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Landmark based navigation in brain-damaged patients with neglect

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Abstract

We tested navigational abilities of brain-damaged patients suffering from representational or perceptual neglect asking them to retrieve a location according to salient spatial cues included in a rectangular empty room. Both groups of patients showed difficulties in learning the spatial definition of the target location in relation to two landmarks. However in a delayed attempt performed after several trials the group of patients with perceptual neglect proved able to easily retrieve the target location. In this condition they performed as controls showing a spared ability to navigate according to a stable representation of the room in long-term memory. In contrast the difficulty of patients with representational neglect remained unchanged across experimental conditions. At variance with clinical assessment, in which patients show asymmetrical performances in describing a well-known environment from memory, this latter result depicts a behavioural counterpart of the disorder, namely the inability to orient in a new environment according to an inner representation. Data are further discussed in order to provide a description of the cognitive mechanisms required for space representation for navigation.

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Keywords: Spatial references; Environmental exploration; Representational neglect; Space representation; Orientation; Visuo-spatial hemineglect; Cognitive map

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1. Introduction

A landmark is a salient environmental cue working as a spatial reference. A typical example of landmarks' use is when we move in an unknown town: it's easier to get back by retracing the location of the hotel according to some relevant buildings (such as a museum, a gas station or a market) we came to get in its surroundings. In our daily life the importance of a view-dependent representation of landmarks for the purpose of orientation is widely recognised. People memorise the turning in specific directions in a specific place (Gillner & Mallot, 1998; MacDonald, Spetch, Kelly, & Cheng, 2004) and their "directional" decisions depend on the landmarks array representation rather than on a global map of the spatial scene (Mallot & Gillner, 2000). There are, at least, three different ways in which the spatial information provided by landmarks might be used for orientation. A first way is the "configural strategy": subject encodes an array of landmarks as a configuration and learns the location of the target according to that (*I left my car close to the shop which is on the left of the bank office*). Another way is to couple the "configural strategy" with an "elemental strategy" to encode distance and/or direction from a pattern of landmarks (*my car is on the left of the market and at about 20 metres from the bank office*). A third way is a "beaconing strategy" in which a salient landmark works as a beacon and provide an environmental cue for the search (*I don't remember exactly where I left my car, but I know that it was close to the market and the bank office*) (see for details MacDonald et al., 2004).

These mental representations of an environment according to its relevant items seem quickly at hand and automatically used, but is it really so easy and natural to use landmarks? Literature says it is not, and this seems to hold true from both a phylogenetic and an ontogenetic perspective. Indeed, in human children and in some animal species (i.e. bees, ants, rats; see Cheng,

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1986; Healy, 1998 for more details) reorientation is achieved by using what has been called "the geometric module" (Hermer & Spelke, 1994; Hermer & Spelke, 1996; Learmoth, Newcombe, & Huttenlocher, 2001), a representation of the environment in Euclidean terms (shape, width, etc.) that can be used independently from presence of salient items providing spatial reference (Gallistel, 1990). This mechanism was first demonstrated by Hermer and Spelke (1994) in children of 18–24 months that, after disorientation, were free to look for their teddy bear that they previously saw hidden in a corner of a rectangular room. Toddlers proved unable to memorize which would be the right corner according to salient visual cues in the room but kept on searching only according to geometric feature (i.e. in one of the two homologous corners having a long wall to the right and a short wall to their left). This suggests that while developing our spatial skills the shape of the environment is a basic feature for the orientation system and that the elements included in it will become a reference once the full ability to represent space will be available.

Recently, a model concerning navigational systems, mechanisms and strategies used by humans and animals, has been proposed by Wang and Spelke (2002). These authors suggest a hierarchically organised system in which the ability to use landmarks is a distinct navigational competence together with path-integration and re-orientation mechanisms. It is still unclear whether the mechanisms proposed for navigation are hierarchically organised in terms of a serial processing of spatial information. However, it seems plausible to suppose such a hierarchy according to the increasing complexity of the various cognitive mechanisms involved in navigation. In most cases to find shortcuts and to plan a navigational strategy means to have a mental representation of the environment, namely a cognitive map (O'Keefe & Nadel, 1978) including relevant environmental items, the navigational goal and their relative positions in respect to both the euclidean properties of the environment and to each other. Hence successful orientation relies on the ability to store this mental representation and properly use it to plan and guide displacements towards the desired location. To follow an internal representation of the environment in order to keep track while moving, requires the continuous assessing of our changing position according to the stored map (Iaria, Chen, Guariglia, Ptito, & Petrides, 2007). In other words, to maintain orientation we have to 'egocentrize' our mental representation of the surroundings according to the actual perspective we are using. Landmarks should help this mental spatial operation of rearranging our position, provided a stored cognitive map of the surroundings.

Accordingly, the hierarchy in navigational mechanisms proposed by Wang and Spelke (2002) should be organised following the complexity of the spatial operations involved. As a consequence we should expect that a brain lesion affecting the more basic component (i.e. path integration) would interfere with the general ability to navigate, independently from the strategy subjects employ. However, the existence of a dissociation between navigational modalities has been demonstrated by Pizzamiglio, Guariglia, & Cosentino (1998) in a task in which subjects had to retrieve a location previously learned in two different conditions: using the shape of the environment or a landmark (a red panel on a wall). Results showed that the ability to localise the target according to one of the condition was selectively affected by the site of the brain lesion (Pizzamiglio et al., 1998). This result demonstrates that navigation is supported by mechanisms of spatial representation that are partially independents from each other.

