The potentiality of virtual reality for the evaluation of spatial abilities: the mental spatial reference frame test

S Serino[1], F Morganti[2], P Cipresso[1], E E R Magni[2], G Riva[1,3]

[1]IRCCS Istituto Auxologico Italiano,
via Pellizza da Volpedo, 41, 20149, Milan (MI), ITALY

[2]Department of Human and Social Sciences, University of Bergamo
Piazzale S. Agostino 2, 24129, Bergamo (BG), ITALY

[3]Università Cattolica del Sacro Cuore
Largo Gemelli, 1, 20100, Milan (MI), ITALY

s.serino@auxologico.it

[1]*www.auxologico.com,* [2]*www.unibg.it,* [3]*www.unicatt.it*

ABSTRACT

In recent decades, the use of Virtual Reality (VR) in the context of cognitive evaluation of dementia has considerably increased. The main objective of this preliminary study is to assess the feasibility of a VR-based tool for detecting deficits in using different spatial reference frames by comparing the performances of patients with probable Alzheimer's Disease (AD) with cognitively healthy controls. Although preliminary, our results showed the potentiality of using this VR-based tool to evaluate the ability in encoding and using different spatial reference frames.

1. INTRODUCTION

The ageing population (aged 65 and over) is projected to increase to 1.2 billion in 2025. Consequently, the prevalence of the dementia will significantly increase. Alzheimer's disease (AD) is the most common type of dementia, and it is estimated that the number of elderly affected will reach 81.1 million by 2040 (Ferri et al, 2006). Thus, the identification of early markers of cognitive decline in elderly population is now a worldwide health policy priority. In recent decades, the use of Virtual Reality (VR) in the context of cognitive evaluation of dementia has considerably increased (for a review, see (Bohil, Alicea and Biocca, 2011). VR technologies may be integrated in clinical and research settings to support the detection of early cognitive deficits by offering enriched environments with ecological but controlled demands (Riva, 2009; Rizzo, Schultheis, Kerns and Mateer, 2004). Precisely, VR offers the chance to easily control and manipulate the egocentric point of view to investigate the ability to encode and use different spatial reference frames. Indeed, spatial cognition may be defined as a high-level cognitive process based on two different spatial reference frames: an egocentric spatial frame in which object locations are represented relative to the individual and an allocentric spatial frame in which object locations are represented irrespective of the individual (Klatzky, 1998). Specifically, within the hippocampus, the CA3 region, receiving input from the entorhinal cortex, constitutes a cognitive model of the scene towards which the individual is drawn (namely, an allocentric view-point dependent representation) while the CA1 neurons, receiving input from the CA3 via Schaffer's collaterals, quickly encode abstract object-to-object information (namely, an allocentric view-point independent representation) (Behrendt, 2013; Robertson, Rolls and Georges-François, 1998). Accordingly, VR may be particularly useful for evaluating the cognitive profile of AD, since deficits in spatial cognition distinguish the first stages of this disease (Gazova et al, 2012; Lithfous, Dufour and Després, 2013). Nestor and colleagues (Pengas et al, 2010) who developed and tested a virtual navigation test— the Virtual Route Learning Test (VRLT)— for investigating spatial abilities in AD patients provided an interesting example. In this virtual test, participants are invited to learn four routes of increasing complexity. They are then required to retrieve the same route from memory but in reverse. The results showed that VRLT is able to detect spatial impairment in very early AD, as well as discriminate the AD patients from patients with Semantic Dementia. On these premises, we developed a VR-based tool – the Mental Spatial Reference Frame Test- to specifically evaluate the ability to encode and use different spatial reference frames. The main objective of this preliminary study is to assess the potentiality of utilizing this virtual tool to detect deficits in the use of different spatial reference frames by comparing the performances of patients with probable AD with cognitively healthy controls.

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2. MATERIALS AND METHODS

2.1 Participants

Overall, 16 participants, 8 cognitively healthy participants (CG, control group), and 8 participants suffering from probable AD (probable AD) according to NINCDS-ADRDA criteria, participated in the study (McKhann et al, 1984). The probable AD group comprised 2 women and 8 men while CG included 4 women and 4 men. CG and probable AD participants were recruited from different social senior centers located in Lombardy, Italy. Individuals did not receive monetary reward for their participation in the study and was asked to sign the informed consent to participate in the study.

