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Representational neglect and navigation in real space

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Abstract

Topographical orientation relies on several cognitive strategies adopted by humans to move within the environment. In the present study, we investigate whether mental representation disorders affect specific cognitive mechanisms subserving human orientation. In order to differentiate distinct cognitive mechanisms involved in topographical orientation, we created a human version of the well-known "Morris Water Maze" and tested left and right brain damaged patients in a place-learning task. The test required the subjects to explore an experimental room in which no visual cues were present, find a target location, and then reach it in different conditions. The ability to memorise target locations in short- and long-term memory was also assessed. We found that all participants were able to reach the target location by using idiothetic cues (vestibular inputs, motor efferent copy, etc.). On the other hand, when starting position changed and re-orientation was necessary to reach the target location, in order to compute a new trajectory, only patients affected by representational neglect got lost. These results provide the first neuropsychological evidence of involvement of mental representation in a specific cognitive process allowing humans to reach a target place from any location in the environment.

Keywords: Navigation; Environment; Orientation; Imagery; Landmarks; Maze

1. Introduction

A recent study (Wang & Spelke, 2002) provides a theoretical distinction between three hierarchically organised systems that underlie navigation in animals and are involved in human topographical orientation: (1) *path integration*, which allows the continuous updating of the relationship between the subject and one or more relevant places while moving in the environment by using idiothetic cues (vestibular inputs, motor efferent copy, etc.); (2) *view-dependent place recognition*, which allows place and landmark recognition by making use of "a snapshot view-matching system"; and (3) *re-orientation*, which allows restoration of the spatial relationship between the subject and the environment when path integration is not available. Experimental findings on animals and humans and clinical neuropsychological data (for a review see Aguirre & D'Esposito, 1999) suggest that these distinct cognitive systems may rely on different neural networks. Aiming at developing a new taxonomy of topographical disorientation, Aguirre and D'Esposito (1999) underlined the association between posterior parietal lobe lesions and specific topographical disorders. However, lesions to the posterior parietal lobe are associated with the hemispatial neglect syndrome, which includes a high frequency and severity of topographical disorders (Bisiach, Pattini, Rusconi, Ricci, & Bernardini, 1997; De Renzi, 1982).

Neglect patients fail to find their room or learn how to go to the bathroom in the hospital since they cannot take into account landmarks on the left side (De Renzi, 1982). When required to describe a familiar route involving leftward turns from memory, neglect patients fail to report the actual path describing long detours with right turns instead of left ones (Bisiach, Brouchon, Poncet, & Rusconi, 1993).

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In addition to these clinical observations, a few studies have attempted to assess the navigational skills of neglect patients in experimental conditions.

Bisiach et al. (1997) reported that the ability to indicate the starting point, after being driven along routes involving left or right turns, was unaffected in a group of seven neglect patients. In the study by Philbeck, Behrmann, and Loomis (2001), neglect patients were able to indicate the distance of a visual target and to walk to it accurately and precisely without vision. Moreover, Pizzamiglio, Iaria, Berthoz, Galati, and Guariglia (2003) demonstrated that neglect patients did not differ from controls in replicating linear translation either in the left or in the right hemispace when the distance coding was based on vestibular and proprioceptive information (i.e., idiothetic).

The failure to find selective navigational deficits may be due to the fact that the tasks administered are very simple and rely on very primitive processes (i.e., path integration) mostly involving idiothetic information (vestibular, somatosensory and proprioceptive). This explanation may account for the absence of deficits in the tasks used by Bisiach et al. (1997), Philbeck et al. (2001) and Pizzamiglio et al. (2003) studies since they used environments in which visual cues were poor or completely lacking. Conversely, if a more complex representation of space is required, a significant asymmetry could appear. In fact, in a task requiring the integration of visual and non-visual information, neglect patients showed significant asymmetry in replicating linear displacements (Pizzamiglio et al., 2003). On the other hand, caution must be taken to avoid tasks performed in complex environments, such as way-finding in environments with many landmarks. In fact, rich environments include many different information that may be used by the subjects to adopt alternative navigational strategies (Iaria, Petrides, Dagher, Pike, & Bohbot, 2003), making the segregation of selective impairments unlikely.

