The Contribution of Allocentric Impairments to the Cognitive Decline in Alzheimer's Disease

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Abstract. An early decline in navigation abilities is one of the first sign of Alzheimer's Disease (AD). More specifically, it has been suggested that allocentric impairments contribute significantly to this pathological decline. In this vein, the objective of the current work was to investigate the contribution of different spatial abilities involved in navigation (including allocentric ones) to the cognitive decline. Thirty elderly participated in the study, divided into two groups: Fifteen cognitively healthy aged individuals and fifteen individuals with AD. Our results showed that patients with AD performed significantly poorer in almost all tests evaluating spatial abilities in comparison to cognitively healthy aged individuals. Interestingly, we found that the allocentric abilities were the only significant predictor of the cognitive decline. Overall, these results suggested the primary role of allocentric impairments in contributing to the cognitive pathological decline.

Keywords: Allocentric abilities · Spatial navigation · Virtual Reality Alzheimer's Disease

1 Introduction

Getting back home using a new route, visiting a museum in a new city, finding our car in a large parking lot: These are very common daily life situations in which spatial abilities play a key role. Spatial navigation, i.e. the ability of finding and tracking a path from one place to another [1, 2] is crucial ability needing the contribution of different cognitive abilities. Above all, it requires the ability to maintain an internal representation of the external environment, which includes the storage of spatial information in short and long-term memory collected from different sensory systems, and the manipulation of these representations for different navigational purposes [1]. A robust body of studies indicated that the cognitive profile of Alzheimer's Disease (AD) is

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severely characterized by early spatial navigation impairments [3–8]. Moreover, spatial impairments contribute seriously to the initial pathological decline observed in individuals suffering from Mild Cognitive Impairment (MCI), i.e. a transitional state between the physiological and the pathological aging, marked by a slight deterioration of cognitive abilities, especially involving memory [9]. Interestingly, AD and MCI patients show profound impairments involving both allocentric (i.e., a spatial reference frame based on object-to-object relations) and egocentric (i.e., a spatial reference frame based on self-to-object relations), with a major degeneration in using allocentric strategies [6]. Recently, Laczó and co-workers [10] found in a sample of 108 older adults (53 cognitively normal individuals and 55 individuals with amnestic MCI) that spatial navigation deficits may be distinguished from deficits occurring in other cognitive domains, thus suggesting the importance of a prompt testing of this cognitive ability to early detect suspicious cases of cognitive decline. Allocentric impairments are the core spatial difficulties in individuals suffering from AD and MCI [4, 6], since neurodegenerative processes primarily involve the medial temporal lobes and related areas [11–15]. Indeed, allocentric deficits could lead to great navigational impairments, preventing the patient from maintaining a coherent "cognitive map" of the external environment [16, 17]. A decline in spatial abilities characterizes also normal aging, with an impact in the ability to retain information [18–20] and use them for navigating in surrounding environment [4, 21]. In particular, this decline in spatial abilities concerns the ability to store allocentric representations, and a growing body of studies indicated that it starts around the 60 years of age, when there is a concurrent deterioration of medial temporal lobes [22–25]. For instance, Gazova and co-workers [22] used a human adapted version of the Morris Water Maze Test to investigate differences in allocentric, egocentric and learning abilities between younger and older participants. Findings pointed out a specific deficit in allocentric retrieval in older individuals, but no impairments in the other spatial abilities investigated. Starting from these premises, the aim of the current study was to conduct a systematic investigation of spatial abilities in a sample of patients suffering from AD and in a matched control group of cognitively healthy elderly individuals, focusing on the relation between spatial abilities involved in navigation (including the allocentric ones) and the general cognitive functioning.

2 Methods

2.1 Participants

Thirty elderly subjects participated in the study, divided into two groups: 15 elderly suffering from probable AD ("AD group") and 15 cognitively healthy elderly individuals (CG, control group). AD patients were recruited from a social senior centre located in Lombardy (Italy) from those referred as meeting the NINCDS-ARDRA criteria for probable AD [26]. These patients were further evaluated with the Milan Overall Dementia Scale [27] and only those having a score under 85.5 were included in the study. AD group had a mean score at the Mini-Mental State Examination - MMSE [28] of 22.11 (SD = 2.12). The cognitively healthy elderly individuals, who were recruited from a panel of volunteers without neurological or psychiatric disorders (evaluated with a brief interview), had a mean score of MMSE [28] of 28.79 (SD = 1.84). The AD group was composed of 11 women and 4 men, while the CG included 12 women and 3 men [(χ^2 = 0.186(1); p = 0.666)]. The mean age for the AD group was 86.73 (3.97), with a mean years of education of 7.33 (SD = 1.91), while the mean age for the CG was 83.53 (5.62), with a mean years of education of 5.87 (SD = 2.92). There were no significant differences between the two groups concerning neither age [t(28) = 1.801; p = 0.082)] or education [t(28) = −1.625; p = 0.115)].