Evidences from brain-damaged patients provide further information about the cognitive organization and functioning of navigational mechanisms. Indeed, a taxonomy of topographical disorientation has been proposed as a consequence of impairments in distinct neuroanatomical districts (Aguirre & D'Esposito, 1999). Following Aguirre and D'Esposito's taxonomy, a lesion involving the parietal lobe appears to produce a specific topographical disorientation disorder, namely an egocentric disorientation: an inability to represent objects' location with respect to self. Several studies moved further in the exploration of how egocentric perturbation interferes with navigation and focussed on hemineglect following parietal lesion of the right hemisphere. Hemineglect is a pervasive disorder in spatial representation affecting the contralesional side of egocentric space (Kerkhoff, 2001). Recent results demonstrated that, despite a severe impairment affecting the ability to explore and detect contralesional stimuli, neglect patients maintain some navigational skills (Bisiach, Pattini, Rusconi, Ricci, & Bernardini, 1997; Philbeck, Behrmann, & Loomis, 2001; Pizzamiglio, Iaria, Berthoz, Galati, & Guariglia, 2003). Indeed, according to several studies patients suffering from hemispatial neglect showed the sparing of some basic navigational competence mostly based on path integration processes and on the processing of idiothetic information, such as the ability to point to the starting position after passive displacements including two or three leftward or rightward turnings (Bisiach et al., 1997), the ability to store in memory the egocentric position of a target to be reached without the help of vision (Philbeck et al., 2001), the ability to judge without vision the extent of a passive displacement independently to its relative direction according to the egocentric coordinates (Pizzamiglio et al., 2003). This could raise the question of how brain-damaged patients suffering from egocentric perturbation can correctly compute their position or retrieve a target, thus maintaining orientation in a space they are unable to explore. One possibility could be that real displacements facilitate space representation allowing physical exploration of the environment while providing a richer source of information (via proprioception, vestibular inputs, retinal optic flow, etc.). Actually in the most typical situations of clinical assessment, space exploration is visually performed while standing and scanning with the eyes and the head. A first distinction could then be attempted between a 'static' representation of space and a motion-derived, 'navigational' one, both of course should be egocentric. In these terms we could also try an alternative approach to the clinical distinction between perceptual and imaginative (representational) neglect (for a review see Kerkhoff, 2001). Namely a distinction between a deficit in the ability to use the egocentric reference of the body's main axis in order to explore space, here and now, opposed to a perturbation of an egocentric representation of a space that would

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be stable, probably navigational-based and multimodal, such as in the original Bisiach and Luzzatti's 'Piazza del Duomo' task (1978).

In a previous work (Guariglia, Piccardi, Iaria, Nico, & Pizzamiglio, 2005) a navigational task in a human version of the Morris water maze has been used to compare performances of patients with representational neglect with those of patients with perceptual neglect (i.e. neglect affecting visuo-spatial perception and exploration but not visual mental representation). Patients were required to memorize and reach the location of a target in a rectangular empty room in which no visual cue was available. The only source of information was the idiothetic (i.e. vestibular and proprioceptive information relative to physical displacement) and the euclidean one (i.e. information concerning shape and dimensions of the room). Thus successful navigation could be achieved only through path integration (that is based on idiothetic information) or the geometric module. It should be noted that correct retrieval of the target after a long delay can be accomplished by relying on a representation of the environment based on euclidean information only, since path integration processing cannot access long-term memory storage (see Wang & Spelke, 2002). Results showed that only patients with perceptual neglect were able to build a spatial representation stable enough to use a specific navigational strategy in such a simplified environment in which the only relevant information were the euclidean ones. In contrast, representational neglect patients got lost when they could not rely on path integration, demonstrating a correspondence between their mental imagery impairment and the defective ability in navigational processing (Guariglia et al., 2005). In that work it was suggested that only a particular form of neglect could perturb one of the navigational systems suggested by Wang and Spelke (2002).

Previous observations provided interesting data linking representational neglect and orientation. For instance, Rode and co-workers demonstrated that contralesional stimuli of an inner representation could get unreported depending on task requirements. Indeed, when a (spatial) perspective taking was necessary (i.e. by asking a mental scanning of an imaginary geographic map), their patient (J.D.) was unable to report the towns of France he could correctly list in a free recall set up (Rode, Rossetti, Perenin, & Boisson, 2004). This result suggested that geographic knowledge's recalled from a linguistic description would be intact while the ability to arrange it according to a spatial representation would be not. Guariglia and Pizzamiglio (2006) proposed that two different types of space representation exist, which may be selectively damaged in neglect, and that may be defined as "topological images" and "non-topological images". Topological images are described to be mental representation of stimuli in which is possible to navigate, while non-topological ones are the representation of objects or visuo-spatial displays in a space that could not be navigated. In a previous study, Ortigue et al. reported the case of a patient showing a left representational neglect affecting selectively the far space of an inner representation in the absence of any perceptual neglect. When asked to imagine her near space (the inside of her car from and some objects placed on a table) there was no detectable omission. On the contrary, when asked to bring back memories of a familiar square in Geneva and of the map of France, she 'forgot' elements that always fell on the left of the representation (Ortigue et al., 2003). We can interpret the performance of this patient like affected by a deficit in "topological images" with no impairment for "non-topological ones".

However, despite these significant suggestions, no explicit assessment of the ability to retrieve orientation in patients suffering from representational neglect has been attempted. The issue would be relevant since recent studies on the topic of representational neglect do not differentiate between spaces (far, near, personal, extrapersonal; see also Ortigue, Mégevand, Perren, Landis, & Blanke, 2006) or objects (i.e. non-topological images) versus environments (topological images, Guariglia & Pizzamiglio, 2006).