2.2 Spatial neuropsychological assessment

To evaluate the cognitive functioning of the participants in the study, the Mini Mental State Examination – MMSE - (Folstein, Folstein and McHugh, 1975) was administered. Moreover, the probable AD group was also assessed using Milan Overall Dementia Assessment - MODA- (Brazzelli, Capitani, Della Sala, Spinnler and Zuffi, 1994), a brief neuropsychological test developed to evaluate dementia. To specifically evaluate the spatial abilities, the following standard neuropsychological tests were administered: Corsi Block Test (Corsi, 1972; Spinnler & Tognoni, 1987) to measure short-term spatial memory (Corsi Span) and long-term spatial memory (Corsi Supraspan); Money Road Map (Money, Alexander and Walker, 1965) paper and pencil assessment of left-right discrimination that requires an egocentric mental rotation in space; Manikin's Test (Ratcliff, 1979) used to evaluate general mental rotation abilities by asking participants to evaluate in which hand a "little man" (showed with different views) was holding a ball; and Judgment of Line Orientation (Benton, Varney and Hamsher, 1978) neuropsychological test to assess visuospatial judgment. All scores obtained from these neuropsychological tests were corrected for age, education level, and gender according to Italian normative data. Detailed demographic and clinical characteristics of the two groups are reported in Table 1.

Table 1. *Mean scores at neuropsychological spatial assessment tasks reported by the two groups of the study.*

	Group	
	Probable AD	**Control Group**
Age	82.2 (6.69)	82.9 (9.12)
Years of Education	6.13 (2.8)	9.38 (4.81)
MMSE	23.1 (1.49)	28.7 (.965)
MODA	66.2 (9.66)	
Corsi Block Test - Span	4.19 (.91)	4.75 (.5)
Corsi Block Test - Supraspan	5.58 (1.24)	9.61 (2.86)
Money Road Map	17.6 (3.70)	19.4 (6.02)
Manikin's Test	17.00 (3.07)	26.00 (3.55)
Judgment of Line Orientation	6.38 (5.63)	15.63 (5.75)

2.3 Mental Spatial Reference Frame Test

The Mental Spatial Reference Frame Test consists of two main tasks that assess the abilities to encode and use different spatial reference frames. In the encoding phase, the participant is asked to navigate in a virtual room including two objects, that is, starting from the center of the room oriented toward North, he/she has to memorize the position of two objects. On the first task (Task 1), she/he is asked to indicate the position of one object on a real map (namely, a retrieval with spatial allocentric information independent of point of view). On the second task (Task 2), she/he is asked to enter an empty version of the same virtual room. The participant has to indicate position of the object, starting from the position of the other object (namely, a retrieval without any spatial allocentric information). In both tasks, the accuracy of the answer is the dependent variable [1= poor answer, for example, choosing the opposite of the virtual room (i.e., choosing the southern side when the object in the learning phase was in the northern part); 2= medium answer, for example bad left-right discrimination (i.e. the eastern part of the virtual room, when the object in the learning phase was in the western side); 3= correct answer)]. The entire procedure was repeated across three different trials. In the first trial, the object in the learning phase was on the East side, in the second trial the object was on the West side, in the third trial the object was on the South side. From a technical point of view, the Mental Spatial Reference Frame was created using NeuroVirtual 3D, a recent extension of the software NeuroVR (Cipresso, Serino, Pallavicini, Gaggioli and Riva, 2014; Riva et al, 2011), which is a free virtual reality platform for creating virtual environments useful for neuropsychological assessment and neurorehabilitation. The virtual environments was rendered using a portable computer (ACER ASPIRE with CPU Intel® Core™i5 and graphic processor Nvidia GeForce GT 540M). Participants also had a gamepad (Logitech Rumble F510), which allowed them to explore and to interact with the environment.

3. RESULTS

The data were entered into Microsoft Excel and analyzed using SPSS version 18 (Statistical Package for the Social Sciences–SPSS for Windows, Chicago, IL, USA). First, differences in neuropsychological tests of spatial abilities between groups (CG vs. Probable AD) were calculated using one-way ANOVAs. The results showed significant differences between the two groups in all tests, with the exception of the Corsi Block Test - span and the Money Road Map. Specifically, when compared to CG, probable AD participants showed poorer spatial abilities. Then, differences in the scores on the Mental Spatial Reference Frame Test were calculated using a repeated measure ANOVA (Bonferroni's adjustment): 2 Tasks (Task 1 vs. Task 2) × 3 Trials as within factors, and Group (CG vs. probable AD group) as between variable. The results showed a significant effect of Trials, $F(2, 26) = 5.48$, $p < .05$, $\eta_p^2 = .301$. Specifically, pairwise comparisons indicated that the average scores were significantly lower on the third trials (M = 1.99, SD = 0.11) compared to the first trials (M = 2.55, SD = .12). Second, the results showed significant differences between the two different Tasks, $F(1, 13) = 20.30$ $p < .001$, $\eta_p^2 = .610$. In particular, pairwise comparisons revealed that the average scores were significantly lower in the Task 2 (M = 1.96, SD = 0.13) compared to the Task 1 (M = 1.96, SD = .13). Although we found no significant differences between Groups, it is possible to observe a trend toward significance in the interaction Trials x Tasks x Groups $F(2, 26) = 2.70$ $p = .086$, $\eta_p^2 = .176$. In particular, probable AD participants performed poorer on the third trial of the Task 2 (see Figure 2).