In summary, although clinical observations frequently point to an association between topographical disorders and spatial hemineglect, an experimental approach can identify navigational impairments only under specific conditions. Since hemineglect is a complex syndrome that can affect different aspects of space cognition (Halligan, Fink, Marshall, & Vallar, 2003), different types of hemineglect may have different effects on navigational abilities. Namely, visuo-spatial neglect (i.e., the inability to perceive left-sided stimuli) affects the ability to detect and, therefore, to utilise visual cues and landmarks on the contralesional side of an environment. Instead, representational neglect (i.e., the inability to describe from memory landmarks on the left side of a familiar place as it would appear from a given point of view (Bisiach & Luzzatti, 1978) may directly affect the ability to navigate when complex representations of the environment are required.

In the present study, considering Wang and Spelke's (2002) theoretical distinction between the cognitive processes sub-serving topographical orientation, we, first, created a human version of the well-known "Morris Water Maze" (Morris, 1981) to differentiate between the previously described cognitive systems (i.e., path integration, re-orientation, view-dependent place recognition); then, we tested brain damaged patients with and without different neglect deficits in solving a place learning task.

2. Methods

2.1. Participants

Five groups of participants gave their informed consent to participate to the study: (1) 11 subjects without any sign of neurological or psychiatric impairment (C); (2) 5 right brain damaged patients affected by visuo-spatial neglect without any sign of representational neglect (N+); (3) 7 right brain damaged patients affected by visuo-spatial and representational neglect (Rep+); (4) 14 right brain damaged patients neither affected by visuo-spatial nor representational neglect (RN−); (5) 11 left brain damaged patients neither affected by visuo-spatial nor representational neglect (LN−).

Age, education and time from onset were the same for all groups. Demographic and clinical data are reported in Table 1. All brain-damaged patients were submitted to a neurological examination and a neuro-radiological scan (TC or MRI). Approval for the experiment was obtained from the local ethics committee.

2.2. Neuropsychological testing

All control subjects were submitted to M.O.D.A. (Branzelli, Capitani, Della Sala, Spinnler, & Zuffi, 1994) to exclude any sign of mental deterioration.

Brain damaged patients were submitted to an extensive neuropsychological evaluation that assessed language (Ciurli, Marangolo, & Basso, 1996), short-/long-term memory (Spinnler & Tognoni, 1987) and abstract reasoning (Raven, 1938; Spinnler & Tognoni, 1987).

The standard battery for neglect (Pizzamiglio et al., 1992) was used to assess the presence and severity of visuo-spatial neglect. Representational neglect deficits were assessed by asking the patients to describe a familiar place from memory, as it would appear from two opposite points of view (Bisiach & Luzzatti, 1978). The Laterality Quotient was calculated on the number of elements reported on each side in the two descriptions (Bartolomeo, D'Erme, & Gainotti, 1994): a score equal or inferior to −20 was considered sign of representational neglect.

No subject was affected by mental deterioration or short-/long-term memory deficits. No difference in the severity of visuo-spatial neglect between N+ and Rep+ group was evidenced (*t*-test: $t = 1.75$; $p = 0.1106$). In left brain damaged patients, the language assessment showed they had sufficient comprehension skills to fully understand the experimental instructions.