In this study, we used a variation of the human version of the Morris water maze (Bohbot et al., 1998) to analyze the ability in orienting of patients with representational neglect in a landmark-based navigation task. When environmental landmarks are available different navigational strategies become possible. Indeed the effective reaching of the goal may be based on the representation of its position according to landmarks without any reference to path integration or to geometric module as in the study of Guariglia et al. (2005). As a consequence, depending on the type of neglect, different results could be expected. In particular, if representational neglect affects only the geometric module, landmarks availability as a spatial reference should improve patients' performances. On the other hand, if representational neglect interferes with the ability in building or using cognitive maps, these patients should then perform in line with Guariglia et al., previous report (2005). The presence of landmarks could also affect the ability of perceptual neglect patients to correctly code, store and retrieve target position. In this case, due to the difficulty in exploring contralesional hemispace, these patients could be unable to create a cognitive map resulting from the euclidean information about the environment and relative to landmark identity and position.

2. Methods

2.1. Subjects

All subjects gave their informed consent to participate to the study. Approval for the experiment was obtained from the local ethics committee. After clinical assessment subjects were included in one of the following five experimental groups and submitted to the experimental sessions.

Perceptual Neglect patients (N+): 5 right-brain-damaged patients (3 men and 2 women: mean age 61.8 years, S.D. ±9.52; mean education 8.2 years, S.D. ±5.63) showing only signs of perceptual neglect to clinical testing.

Representational Neglect patients (Rep+): 6 right-brain-damaged patients (5 men and 1 women: mean age 58.67 years S.D. ±7.23; mean education 9.50 years, S.D. ±5.09) showing pathological scores to clinical testing for representational neglect; patient no. 7, and 9 suffered from neglect due to a pure imaginative disorder. Patients nos. 6, 8, 10 and 11 showed also perceptual neglect on clinical assessment (see Table 2).

No-Neglect Right-brain-damaged patients (RN−): 8 right-brain-damaged patients (5 men and 3 women: mean age 54.63 years, S.D. ± 9.84; mean education 10.00 years, S.D. ± 4.93) without clinical signs of neglect at the clinical assessment.

No-Neglect Left-brain-damaged patients (LN−): 9 left-brain-damaged patients (8 men and 1 woman: mean age 55 years, S.D. ± 11.21; mean education

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Table 1
Demographic and clinical data of brain-damaged patients

No.	Group	Age (years)	Schooling (years)	Onset (months)	Lesion's site and Brodmann's areas
1	N+	62	18	7	th, ic, bg
2	N+	63	5	1.5	T (bg): 22, 37
3	N+	71	8	4	F-T-P (bg): 38, 22, 6, s, 41, 42
4	N+	46	5	4	Wm
5	N+	67	5	4	F-T-P
6	Rep+	53	13	1	F-T-P; bg; wm
7	Rep+	52	18	8	Th; wm
8	Rep+	71	8	10	T-P: 22, s, 40, 41, 42
9	Rep+	61	5	2.5	T-P: 21, 22, 37, s, 39, 40
10	Rep+	61	5	3.5	F-T-P (ic, bg): 47, 45, 44, 6, 21, 22, 41, 42, s, m, 40, 39)
11	Rep+	54	8	2.5	T-P
12	RN−	52	5	7	bg/ic/wm
13	RN−	39	8	16	T-F;bg
14	RN−	58	13	2	Ic
15	RN−	74	13	2	F: 4/6
16	RN−	55	5	3	th/ic/bg
17	RN−	53	5	365	F-T-P, th, bg
18	RN−	49	18	2	Brain-stem, pons
19	RN−	57	13	15	F
20	LN−	47	13	2	wm
21	LN−	46	13	1.5	wm
22	LN−	47	17	2	F-P
23	LN−	68	18	19	F-T-P: 22, 41, 42, 6, s, m, 40
24	LN−	66	18	1.5	th, ic
25	LN−	52	13	15	F-P
26	LN−	51	18	2	T, ic
27	LN−	44	18	3	Th, ic, bg
28	LN−	74	8	1.5	wm

Th: thalamus; ic: internal capsula; bg: basal ganglia; wm: white matter; F: frontal; P: parietal; T: temporal.

15.11 years, S.D. ± 3.55) without clinical signs of spatial neglect affecting their contralesional space and with spared verbal abilities allowing comprehension of the experimental instructions.

Control subjects (C): 8 healthy subjects (7 men and 1 woman: mean age 66.67 years, S.D. ± 9.52; mean education 8.67 years S.D. ± 3.61) with no history of neurological or psychiatric illness.

Demographical and clinical data of each subject are resumed in Tables 1 and 2.

Brain-damaged patients were submitted to an extensive neuropsychological examination assessing: language functions (Ciurli et al., 1996), short and long-term memory (Spinnler & Tognoni, 1987), visual perception (VOSP: Warrington & James, 1991) and abstract reasoning (Raven, 1938 adapted by Basso, Capitani, & Laiacona, 1987; Spinnler & Tognoni, 1987). No sign of global cognitive deterioration or psychiatric symptoms were detected. Normal memory abilities were observed in the whole group of participants.