2.2 Spatial Assessment

In order to examine the various aspects of spatial navigation, we carried out a comprehensive assessment of spatial abilities in terms of short and long-term spatial memory [the Corsi Block Test [29, 30] in both its version Corsi Span and Corsi Supraspan], visuo-spatial abilities [Judgment of Line Orientation - JLO [31], navigation abilities [Money's Standardized Road Map Test [32], and egocentric mental rotation abilities [the Manikin Test [33]. As concerns the assessment of allocentric abilities, a Virtual Reality (VR)-based procedure was employed (for a detailed description, please see [34, 35]) After an initial training in the use of VR technology, elderly individuals were invited to enter in a virtual room which included only two objects (i.e., a plant and a stone) and an arrow drawn on the floor, which pointed to the North (i.e., *encoding phase*). Elderly were asked to memorize the position of the plant, which was positioned at different points in the virtual environment. The entire procedure was repeated across four randomized trials. In the first trial, the stone was located on the north and the plant on the east side of the environment, while in the second one the stone was still located on the north, but the plant was on the west. In the third and in the fourth trial, instead, the stone was on the south, whereas the plant was posited on the east side for the third trial and on the west side during the fourth one. Successively, participants were asked to retrieve the position of the object they had previously memorized on a map – a full aerial view of the virtual room (i.e., *retrieval phase*). This task was used as a measure of the ability to retrieve a stored allocentric representation. The accuracy of spatial location was the dependent variable: 0 = no answer or poor answer (for example, choosing the same side of the retrieval point (i.e. the North); 1 = correct answer. To obtain a composite score, we also added up the scores obtained from each trial (namely, we obtained an index measuring the allocentric abilities, "Allocentric Abilities"). This VR-based procedure was developed using the software NeuroVirtual 3D [36].

2.3 Procedure

After administering the Mini-Mental State Examination to obtain a picture of the general cognitive functioning, the comprehensive assessment of different spatial abilities involved in navigation was delivered (i.e., Money's Standardized Road Map Test, Manikin Test, Corsi, Judgment of Line Orientation) by an expert neuropsychologist. As regards the VR-based task for measuring the allocentric abilities, participants were invited to sit comfortably in front of a portable computer (ACER ASPIRE with CPU Intel® Core™i5 and graphic processor Nvidia GeForce GT 540 M, 1024 × 768 resolution). A gamepad was used to explore and interact with the virtual room (Logitech

Rumble F510). The training phase was delivered to allow participants interacting autonomously with VR (approximately two-five minutes). Then, the VR-based task started.

3 Results

AD patients, relative to CG, displayed significantly poorer long-term, visuo-spatial and egocentric mental rotation skills, with greater deficiencies also in the "allocentric retrieval" (Table 1). In other words, AD patients performed significantly poorer in respect to cognitively healthy elderly controls in most of the spatial abilities investigated.

Table 1. Performance of participants suffering from Alzheimer's Disease (AD group) and of cognitively healthy elderly controls on spatial abilities. Values are shown as mean (SD)

	AD group	CG	t	df	p^1	d^2
Corsi Block Test-Span	4.217 (0.706)	4.617 (0.674)	−1.587	28	0.124	0.57
Corsi Block Test-Supraspan	5.001 (2.959)	9.904 (7.124)	−2.052	18.69	0.024	0.89
Manikin Test	20.60 (4.421)	25.53 (4.912)	−2.891	28	0.007	1.05
Judgment of Line Orientation	9.27 (5.946)	17.227 (6.273)	−3.585	28	0.001	1.30
Money Road Map	18.23 (4.809)	21.40 (4.748)	−1.872	28	0.072	0.66
Allocentric Abilities	1.933 (0.799)	2.733 (0.799)	−2.743	28	0.011	1.00

[1] *p*-value; [2] effect size (d > 0.80 can be considered as a high effect size).