Table 1
Demographic and clinical data of brain damaged patients

No.	Group	Age	Schooling	Onset (months)	Lesion's site	Broadmans' areas
1	REP+	65	13	2	F-T-P-(ic/t)	9/44/45/46/47/4/6/s/21/22/39/40
2	REP+	71	13	8	T-P	21/S/40/41/42
3	REP+	61	5	9	F-T-P	47/45/44/6/21/22/41/42/s/m/40/39/
4	REP+	49	8	2	F-T-P-(ic, bg)	44/45/4/6/s/21/22/40/41/42
5	REP+	72	5	2	ic/nc	
6	REP+	58	8	1.5	T-P	22/39/40
7	REP+	60	5	2	T-P	21/22/37/8/39/40
8	N+	64	8	25	F-T-P-O	44/45/46/6/m/s/22/41/42/37/39/40/19
9	N+	58	17	2	t	
10	N+	66	8	2	F	44/45/46/9/32/24/8/6
11	N+	58	8	3	F-T-P	44/45/6/s/41/42/38/22/21/37/39/40
14	N+	61	17	7	t/ic/bg	
15	N+	71	8	3	F-T-P-(bg)	38/22/6/s/41/42
16	N+	63	5	2	T-(bg)	22/37
17	RN−	66	8	1	T-P	22/41/42/s/40
18	RN−	64	17	1	ic/bg	
19	RN−	48	8	152	F-T-(ic/bg)	45/6/s/41/42/22
20	RN−	86	8	1.5	–	–
21	RN−	71	8	48	ic/bg	
22	RN−	64	8	24	ic/bg	
23	RN−	75	8	3	P-O-(t)	39/19
24	RN−	43		2	–	–
25	RN−	51	13	20	T-(ic/bg)	38/21/22
26	RN−	58	10	4	ic	
27	RN−	59	8	5	ic/bg	
28	RN−	52	5	7	bg/ic/wm	
29	RN−	62	17	2	–	–
30	RN−	55	5	7	t/ic/bg	
31	RN−	74	13	4	F	4/6
32	LN−	56	5	11	F-P	6/4
33	LN−	71	13	1.5	T-P-O	22/41/42/37/39/40/19
34	LN−	85	6	9	–	–
35	LN−	64	5	1	T-O-(t)	28/36/37/38/17/18/19
36	LN−	42	13	262	FTP-(bg, t)	21/22/10/9/8/24/32/44/45/46/47/6/m/s/40/39/7
37	LN−	55	8	1	F-T-P-O-(ic)	45/46/6/21/22/s/41/42/37/39/40/19
38	LN−	69	17	19	F-T-P	22/41/42/6/s/m/40
39	LN−	52	13	14	–	–
40	LN−	52	18	26	–	–
41	LN−	44	17	5	t/ic/bg	–
42	LN−	65	18	5	t/ic	

Number of females and males and mean age and schooling (and S.D.) of controls are reported in the last row. Control healthy subjects ($N = 11$): 8 males, 3 females, Mean age 55.3 years (S.D. = 10.4). Mean schooling 12.4 years (S.D. = 4.1).

2.3. Experimental task and procedure

The experiment was performed in a rectangular room (5 m × 6 m); the walls were completely covered in homogeneous grey curtains that hide all the environmental cues (i.e., door, heater, electrical plugs, etc.). The floor was painted grey to mask any differences in the floor tiles that could be used as a landmark. Four lamps were positioned symmetrically on the ceiling. In each corner, there was a black box with a hole in the centre; one of those boxes masked a micro-camera with a wide-angle lens. The micro-camera was connected to a VHS recorder system and a monitor located in the adjacent room, where an experimenter followed the recording of the experimental sessions. In the room, there was a photocell connected to a sound device placed at the centre of the ceiling. The photocell located on the ceiling above the hidden target location switched on the sound device whenever the head of the subject passed to that target point. Subjects moved in the experimental room by sitting on a motorised wheelchair and using a joystick.

The participants were required to perform the following three experimental conditions:

1. *Searching*: this condition consisted of a unique trial. The subjects were blindfolded and placed at the centre of the room facing wall A (starting position A, see Fig. 1). Then, moving in full vision, they were asked to find a hidden location indicated by an acoustic signal. Once the target location was found, the subjects were required to memorise the location in order to reach it in the next trials by following the shortest pathway. Then, the subjects were blindfolded, disoriented by mov-

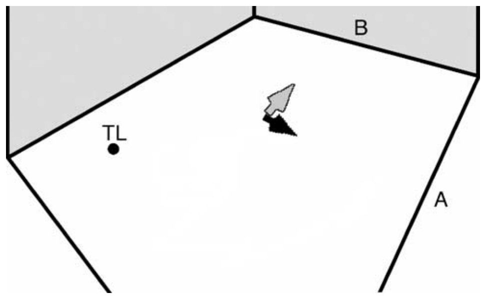

Fig. 1. Schematic draw of the experimental room and conditions. Black arrow: starting position facing wall A; grey arrow: starting position facing wall B. TL, target location.

ing within the room including clockwise and counter-clockwise rotations, and again taken to the centre of the room.