Neglect was assessed through a standardized battery including line cancellation, letter cancellation, sentence reading and the Wundt-Jastrow illusion test (Pizzamiglio, Judica, Razzano, & Zoccolotti, 1989). Pathological performances on two out of four tests were considered indicative of the presence of perceptual neglect. Presence of representational neglect was assessed through the familiar square description task: patients have to describe in details from memory a familiar public square, as it would appear from two opposite perspectives (Bisiach

Table 2
Neglect assessment according to a standardized battery of clinical test (Pizzamiglio et al., 1989)

No.	Group	Left "H" (hits)	Right "H" (hits)	L. line (hits)	R. line (hits)	W–J test (unattended responses)	Sentence reading (hits)	Imagery Neglect (square description)
1	N+	30/53*	41/51	10/11*	10/10	0	4/6*	−4.76
2	N+	6/53*	37/51	11/11	10/10	7*	1/6*	0
3	N+	17/53*	47/51	11/11	10/10	2*	3/6*	−4,35
4	N+	2/53*	50/51	11/11	10/10	4*	4/6*	0
5	N+	0/53*	19/51	11/11	10/10	20*	1/6*	15,789
6	Rep+	0/53*	43/51	10/11*	10/10	5*	6/6	−50*
7	Rep+	49/53	48/51	11/11	10/10	0	6/6	−31,818*
8	Rep+	16/53*	44/51	8/11*	10/10	0	4/6*	−53,846*
9	Rep+	53/53	50/51	11/11	10/10	5*	6/6	−25,71*
10	Rep+	46/53*	51/51	11/11	10/10	0	5/6*	−41,67*
11	Rep+	48/53*	51/51	8/11*	10/10	12*	1/6*	−38,46*

Left H = Letter cancellation test (left side) Right H = Letter cancellation test (right side); L. Line = Albert test → line cancellation (left side) R. Line = Albert test → line cancellation (right side); W–J test (unattended responses) = Wundt–Jastrow illusion test.

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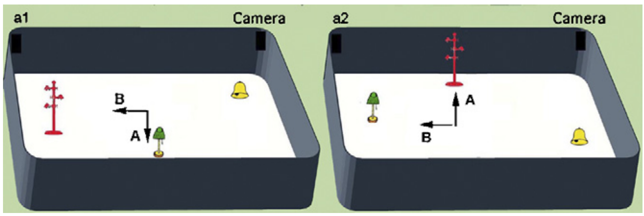

Fig. 1. Schematic drawing of the experimental room and conditions. The bell illustrates the target location; lamp and clothes-stand indicate the landmark position and their order of presentation.

& Luzzatti, 1978). A Laterality Quotient (LQ)[1] was calculated on subjects' reported items according to Bartolomeo, D'Erme, & Gainotti (1994): scores equal or inferior to −20 were considered as pathologic. All control subjects were submitted to the M.O.D.A. battery (Branzelli et al., 1994) to assess mental deterioration. Brain-damaged patients were also submitted to neurological examination and to CT or MRI scan to define lesion site and size.

2.2. *Procedure*

Experimental setting and procedures were identical to those used by Guariglia et al. (2005) with the addition of two well-distinguishable landmarks (a black stand-lamp and a red clothes-stand). Landmarks were of equal size and of similar shape. They were placed approximately in the middle of the wall facing the starting point and in the middle of the adjacent wall to the immediate right or left. During the whole experimental sessions landmarks' position was unchanged. However, their relative position according to the starting point was counterbalanced across subjects (see Fig. 1; a1 and a2 for experimental design).

All subjects were tested individually. The task required to look for and to memorize a precise hidden location (target location: TL) in a rectangular 7 m × 5 m room. The walls of the experimental room were completely covered by homogeneous grey curtains to eliminate all the environmental cues with the exception of the two experimental landmarks. A photocell placed in the ceiling was directed toward TL on the floor (15 cm diameter circular receptive field) so that whenever a subject passed through the TL an acoustic signal and light signal were delivered from the centre of the room.

Subjects performed the experiment by moving with a motorised wheelchair driven by a joystick. Before testing, the subjects were allowed to practice with the wheelchair by driving freely in another room for several minutes. The experimental session comprised three different conditions:

Searching: blindfolded subjects were placed in the centre of the room and curtains were closed before removing the blindfolding; they were asked to move in the room in order to find TL. Searching started from position A, facing one of the room's long walls (see Fig. 1) and was performed in full vision. Once TL was found, subjects were informed that its position would be held constant during the whole session and that in the following trials they have to reach TL as quickly as possible and following the shortest way. All participants were allowed to remain on TL for a while, they could look around but could not move. Subjects were then blindfolded, randomly displaced in the room for a minute and placed in the starting position for the next search.

Immediate reaching: this task was performed immediately after the *searching* and consisted of six trials. In the first three trials, subject started reaching from position A (IR-A); in the remaining attempts starting point was rotated 90° to the left (position B: IR-B; see Fig. 1). Each trial stopped when the subject successfully reached the TL; then, he/she was blindfolded, disoriented and placed in the corresponding starting position, and a new trail began. All trials were performed in full vision.

Delayed reaching: after the last trial of Immediate Reaching, the blindfolded subject was taken in another room and engaged in 30 min of verbal testing such as phonetic and semantic fluency, handedness questionnaire and verbal reasoning. Thereafter the subject was blindfolded and re-introduced in the experimental room, disoriented and placed in position A. Then blindfolding was removed and the subject was required to reach the TL by following the shortest and quickest pathway (1 trial).

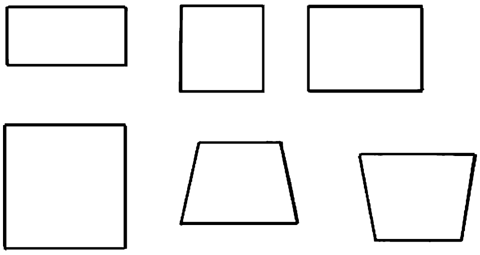

Fig. 2. Participants were asked to choose the actual shape of the room in a multiple-choice sheet. They were also asked to place landmarks and target location in the shape chosen. Drawings reproduced the room on a 1:100 scale (1 cm = 1 m). The small square corresponds to the short wall of the room; the large square corresponds to the long wall of the room. The minor base of the trapezium has been obtained by dividing for 1.5 the long side of the rectangle.