A linear regression analysis was carried out to investigate the extent to which scores on the spatial assessment might contribute to the cognitive decline, using scores of MMSE (as a measure of cognitive functioning) as dependent measure. All independent variables were entered singularly into the model using the 'enter' method. Findings showed that spatial assessment was able to predict the pathological decline [R2 = 0.546; F(6; 23) = 4.61823; $p = 0.003$). However, results showed that the allocentric abilities were the only significant predictor of cognitive functioning (see Table 2).

Table 2. Summary table of the regression analysis with spatial abilities as predictors and MMSE as dependent variable. Beta unstandardized coefficient are reported.

	B	SE	t	*p*
Corsi Block Test-Span	0.649	0.827	0.784	0.441
Corsi Block Test-Supraspan	0.223	0.119	1.879	0.073
Manikin Test	0.103	0.162	0.638	0.530
Judgment of Line Orientation	0.074	0.099	0.747	0.462
Money Road Map	−0.101	0.145	−0.696	0.494
Allocentric Abilities	1.983	0.698	2.840	0.009

4 Discussion

An abundant body of studies indicated that spatial abilities impairments are present in the cognitive profile of both normal and pathological aging. This means that a premature deterioration of navigational abilities, and in particular a deficit in the ability to encode and store allocentric information for navigating in the surrounding environment, represents one of the first hallmarks of Alzheimer's Disease (AD). However, as previously discussed, allocentric difficulties characterize the cognitive status of cognitively healthy aged people (for a review, see [37]). In this view, the current study was aimed to investigate the contribution of allocentric impairments to general cognitive decline, measured with the Mini-Mental State Examination (MMSE).

Our results showed that patients with AD performed significantly poorer in almost all tests evaluating spatial abilities in comparison to the cognitively healthy aged individuals, including the ability to retrieve allocentric representations (measured with the VR-based task [34, 35]). Moreover, we found that the allocentric abilities were the only significant predictors of cognitive functioning (as measured with the MMSE), thus suggesting its primary role in predicting the cognitive decline.

First of all, these results are in line with literature about spatial navigational deficits early manifested in AD [3–7]. Interestingly, our results did not suggest the presence of a significant difference between the two groups in the short-term spatial memory and general navigation abilities, but in other more specific spatial abilities that are essential for a successful navigation, such us the visuo-spatial and the egocentric mental rotation skills. Our findings are also in line with recent studies suggesting early impairments in crucial spatial abilities in AD, such as the perspective taking abilities [38–40]. Perspective taking (i.e., the ability to take different viewpoints in space) requires a manipulation centred on one's own body and it is traditionally distinguished from the object-based manipulation [41], where the observer remains mentally fixed and is asked to mentally rotate the object. Moreover, from our results emerged a central role of allocentric impairments among other spatial abilities in predicting the general cognitive functioning of participants and, therefore, the pathological cognitive decline of AD patients. Beyond the hippocampal decline observed in both normal aging and AD, allocentric and egocentric frames show different underlying cognitive mechanisms. Consistently with literature [8, 42–46], our results supported the idea that the allocentric decline may be a disease-specific marker of pathological degeneration. More interestingly, it is possible that this deficit in egocentric frame may be linked to another spatial ability involved in navigation, namely the capacity in the allocentric-to-egocentric switching or synchronization [35, 40, 47]. Indeed, it is suggested that egocentric short-term representations are transformed in long-term allocentric ones for storage; then, when there is retrieval cue, allocentric representations are transformed again in an egocentric format, which is more useful for navigation [48, 49]. In this perspective, the cognitive profile of AD may be marked by a very early deficit in the storage of an allocentric representation, combined with another early impairment in the ability to retrieve this representation and transform it an egocentric format with a synchronized egocentric direction useful for an effective orientation in the environment [16, 17, 47].

These results surely open future possibilities for new research studies; however it is crucial to acknowledge some limitations. First of all, the two samples recruited for this study are rather small, although they were well-matched for the main sociodemographic characteristics. However, although the between-group difference is not statistically significant, it is noteworthy to note that the healthy sample had mean years of education of 5.87, much lower than AD patients. Moreover, we could not deeply investigate the cognitive mechanisms involved in allocentric elaborations, as we did not assess participants for executive functions or attentional abilities. Although these findings are promising and may stimulate further research in this field, future studies should investigate the potential value of different spatial abilities as cognitive diagnostic markers in AD.

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