2. *Immediate Reaching*: the participants were administered six trials. In the first three trials, the subjects started the task facing the same wall A used in the Searching condition (IR-A); in the last three trials, the subjects started the task facing wall B (IR-B) (see Fig. 1). When facing wall A, the target could be reached by just relying on idiothetic information since the subjects were placed in the same starting position they had in Searching. Moreover, the absence of any landmark in the room made the use of view-dependent processes unlikely. On the other hand, facing wall B, previous idiothetic information were useless and subjects were forced to use the re-orientation system, which relies on the geometry of the environment and on its mental representation: re-orientation allows subjects to restore the relationship between themselves and the target place in order to compute a new trajectory. Each trial stopped when the subjects successfully reached the target location. After each trial the subjects were blindfolded, disoriented and taken to the centre of the room by the experimenter.
3. *Delayed Reaching*: to test long-term memory, after the Immediate Reaching condition was performed, the subjects were blindfolded and taken into a different room. Then, the blindfold was removed and the subjects were asked to perform paper and pencil verbal tasks (i.e., phonetic and semantic fluency, verbal reasoning, and handedness questionnaire). Thirty minutes later, the subjects were blindfolded again, taken into the experimental room, disoriented and placed to the centre of the room facing wall A. Finally, the blindfold was removed and they were asked to reach the previously found target location by following the shortest pathway.

Two researchers, who were blind to the hypothesis and the participants' identity, scored the performances by watching the video-recordings. The time required to perform each trial was used for scoring, and the pathway followed in each trial was reported on separate sheets.

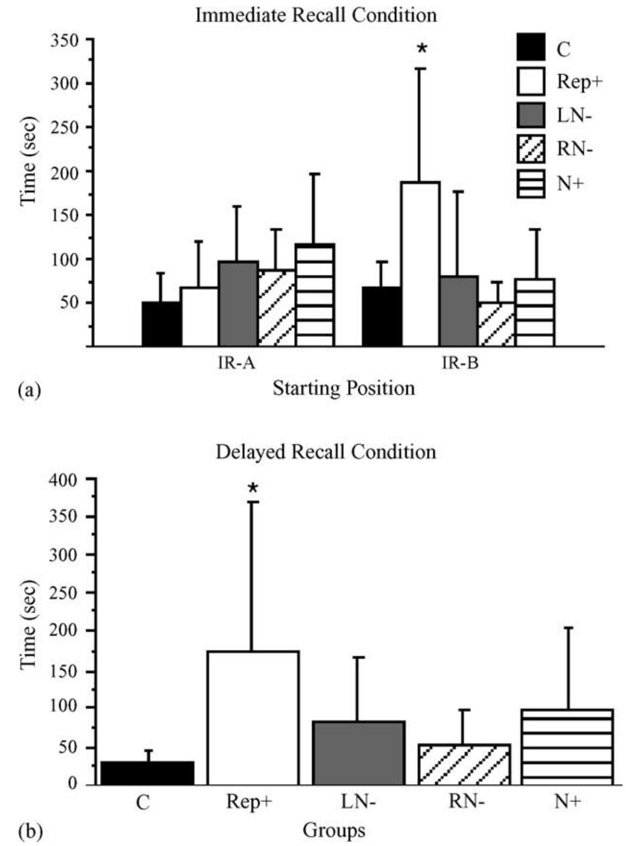

Fig. 2. The figure shows average and S.D. of the time needed by the different groups to reach the target location in immediate recall (a) and delayed recall (b) conditions.