Each trial of each condition was monitored and recorded by a hidden micro-camera placed on the ceiling and performances were scored by two independent examiners naïve to the aim of the experiment. For each trial, duration and pathway followed in the searching condition were analysed. Even if pathways' reconstruction did not allow statistical comparisons because of its intrinsic qualitative nature, a descriptive analysis is still provided in the results section due to its behavioural relevance.

An interview was performed at the end of the experimental session to investigate which kind of spatial strategy subjects adopted. In order to analyse accuracy of mental representation of the environment, subjects were also asked to choose between different geometrical shapes depicting the experimental room (the actual room was reproduced in an 1:100 scale where 1 cm corresponds to 1 m; see Fig. 2) and to mark landmarks and TL relative to it.

3. Results

3.1. *Time*

Separate statistics were performed for the three experimental conditions. In Table 3 are reported mean and standard deviation of the time spent by the different groups to reach target location in the three experimental conditions.

A 1-way ANOVA with Group (C, Rep+, N+, RN−, LN−) as independent variable and time (seconds) spent in *Searching* revealed a significant difference between groups ($F_{(4,31)} = 4.437$; $p < .01$). Means of performances showed that perceptual neglect patients (N+) spent more time in searching the target location compared to controls (Duncan post hoc test: $p = .001$), right brain-damaged patients without neglect (Duncan post hoc test: $p = .001$) and left brain-damaged patients (Duncan post hoc test:

Table 3
Mean (and standard deviation) of the time spent by the different groups to reach target location in the three experimental conditions

Group	Searching	Immediate reaching		Delayed reaching
		IR-A	IR-B	
C	60.38 (37.35)	48.38 (42.69)	28.38 (14.69)	34.38 (41.72)
Rep+	109.33 (61.99)	73.83 (51.88)	75.72 (53.39)	75.67 (55.94)
N+	155.80 (78.35)	84.20 (63.44)	75.33 (40.02)	33.40 (15.31)
RN−	64.13 (42.00)	43.50 (25.79)	30.88 (16.81)	27 (14.34)
LN−	63.11 (27.42)	47.72 (54.01)	22.04 (10.87)	23.11 (8.92)

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[1] LQ = (Number of left-sided items − Number of right-sided items)/(Number of left-sided items + Number of right-sided items) × 100.

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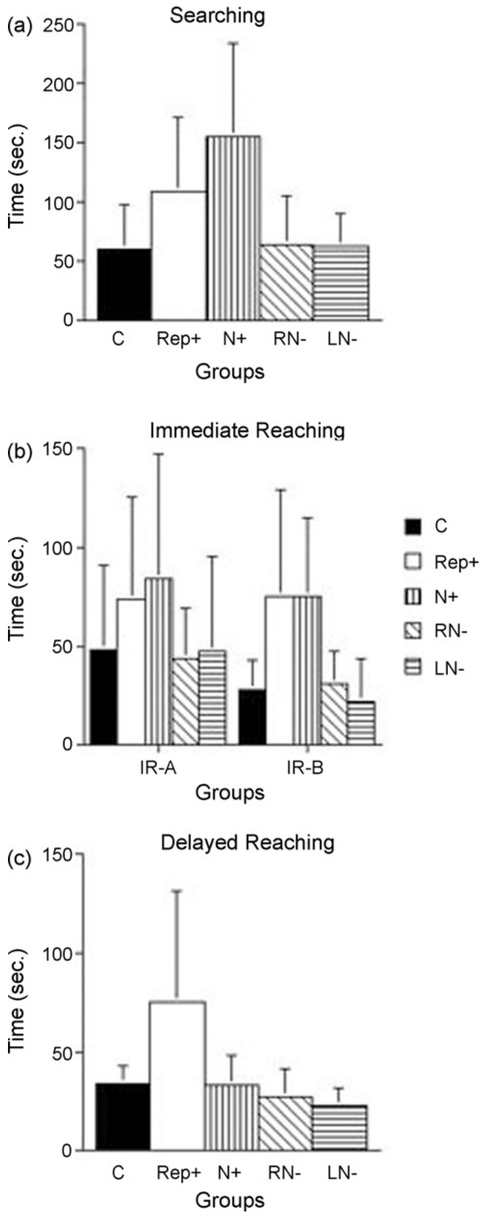

Fig. 3. The figure shows mean and S.D. of the time spent by the different groups to reach the target location in searching (a); in immediate reaching (b) and delayed reaching (c) conditions.

$p = .002$) but their performance did not differ from Rep+ (see Figs. 3 and 4). No other significant differences were detected between groups (see Fig. 3). In order to rule out a possibility that the significant effect of group might be driven by an over-all differential pattern across all groups we run separate post hoc t-tests showing that patients with neglect spent significantly more time compared to all groups of subjects (C vs. N+: $t_{(11)} = -2.997, p = .012$; RN− vs. N+: $t_{(9)} = -1.1, p = .018$; LN− vs. N+: $t_{(12)} = -3.292$, $p = .006$).

In the *Immediate Reaching* condition a two-way ANOVA on time (seconds) spent to reach the target location was run with Group (C, Rep+, N+, RN−, LN−) as independent variable and starting positions (IR-A; IR-B) as repeated measure. Analysis showed only a main effect of *Group* ($F_{(4,31)} = 3.168$; $p < .05$). Post hoc comparison (Duncan test) revealed that both groups of patients affected by perceptual (N+) or representational neglect (Rep+) took longer in reaching the target location compared to the other groups of subjects ($p < .05$). *Starting Positions* ($F_{(1,31)} = 2.665$; $p =$ n.s.) and Group × Positions interaction ($F_{(4,31)} = .360$; $p =$ n.s.) did not reach statistical significance.