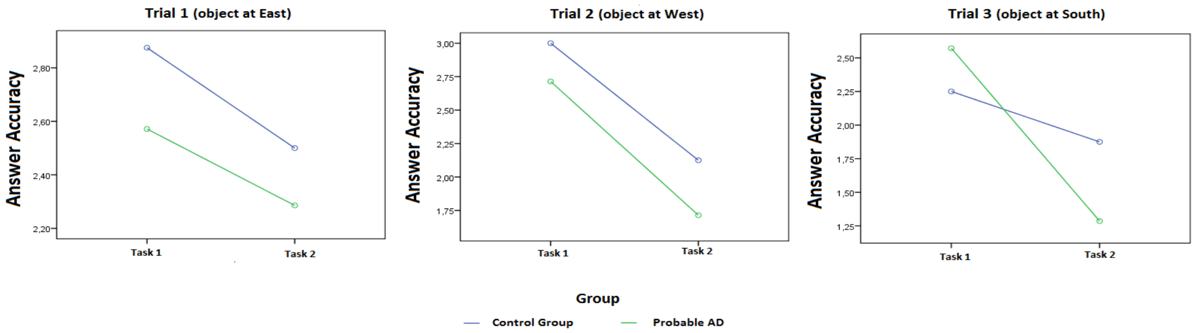

Figure 1. *Probable AD group performed poorer on the third trial (object in the South of the virtual room), especially in the Task 2.*

4. CONCLUSIONS

Due to the impressive growth of the ageing population, the identification of cognitive markers to characterize the profile of AD has been recently the focus of considerable research interest. In this direction, our main objective was to investigate the potentiality of using the Mental Spatial Reference Frame Test in the traditional neuropsychological evaluation of spatial abilities in patients suffering from probable AD. First, as expected, our results confirmed that probable AD patients were impaired in the traditional neuropsychological evaluation of spatial functions when compared with the control group. Concerning the results from the Mental Spatial Reference Frame Test, our findings showed that all participants were less accurate in completing the third trial, significantly when compared to the first one. The third trial may have been more difficult since the object was presented at the South end of the virtual room in the encoding phase, requiring a complete spatial rotation to retrieve it. Moreover, our results showed that all participants performed poorer on Task 2 when compared to Task 1. While the Task 1 measured the ability to encode and store an allocentric reference frame by asking participants to retrieve the position of the object on a real map, the Task 2 evaluated a more complex spatial ability, since the participants were required to indicate the position of the object in an empty virtual room without any spatial allocentric information. Indeed, to solve the Task 2, it was necessary to retrieve the object-to-object abstract cognitive representation of the scene and impose on it a new egocentric view- point. According to Burgess and colleagues (Byrne, Becker and Burgess, 2007), an effective spatial orientation in the surrounding environment requires a translation from a long-term allocentric reference frame to an egocentric one. Starting from this model, Serino and Riva proposed that for an effective translation between allocentric and egocentric spatial reference frames, it is crucial that allocentric view-point independent representation has to be synced with the allocentric view-point dependent representation (Serino & Riva, 2013, In press). From this perspective, our findings showed that probable AD participants performed poorer on the third trial of the Task 2, that is, when they were required a complete mental rotation, they showed a deficit in the synchronization between the allocentric view-point independent representation and the allocentric view-point dependent representation. A break in the "mental frame syncing", underpinned by damages to hippocampus, may be a crucial cognitive marker both for early and differential diagnosis of AD (Serino & Riva, 2013). The findings of this preliminary study are interesting, although some limitations should be acknowledged. First, the sample size was very small.

Moreover, it would be interesting to replicate this study using an immersive VR set-up. Future studies should investigate whether the detection of subtle spatial deficits could be used to identify individuals most at risk for progression to AD.

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