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Cognitive maps in imagery neglect

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ABSTRACT

Patients with imagery neglect (RI+) show peculiar difficulties in orienting themselves in the environment. Navigational impairments could be due to a deficit in creating or using a mental representation of the environment (Guariglia, Piccardi, Iaria, Nico, & Pizzamiglio, 2005) or, according to the BBB model (Burgess, Becker, King, & O'Keefe, 2001), to a specific deficit in a mechanism that transforms an allocentric representation into an egocentric one and vice versa.

Previous studies, however, do not allow discerning between a deficit in forming or in using a cognitive map, taking no notice of the fact that these are two different abilities underlain by different neuroanatomical areas, which could be independently impaired. Furthermore, the BBB model has never been verified in a population of brain-damaged patients.

Therefore, we administered two tasks that separately assess the ability to create and use a cognitive map of the environment to 28 right brain-damaged patients (4 patients with imagery neglect and 4 patients with perceptual neglect) and 11 healthy participants.

RI+ patients showed no specific deficit in creating or using a cognitive map, but failed to transform an egocentric representation of the environment into an allocentric one and vice versa, as predicted by the BBB model.

1. Introduction

Patients affected by imagery neglect (RI+), that is, a deficit in processing the left side of a mental image (Bisiach & Luzzatti, 1978), have difficulty with topographical orientation (Guariglia et al., 2005; Nico et al., 2008; Piccardi, 2009). For example, Palermo, Nori, Piccardi, Giusberti, & Guariglia, (2010) described the case of a patient with imagery neglect who had difficulty orienting himself in the environment. Furthermore, group studies using a human version of the Morris Water Maze showed that RI+ patients had deficits in finding a target location in a rectangular environment (Guariglia et al., 2005; Nico et al., 2008). Guariglia et al. (2005) found that in RI+ patients navigational deficits arise from defective processing of mental representations of the environment (i.e. cognitive maps).

The BBB model (Burgess et al., 2001; Byrne, Becker, & Burgess, 2007), which quantitatively describes the interactions between brain regions involved in spatial memory and mental imagery, provides another interpretation of navigational deficits in RI+. According to this model, the spatial orientation difficulties of individuals with RI+ could arise from a specific deficit in a mechanism that transforms allocentric representations into egocentric ones and vice versa.

The BBB model (Burgess et al., 2001; Byrne et al., 2007) assumes that an egocentric representation of space, that is, the locations of all landmarks visible from a subject's current location in space or from a location the subject recalls from previous experiences, is maintained in the parietal cortex, and that an allocentric representation of object locations is constructed in the parahippocampal regions and projected to the hippocampus, where long-term spatial memories are stored. The idea of separate egocentric representations in parietal areas from allocentric representations in temporal areas goes back to the literature about the dorsal and ventral streams (Milner & Goodale, 1995; Dijkerman, Milner, & Carey, 1998), that is to the idea that the dorsal stream supports the representation of the locations of stimuli in the various egocentric reference frames appropriate to sensory perception and motor action while the ventral stream supports the visual perceptual processes related to object recognition. In the BBB model these two types of representation are supposed to interact. In particular, the BBB model postulates the existence of a transformation circuit, which transforms allocentric representations of space into egocentric ones and allows the recall of locations and identities of environmental boundaries relative to one's own location and orientation; the same circuit transforms egocentric representations of space into allocentric ones. The authors suggest that the format transformation (from-egocentric-to-allocentric and vice versa) is

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mediated by the retrosplenial cortex/intraparietal sulcus, and by using the representation of head-direction found along Papez's circuit (Byrne et al., 2007; Bird & Burgess, 2008).

At the present state of the art, data do not allow accepting or rejecting either or both of these interpretations. Furthermore, although the BBB model has received some support from experimental data, it has never been tested directly in brain-damaged patients. Indeed, the assumption of the deficit in imagery neglect patients derives from a review of previous studies and a computer implementation. And results obtained using the Human Morris Water Maze (Guariglia et al., 2005; Nico et al., 2008) in previous studies in brain-damaged patients do not clarify whether RI+ patients have a problem in creating a cognitive map or in using it. This task requires subjects to memorize a target point after they perform an active *searching task*. They have to move around in a rectangular environment, which can be completely devoid of visual cues or contain two landmarks, until they find the target point they have to memorize. Then, they have to reach the target point in a series of subsequent trials carried out soon after the end of the searching (immediate reaching) and after a 30-min delay spent in a different environment (delayed reaching). Patients with imagery neglect showed a specific deficit in the *immediate* and the *delayed reaching* tasks both when landmarks were present and when they were absent. Although this experimental paradigm is useful in confirming the presence of specific navigational disorders in RI+, it does not clarify whether failure to reach the target point is due to a deficit in the ability to create a cognitive map or to use a well-developed cognitive map.

Inasmuch as creating and using a cognitive map are two different abilities (Iaria, Chen, Guariglia, Ptito, & Petrides, 2007; Palermo, Iaria, & Guariglia, 2008), underlain by different neuroanatomical areas (Iaria et al., 2007; Wolbers & Buchel, 2005) that could be independently damaged, the issue about the nature of the navigational deficit in imagery neglect (i.e. whether it is due to a defect in forming a map or in using it) seems relevant to clarify the role of extra-hippocampal areas in navigation processing.