In the Delayed Reaching condition a 1-way ANOVA with Group (C, Rep+, N+, RN−, LN−) as independent variable and Time (seconds spent in *reached the TL after 30* min) *as dependent variable* showed a statistical difference for the variable Groups (ANOVA: $F_{(4,31)} = 2.920$; $p < .05$). Duncan test showed that Representational neglect patients (Rep+) were significantly slower than all other subjects ($p < .05$).

3.2. Pathways

Video recording of each trial was scanned frame by frame and pathways followed by each subject in each condition were reported on a transparency; visual inspection of the participants' performance was executed by independent observers.

In the Searching condition, Controls and Brain-damaged patients without neglect and with representational neglect followed a systematic method of searching according to what has been defined as "circle" search strategy (Astur, Tropp, Sava, Constable, & Markus, 2004; Kallai, Makany, Kazmer, & Jacobs, 2005; see Fig. 4). Patients with perceptual neglect did not show any systematic strategy: they appeared to perform a rapid search, with small direction changes and some straight lines of displacement; an analogous of the so-called "back and forth" strategy (Astur et al., 2004; Kallai et al., 2005).

As reported in Fig. 4, pathways in the *Immediate Reaching* condition show that only controls and brain-damaged patients without neglect made displacements straight towards target's location.

In some occasion, mostly in the first trial from IR-B starting point, neglect patients performed a visual scan search strategy by turning the wheelchair standing on the spot.

In *Immediate Reaching* condition, neglect patients made "accuracy" errors: once arrived near target's location they failed in reaching exactly its precise spot and moved around the target (see Fig. 4). In the same group of patients a "rotational" error (Hermer & Spelke, 1994) was also observed (i.e., looking for the target in the homologous corner as defined by room's rectangular shape; see Fig. 4).

In the *Delayed Reaching* condition, all groups but patients with representational neglect (Rep+) were able to reach the target following the shortest path from the starting point (according to a straight trajectory, see Fig. 4c). Pathways followed by Rep+ subjects in this condition showed that they made mostly "rotational" errors and when target remained undetected they restart searching according to a circle strategy.

All patients reported the presence of landmarks and were able to describe them; however, neglect patients failed in marking their relative position (according to each other and to TL) in a blank sketch of the room.

One perceptual neglect patient (subject no. 4, see Table 1) stated that the room was empty and two right brain-damaged

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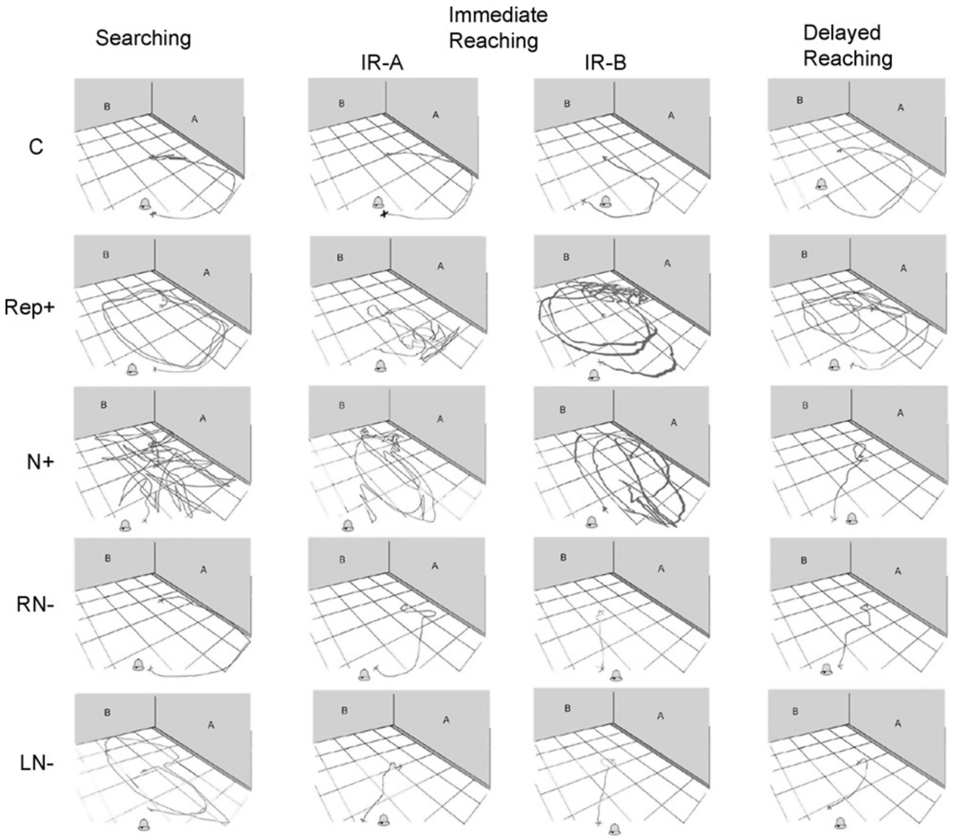

Fig. 4. Examples of the pathways followed by healthy subjects (C), right brain-damaged patients with representational neglect (Rep+), right brain-damaged patients with perceptual neglect (N+), right brain-damaged patients without neglect (RN−) and left brain-damaged patients without neglect (LN−). In the first column example of pathways followed when subjects performed the Searching condition are showed. In the second and third columns examples of pathways performed the Immediate Reaching condition, when they started the task, facing wall A (IR-A) and wall B (IR-B), respectively, are reported. In the fourth column, examples of the pathways followed during the Delayed Reaching.

patients, one without neglect and another with pure imagery neglect, reported only one landmark (subject no. 12 and 7, respectively). Healthy subjects were all accurate in reporting both items and target position according to them. One subject relied on an "elemental strategy" (encoding distance and/or direction from one single landmark).