3. Results

3.1. Time

Separate statistics were performed for the three experimental conditions. An ANOVA with Group (C, Rep+, N+, RN−, LN−) as independent variable and time (s) spent in Searching revealed the absence of any significant difference between groups ($F = 1.527$; n.s.). An ANOVA with Group (C, Rep+, N+, RN−, LN−) as independent variable and the time (s) spent to reach the target location in the Immediate Recall conditions (IR-A, IR-B) as a repeated measure showed no main effect of Group ($F = 2.503$; n.s.) and Condition ($F = 0.876$; n.s.). The Group × Condition interaction effect reached statistical significance ($F = 4.882$; $p < 0.005$): Post-hoc comparisons (Duncan test) showed that, when they reached the target location, the patients affected by representational neglect (Rep+ group) took longer in reaching the target location when they started facing wall B (IR-B) than when they started facing wall A (IR-A) (see Fig. 2a). Furthermore, their performance in IR-A did not differ from that of the other participants, whereas in IR-B they were slower than all the other groups, which did not differ from each other. A statistically significant interaction effect was also present in the Delayed Reaching condition (ANOVA: $F = 2.980$; $p < 0.05$):

the Rep+ group was slower than the other four groups, which did not differ from each other (see Fig. 2b).

3.2. Pathways

The reconstruction of the pathways followed in each trial was performed by two experimenters who were blind to the participants' identity. It should be noted that this is an observational analysis, without statistical significance, that has been performed in order to better understand the differences evidenced by the previous analysis. In the Searching condition, there was no difference between the participants: all subjects explored the room in a systematic way until they reached the target location. In a similar way, in the IR-A condition no difference was evident in the individual performances. In fact, all participants were able to reach the target location by performing a similar pathway (see Fig. 3a). In sharp contrast, in the IR-B condition there was a great difference between Rep+ and the other four groups that did not differ from the pathways followed performing IR-A condition (see Fig. 3b). Patients affected by representational neglect showed they were unable to compute a short pathway when the starting position changed. For instance, patient no. 5, who was affected by severe representational neglect without any sign of visuo-spatial impairment, reached the target location in a short time by following a straight route when he started facing wall A (IR-A) (see Fig. 3a, panel on the right bottom). On the contrary, when the patient started facing wall B (IR-B) he reached the target location after long and imprecise wandering, clearly showing the inability to go straight toward the target location (see Fig. 3b, panel on the right bottom).

In the delayed recall condition, the pathways followed by the Rep+ patients are evidence of an impaired performance with respect to the other group of subjects. In Fig. 3c, we reported an example of Rep+ patient performing the delayed condition (panel on the right bottom) and an example of the pathway followed by the other participants performing the same condition (panel on the left top and center).

4. Discussion

Our data clearly show a specific navigational impairment in right brain damaged patients affected by representational neglect. This group of patients, when asked to reach the target location starting from the same position used in Searching (IR-A condition), did not differ from either the other brain-damaged patients or the healthy control subjects. On the contrary, when starting from a different position (IR-B condition), the target location was reached only after a long and imprecise wandering. This behaviour did not change during the consecutive trials, while all the other groups were perfectly able to reorganise their navigation soon after the starting position changed. These findings are unlikely to be explained by differences in size and side of the brain lesions since the inspection of the lesions' maps seems largely overlapping.