In the present study, we aimed to investigate (a) how the imagery deficits of patients with imagery neglect affect their ability to create and use cognitive maps and (b) to verify the predictions of the BBB model in a population of right brain-damaged patients using two tests that allow selectively assessing the ability to form maps, use cognitive maps and transform allocentric representations of the environment into egocentric ones and vice versa. In the first test, we assessed the ability to develop cognitive maps from real navigation of a novel environment ("egocentric experience"); and in the second one, we assessed the ability to use cognitive maps acquired by studying a blueprint of a different novel environment ("allocentric experience"). Both tests assess the ability to use acquired knowledge of the novel environments by relying on allocentric and egocentric representations.

2. Methods

2.1. Participants

We enrolled 28 right brain-damaged patients (R) and 11 healthy controls (C), who had no signs of neurological or psychiatric impairment. All gave their informed consent to participate in the study, which was approved by the local ethics committee.

The R patients included:

- 4 right brain-damaged patients affected by perceptual neglect (RN+);
- 4 right brain-damaged patients affected by imagery neglect (RI+). Specifically, one patient was affected by pure imagery neglect (S.C.) and three patients by imagery neglect associated with perceptual neglect (U.L.; S.M.; M.P.);
- 14 right brain-damaged patients with no signs of perceptual or imagery neglect (RN−).

Table 1
Personal and clinical data.

Group	Sex	Age in years/mean (ds)	Education in years/mean (ds)	Stroke onset in days/mean (ds)
RN−	11M; 3F	53.79 (13.53)	11.93 (3.32)	58.7 (26.3)
RN+	4M	60.75 (6.24)	11.5 (4.36)	240.75 (376.85)
RI+	3M; 1F	58 (15.08)	13 (10.75)	1044.25 (178.26)
C	5M; 6F	53.55 (12.23)	12.1 (3.7)	

Note: RN−: right brain-damaged patients with no signs of neglect; RN+: right brain-damaged patients affected by perceptual neglect; RI+: right brain-damaged patients affected by pure imagery neglect or imagery neglect associated with perceptual neglect; C: control participants; M: male; F: female.

Age, education and time from stroke onset did not differ among groups: (age: $F_{(3,29)} = 0.46$; p = n.s.; education: $F_{(3,29)} = 0.14$; p = n.s.; stroke onset: $F_{(2,19)} = 2.36$; p = n.s.) (see Table 1, for personal and clinical data).

2.2. Neuropsychological testing

All healthy participants were submitted to the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; Magni, Binetti, Bianchetti, Rozzini, & Trabucchi, 1996) to exclude the presence of mental deterioration.

Brain-damaged patients underwent an extensive neuropsychological evaluation, which assessed abstract reasoning (Basso, Capitani, & Laiacona, 1987; Raven, 1938), language (Ciurli, Marangolo, & Basso, 1996; Miceli, Laudanna, Burani, & Capasso, 1994), short verbal memory (Digit Span, Spinnler & Tognoni, 1987), short visuo-spatial memory (Corsi Block-Tapping test: Corsi, 1972; Spinnler & Tognoni, 1987), long-term memory (Carlesimo et al., 2002; Carlesimo, Caltagirone, & Gainotti, 1996; Novelli, Papagno, Capitani, Laiacona, Cappa, & Vallar, 1986; Rey, 1941, 1958; for memory test scoring see Table 2), visual integration ability (Street Completion Test; Street, 1931; Spinnler & Tognoni, 1987) and constructional apraxia (Spinnler & Tognoni, 1987).

No participant was amnesic or had mental deterioration.

Right brain-damaged patients were subdivided into three groups (RN−; RI+; RN+) according to their performance on the Standard Battery for the Evaluation of Hemineglect (Pizzamiglio, Judica, Razzano, & Zoccolotti, 1989) and two tests of imagery neglect: the O'Clock Test (Grossi, Modaferri, Pelosi, & Trojano, 1989) and the Familiar Squares Description Test (Bisiach & Luzzatti, 1978).

Patients were considered to have visuo-spatial neglect if their performance was below the cut-off in two of the four tests included in the Standard Battery for the Evaluation of Hemineglect (Pizzamiglio et al., 1989).

An LQ (LQ = (left elements − right elements)/(left elements + right elements) × 100; Bartolomeo, D'Erme, & Gainotti, 1994) below −18 (Palermo, Piccardi, Nori, Giusberti, & Guariglia, 2010) on one of the imagery neglect tests was considered to indicate imagery neglect.

See Table 3 for the neuropsychological assessment of perceptual and imagery neglect.

2.3. Experimental tests

2.3.1. Egocentric experience (formation of a cognitive map of a real environment/egocentric–allocentric transformation)

This test was created to assess the ability to form a cognitive map and to identify the mechanism that transforms an egocentric representation into an allocentric one, according to the BBB model. The test, which was performed in a hospital ward the patients had never explored, included three tasks:

(a) Learning 1 – egocentric experience

The examiner guided the participants through a hospital ward they had never explored before; they followed a path from the hall to the "room with pictures" and vice versa (see Fig. 1). The participants had to memorize the environment. Subsequently, they had to describe the environment from four different points of views (for example "Imagine being in the hall with the main door behind you. What can you see on your left, on your right and in front of you?"). Based on the results of a pilot study in elderly healthy individuals, the learning was considered successful if the participants were able to report at least two elements located on two different sides (e.g. one on the left side and one in front) in each of the four descriptions. During the test, if the participants were unable to report at least two elements located on two different sides, even in just one of the four descriptions from different points of view, the examiner led them along the path again (maximum: 3 repetitions). We assigned 4 points if the participants were able to describe the environment at the first attempt, 3 points after the first repetition, 2 points after the second, 1 point after the third repetition and 0 points if they were unable to describe the environment after three repetitions.

No participant scored 0.

(b) Map drawing 1 – egocentric experience