Left brain-damaged patients reported to use mostly a "configural strategy" (namely encoding the array of landmarks as a configuration). Just three of them (subjects 24, 25, 26) preferred an "elemental strategy".

All right brain-damaged patients without neglect used landmarks following an "elemental strategy".

Table 4
Number of subjects reporting landmarks and their use in the debriefing after the experimental session

Group	Landmarks recognised			Landmarks used		
	2	1	0	2	1	0
C	8	–	–			
Rep+	4	2	–	3	3	–
N+	4	–	1	1	2	2
RN−	7	1	–	1	6	1
LN−	7	2	–	6	3	–

In Table 4 number of subjects using landmarks and the strategy employed to find TL is reported.

4. Discussion

The experiment we report here was composed by three different tasks that assessed specific navigational abilities according to the novelty of the environment in which navigation occurred. The conditions were: searching, immediate and delayed reaching.

The Searching condition mirrored the daily life situation in which a subject explores a new environment looking for a specific location. In our case the goal was a small spot (not visible to the subjects) triggering an infrared sensor and cued by a light and a tone. Patients were free to organise their searching the way they preferred. Salient spatial cues were provided by room's rectangular shape (creating two couple of homologous corners, each spatially defined by the relative position of the long and small wall at its sides) and two items placed close to the middle of two walls, in front of the starting point and to the small wall to its side, respectively (see Fig. 1). These spatial cues were of scarce utility during the first search when target location was unknown but became crucial to code its location and to help planning and following a shortcut in successive reaching.

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In the Searching condition patients with perceptual neglect (N+) showed an incoherent pattern of exploration. At variance with what was observed in a previous study (Guariglia et al., 2005), they wandered randomly in the room without any detectable spatial organization in their searching strategy, actually spending a significantly greater amount of time than other patients to localize the target for the first time. Their performance in this condition was characterised by small direction changes and some displacement in a straight direction; they also show the typical spatial perseverations observed in clinical assessment with cancellation tasks, namely repetitive passages in the same portion of the room while neglecting other unexplored locations (see Fig. 4). In presence of landmarks, patients did not use more basic exploration strategies that essentially rely on geometric module and idiothetic information. On the contrary it appears that they tended to use landmarks as a point of reference for guiding their search. This pattern of searching is in line with the egocentric disorder showed by N+ patients and mirror the spatial asymmetries usually observed in explorative tasks. A similar behaviour was previously observed in a path replication study (Pizzamiglio et al., 2003) in which neglect patients successfully replicated distances only when blindfolded or when visuo-spatial information could not be used as a reference point.

In “Immediate Reaching” our subjects were asked to reach the previously found target after being disoriented. Here, the two items placed in the room were expected to provide a powerful external reference to facilitate coding of target position according to the room. In this condition both groups of neglect patients were severely impaired and showed great difficulty in retrieving the target they found in a trial performed just few minutes before. Because of the clinical dissociation of symptoms we maintain that the inability to use landmarks in this condition by both groups of neglect patients could depend from different impairments according to neglect sub-type. Actually Rep+ group replicated performances observed when TL had to be found according to the euclidean features of an empty environment (Guariglia et al., 2005). Compared to subjects affected by purely perceptual disorders, they showed normal ability to correctly explore the room, perceive, detect and memorize landmarks, hence their performance appears to reflect a more general difficulty in representing the environment, namely not only its shape but also landmarks' relative position in it. On the contrary N+ patients showed a selective impairment due to landmarks presence, since when the room was empty they efficiently retraced TL (Guariglia et al., 2005). We think their results could be ascribed to a specific perturbation in the ability to represent landmarks in a mental map of the room due to their visuo-perceptual, explorative deficits. Indeed, their typical pattern of exploration would justify an effortful, patchwork-like acquisition of environmental characteristics including relationship between single landmarks and environmental features (wall, angles). As a consequence a strong interference should be expected with the making of a coherent mental map in which several features (distal and proximal landmarks, turnings, etc.) have to be considered as a whole in a representation. If this was the case only after sufficient exploration and several attempts N+ patients should become able to form a reliable map of the room. In fact in delayed reaching N+ patients did not differ from controls showing a spared ability in creating precise cognitive representations provided a sufficient possibility to fully explore the environment. In contrast Rep+ patients remained unable to correctly reach TL even in the delayed attempt. This is compatible with the hypothesis of a general inability in creating a stable representation of the environment or a defective (conscious) access to a mental representation. The first hypothesis however, appears at odds with the deficit observed in clinical assessment for representational disorders. In the well-known ‘square's description’ test (Bisiach & Luzzatti, 1978) patients suffering from representational neglect typically report only relevant items to the right of an imposed point of view. Which side of the square will be correctly described depends on the perspective from which the subject is asked to explore. Yet, as both sides are reported, albeit separately, it follows that a complete representation of the whole square should exist in long-term memory. However, one should take into account the fact that this clinical task is based on a description of a very familiar environment with significant autobiographical meaning, which could possibly facilitate its mental representation. To our knowledge, there is no evidence that patients with representational neglect can show analogous asymmetries in describing from memory locations learned after illness onset.

