessment of the impairment. These systems present a specific virtual scenario and track the patients' performance while carrying out some actions (Kim et al, 2004; Tanaka et al, 2005; Broeren et al, 2007). Other systems provide rehabilitative exercises to diminish the effects of the neglect (Smith et al, 2007; Castiello et al, 2004). Those systems that recreate ecological and dangerous activities are especially interesting, since USN can prevent their safe execution in real life. The street-crossing task represents a good example of those activities. As a proof, this task has been previously used with successful results (Katz et al, 2005).

The objective of the presented work was to design a virtual street crossing system and to analyze its convergent validity with standard clinical scales used to assess unilateral spatial neglect and other cognitive skills (Table 1) in stroke patients diagnosed with and without neglect.

2. METHODS

2.1 Participants

For this study, a sample of chronic stroke patients was recruited from the neurorehabilitation service of the Hospital NISA Valencia al Mar. Inclusion criteria were: 1) chronicity>6 months; 2) Mini-Mental State Examination>23 (Folstein et al, 1975). Exclusion criteria were: 1) severe aphasia (Mississippi Aphasia Screening Test comprehension index<45 (Nakase-Thompson et al, 2005)) or dementia; 2) visual or hearing impairments that prevent the correct interaction with the system. The final sample of the study consisted of 32 chronic stroke patients with a mean age of 54.8±12.2 years (mean±std) and with a mean chronicity of 397.8±241.9 days (mean±std).

According the assessment through the conventional subtests of the Behavioral Inattention Test (BIT) (Hartman-Maeir and Katz, 1995), the sample was divided into two groups: neglected and non-neglected participants. 17 participants were diagnosed as neglected (BIT scores<129) and 15 as non-neglected.

2.2 Instrumentation

The VR system recreates a real scenario of the city of Valencia with a first person view. The virtual scenario covers an area that includes 2 two-way roads where different stimuli, such as cars, traffic lights, and simple lights and sounds, can be configured by the therapists to adjust different distractor levels according the attentional level of the participants (Figure 1).

Figure 1. *Comparison of the virtual (left images) and real (right images) world.*

The output of the VR systems consists of a 42” TV screen and a 2.1 sound system. The participants interact within the virtual environment by means of a joystick and a head tracking system. The joystick transfers translational displacements in discrete spatial directions, moving forwards and sideways, using a strafing technique. The head tracking system estimates the position of the head, although only the yaw rotations of the head are taken into account to change the yaw orientation of the camera view in the virtual environment. The head tracking is carried out by a NaturalPoint TrackIR™ system. The TrackIR™ is an optical tracking system that consists of an infrared optical camera which bounces an infrared light beam on the scene and a clip of reflective marks that reflect the light. The camera estimates the position of the clip from the reflections. The clip is mounted on a cap and can be easily worn (Figure 2).

2.3 Intervention

The study was carried out in a dedicated and controlled room of the neurorehabilitation service. The participants sat in front of the TV screen and held the joystick with their dexterous hand. In case of hemiparesis they used their unaffected hand. The participants were asked to perform twice the same task in the virtual system, which consisted of going from an origin point to an end point (supermarket) and then coming back. In each repetition, the participants were forced to cross the two-way roads 4 times (2 in each direction), avoiding the cars that could appear from the lateral sides. For this study, the time to complete the task and the number of accidents were registered. The task was considered uncompleted if the number of accidents was greater than 4. In addition to the VR outcomes, all the participants were assessed with a battery of scales taking into account different cognitive skills (Table 1).

Figure 2. *Hardware setting of the VR system. 1) TrackIR™ camera; 2) Clip of reflective marks; 3) Joystick.*

Table 1. *Cognitive assessment test battery.*

Behavioral inattention test (BIT)	Unilateral spatial neglect
Conner's performance test-II (CPT-II) (Conners et al, 2003)	Attention, vigilance, and impulsivity
Color trail making test part A and B (CTMT-A, CTMT-B) (Llorente et al, 2003)	Cognitive flexibility, mental processing speed, and visuomotor skills
Behavioral assessment of dysexecutive syndrome (Wilson et al, 1998)	
Zoo map test part 1 and 2 (BADS-ZMT-I and II)	Planning ability
Key search test (BADS-KST)	Problem solving

3. RESULTS

From the total sample, 14 non-neglected participants (93.3%) and only 3 neglected participants (17.6%) managed to fulfil the task. Focusing on the 17 patients that could finish the task, statistical analysis showed that participants without USN finished the task quicker and more safely than patients with USN (time to complete: $F=28.8$, $p<0.01$; number of accidents: $F=55.8$. $p<0.01$).

Besides that, the time to complete the task correlated with the CTMT-A ($r=0.75$, $p<0.01$), the CTMT-B ($r=0.55$, $p<0.01$), the BADS-KST ($r=-0.5$, $p<0.05$), the BADS-ZMT-1 ($r=0.6$, $p<0.01$) and the BADS-ZMT-2 ($r=-0.4$, $p<0.05$), and the hit rate ($r=0.6$, $p<0.05$) and the number of omissions ($r=0.6$, $p<0.01$) of the CPT-II. In addition, the number of accidents correlated with the BIT ($r=-0.7$, $p<0.01$), the BADS-KST ($r=-0.4$, $p<0.05$), the BADS-ZMT-1 ($r=-0.5$, $p<0.01$) and the BADS-ZMT-2 ($r=-0.3$, $p<0.05$).

4. DISCUSSION

The statistical analyses showed that the presence of USN dramatically affected the performance of the participants in the VR system. Most of the non-neglected participants not only finish the task but also achieved better scores in terms of speed and security. As expected in real conditions, neglected participants show worse performance. Consequently, the design of the system is coherent with the real world.

Regarding the relations of the VR outcomes with the neuropsychological tests, the time to complete the task correlated with those tests which take time measurements into account (the CTMT, BADS, and CPT) and did not correlate with the BIT. On the contrary, the numbers of accidents suffered in the VR session correlated with the BIT, which can show that the visual and perceptual skills required to safely carry out the virtual task are also involved in the BIT test to assess the USN. In addition, the requirements of higher executive functions (such as planning, multi-tasking, and problem solving) could explain the correlations of the number of accidents with the BADS scores.

In conclusion, the presented study with chronic stroke patients showed remarkable differences between the performance in the VR system of the neglected and non-neglected participants, and also showed correlations of the VR outcomes of the system with standard cognitive scales, which suggests that virtual reality systems can evidence alterations in cognitive skills, such as neglect, as previously reported (Tsirlin et al, 2009).

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