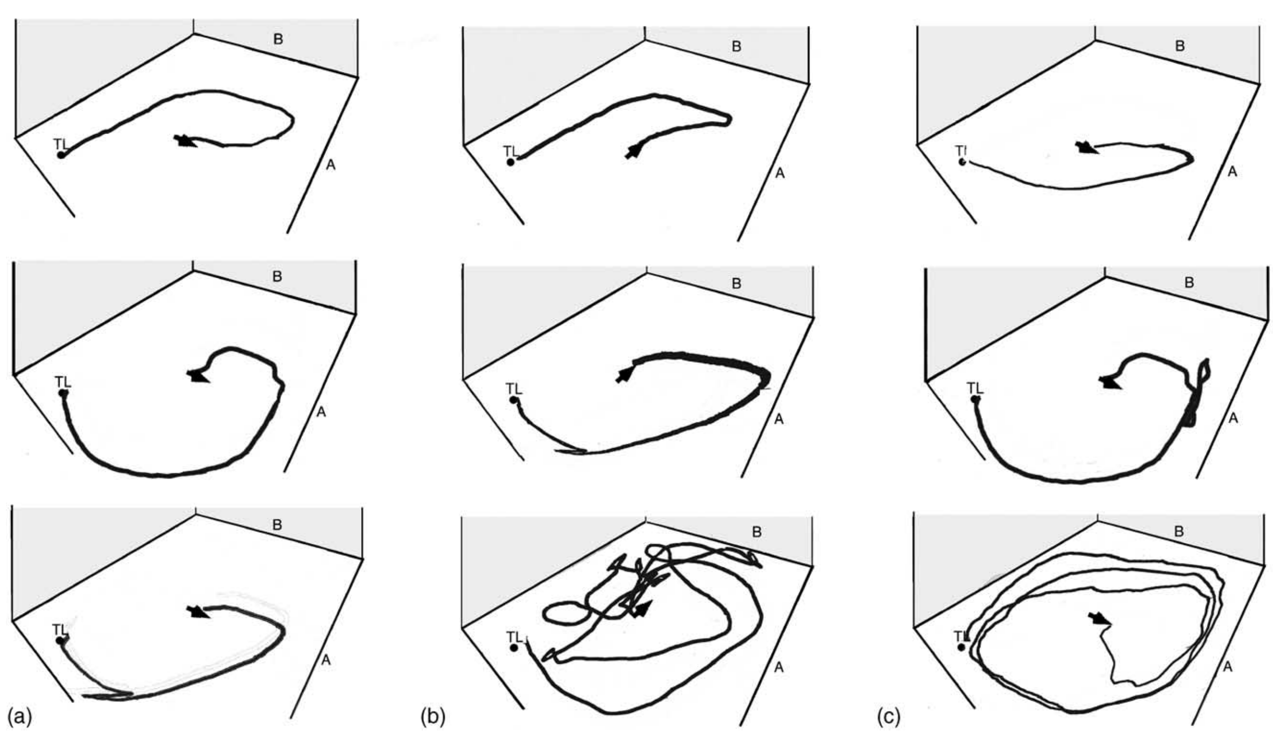

Fig. 3. Examples of the pathways followed by healthy subjects (top), brain damaged patients without representational neglect (centre) and patients affected by representational neglect (bottom). In (a) and (b) example of pathways followed when performing the Immediate Reaching condition when subjects started the task facing wall A (IR-A) and wall B (IR-B), respectively, are reported. (c) Examples of the pathways followed during the Delayed Reaching.

The fact that patients with representational neglect correctly reached the target location in the IR-A condition suggests that their ability to process idiothetic cues is intact. On the other hand, their inability to reach the TL starting from a different position suggests that the mechanism that allows re-orientation may be damaged. Still remain uncertain whether patients with representational neglect can generate mental representation of the environment: even if this is possible, however, they were unable to manipulate that mental representation in order to re-orient themselves into the environment.

Furthermore, representational neglect patients showed a significantly defective performance in the Delayed Reaching condition, although their memory skills did not differ from those of the other brain-damaged patients. One explanation might be that the idiothetic information is subjected to quick forgetting (Wang & Spelke, 2002). That is, idiothetic coding by itself does not allow storing environmental information in long-term memory, while long-term storage requires the use of a mental representation of the environment. Thus, the inability of representational neglect patients to manipulate a mental representation of the environment prevents them from using previous navigational experience even under identical conditions.

These findings suggest that representational neglect is not only due to the deterioration of a cognitive system processing mental images of controlesional landmarks, but also affect re-orientation during environmental navigation.

In summary, the present human version of the "Morris water maze" (Morris, 1981) proved successful in segregating different cognitive mechanisms subserving topographical orientation. By using this experimental paradigm, we provided the first neuropsychological evidence that (1) the cognitive mechanism subserving re-orientation requires the subject to build up and manipulate a mental representation of the environment, and (2) representational neglect syndrome does not allow the use of re-orientation system subserving navigation.

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