An alternative possible explanation for the present results could be that Rep+ patients failed within our experimental set due to the lack of significant visual cues. However, the hypothesis that the richer the environment the easier the orienting seems not in line with several evidences. First, it is well-known that an increased density of visual stimuli exerts a negative effect on performances in neglect patients (such as in typical cancellation tasks; Azouvi et al., 1996; Ferber & Karnath, 2001; Halligan, Marshall, & Wade, 1989). Second, pathological scores at the square description test demonstrate that in spite of rich environmental salience and strong autobiographical relevance, orientation is defective even in a well-known (i.e. over learned) location. It is still possible that Rep+ patients may be able to correctly navigate in a familiar place they cannot properly describe. However, to our knowledge a similar finding has never been reported. It should be noted that if patients with representational neglect would show spared abilities in navigating in a very familiar location, it would be difficult to exclude a confounding role of both cognitive and psychological factors adding to the spatial salience of the eventual landmarks. This in turn would strongly undermine the possibility to draw significant conclusions about the real navigational abilities of these patients. The present data suggest that the impairment affecting Rep+ competence in spatial representation could be a specific disorder in the ability to build or use mental maps of previously unknown environments.

Some other points deserve attention: why our patients did not take advantage of the simpler strategy of memorizing the position of the target in a verbal code? Landmark could have been used in the usual manner we normally refer to them, sort of “the target is close to the red item near the short wall”. Moreover, since N+ patients were able to use path integration or the geometric module (Guariglia et al., 2005) why shifting to a different strategy of navigation was not observed when an attempt

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in the present condition had proved wrong? This issue raises the broader question of how many strategies are available when the original coding of a position is made according to specific spatial cues and whether shifting between them could be possible.

According to the literature, landmarks can serve as representational or navigational helps ("organizing concept" and "navigational tool": Sorrows & Hirtle, 1999). In the first case, a landmark allows the definition of crucial environmental points (in our task: the target is close to/in front of/to the left of the black item); in the second case, by working as a navigational tool, the landmark acts as a guide while subject is displacing, marking a point of spatial choice, a decisional stage during navigation (i.e. *just get there then go searching nearby*). Unfortunately, we cannot tell which alternative was preferred by patients in the present task. Considering the size of our experimental room it appears that a combination of both types of landmarks' use could have been helpful accounting for a successful search. However, it should be noted that a verbal strategy would be adequate only if landmark and target would coincide while in our case a landmark is just a spatial suggestion for a salient part of the room and not for the precise location of the target. Actually even the simple use of a landmark as a navigational tool would always require a set of further spatial transformations to accordingly organize motion once landmark is reached, namely in and on a framework of egocentric coordinates.

It remains that landmarks were not helpful to neglect patients: they rather appeared to work as obstacles in the possibility to revert to alternative strategies of navigation. Apparently, landmarks also prevented N+ patients from re-orienting themselves using corners features (to navigate according to the shape of the room) even when their pattern of search revealed they were lost. Considering this lack of alternative strategies we can assume that brain damage could interfere with the ability of shifting the navigational strategy in two ways: by affecting cognitive flexibility in general or by specifically preventing the use of an alternative strategy when spatial information has been coded according to a specific one. The possibility of a limited access to cognitive resources is not supported by results at clinical assessment for mental deterioration, since all patients showed normal abilities in all tests in which abstract reasoning was required both in the spatial and verbal domain. We rather think that neglect patients did not use alternative strategies because none was available since all relevant information about TL were coded according to landmarks and not to others specific spatial resources. Indeed, a landmark is the most important spatial suggestion to simplify space representation and help navigation: it is a cue for relevant points along a path but also provides crucial information about the relationships between specific locations and paths; it favours the possibility of creating new paths and a cognitive map of the environment in general (Sorrows & Hirtle, 1999). Thus a landmark is simpler to use and immediately available to be picked as a spatial reference. Landmarks' presence in itself may interfere with the possibility to shift the navigational strategy due to the automatic (and maybe implicit) spatial reference each subject made to them. Indeed, experimental results suggest exactly that landmarks are preferred over other form of orientation and that when they are made available navigational strategies are consequently selected (Foo, Duchon, Warren, & Tarr, 2007; Foo, Warren, Duchon, & Tarr, 2005). Accordingly, since in our room they appeared as an easy suggestion popping-out from the context, neglect patients had no reason to look for other spatial features nor tried to memorize their path. It should be also noted that navigation based on path-integration would necessarily require immediate execution since the pathway has to be retraced from memory, namely going backward through the mental reconstruction of the whole displacement. In the present case, a path-integration-based strategy should have been further prevented because of memory decay due to the amount of distance travelled and time spent with previous (unsuccessful) attempts with landmarks.

In conclusion, our data seem to strongly suggest that coding of spatial information through landmarks force the use of a specific (i.e. landmark-based) navigational strategy. However, for both brain-damaged patients without neglect and healthy controls, landmarks helped navigation and performances were not distinguishable from those obtained when no spatial cue was in the room (Guariglia et al., 2005). The following implication would be that navigational strategies are equivalents in terms of cognitive costs and their selection would depend from context (i.e. availability of some landmark) or individual preference. Our experimental set proposed an oversimplified situation that likely did not allow expression of these differences. According to Wang and Spelke's systems for navigation (2002) it remains unclear the type of relation linking each strategy to the other. The data we presented add information to the previous study by Guariglia et al. (2005) and clearly point to a relative independence of navigational systems. As a result, human spatial competence for navigation in the environment should not be considered as a serial organization of navigational mechanisms ranked according to cognitive demands. This would be strictly connected with the variability observed when environmental spatial information is sufficient to equalize several navigational modalities (Iaria, Petrides, Dagher, Pike, & Bohbot, 2003). Our results appear to further confirm this hypothesis because patients suffering from spatial hemineglect lost their ability to successfully navigate through a more basic navigational competence: namely, when navigation was expected to be easier because of landmarks made available in the environment.

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