EVIDENCE FOR SEPARATE ALLOCENTRIC AND EGOCENTRIC SPACE PROCESSING IN NEGLECT PATIENTS

Luigi Pizzamiglio[1,2]**, Cecilia Guariglia**[1,2] **and Teresa Cosentino**[2]

([1]Department of Psychology, University of Rome "La Sapienza"; [2]IRCCS S. Lucia, Rome, Italy)

Abstract

Spatial orientation was investigated in two different conditions: (a) when the shape of the enclosure was the only available information; (b) when a clearly perceivable visual cue was added. Three groups of subjects were investigated: normal controls, right brain-damaged patients without and with hemispatial neglect. The performance of the first two groups clearly demonstrated the capacity to use the geometric properties of the environment and to integrate this information with an additional visual cue. Considered as a group, patients with hemispatial neglect were able to use the shape of the environment and, to a lesser extent, the additional visual cue. However, individual differences suggest two opposite performance patterns: two patients responded randomly when the shape of the environment was the only available information, and they improved considerably when the cue was offered; two other patients showed normal competence in dealing with the geometrical properties of the environment, but were unable to take advantage of the cue.

The different lesion site in these two types of patients suggests a possible dissociation of processing based upon allocentric or egocentric coding of space in humans as well as in animals.

Key words: hemispatial neglect, spatial cognition, navigation, environmental perception

Introduction

In mammals, space perception and orientation are subserved by different neural systems that become effective under specific environmental circumstances. Cell recording during space perception shows neuronal activity in several cortical and subcortical areas such as the parietal lobe, the prefrontal cortex and the superior colliculus. These spatially selective cells respond to visual events coded according to retinal, head or body centered coordinates (Andersen, Snyder, Li et al., 1993; Andersen, 1995; Galletti, Battaglini and Fattori, 1993). Reference to the egocentric framework provides the possibility of locating objects in space and with reference to the subject's own body.

When an animal has to move in an environment that is defined only by the shape of the enclosure (such as a circular or rectangular water maze without additional visual cues), other types of neurons are involved; these were first described in the hippocampus of the rat (O'Keefe and Nadel, 1978; Muller, Bostock, Taube et al., 1994). In these conditions, movements are guided by the cells that encode the location of the animal in relation to the geometric properties of the enclosure and the cells that encode the movements of the body, particularly the head, when the animal moves in the environment (Taube, Muller and Ranck, 1990; Taube, 1995). During navigation in a rich environment, adult animals can integrate the retinocentric and body-centered frames with the overall geometric properties of the space.

It has recently been shown that small children between 18 and 24 months can orient themselves according to the geometric shape of a room, but are unable to integrate this information with other clearly perceivable visual cues (Hermer and Spelke, 1994). In this experiment, the child, accompained by his/her mother, was brought into a rectangular room, where a toy was located in one corner. The child looked at the toy and was then disoriented by a gentle rotation in his/her mother's arms. The toy was removed and the child had to identify its previous location. Children in this age range indicate either the correct corner or the one diagonally opposite to it (rotationally equivalent corner) at a much higher than chance level. This behavior clearly shows that they were able to make use of the shape and the relative length of the two sides of the rectangle.

In a second condition, the same children were again placed in the room which, however, had three white walls and one blue one. They continued to use only the shape of the enclosure without integrating the additional visual cues (i.e., they alternatively chose the correct and the rotationally equivalent corner), at variance with adult controls who easily referred to the colored wall as a cue for locating the object (i.e., in this condition they chose only the correct corner).

The results of this study suggest that man also has independent systems for processing egocentric and allocentric coded space. The different rate of maturation and integration of the two spatial competencies provides the basis for the different performance of children and adults.

We thought it would be interesting to investigate whether a comparable dissociation between these two space-operating systems also occurs following a focal brain lesion, particularly in patients with hemispatial neglect. In these individuals, several other dissociations between dichotomous dimensions of space processing have been described: far versus near space, personal versus extrapersonal space, perceptual versus motor impairment (Umiltà, 1995). Two cases have recently been described, one with a selective hemispatial impairment in imaging familiar squares but no difficulty in other imagery or perceptual tasks (Guariglia, Padovani, Pantano et al., 1993), the other with no detectable disorder in imaging squares or other familiar places, but strong hemispatial neglect and asymmetry in comparing visuospatial images, such as shapes or angles produced by imagery (Pizzamiglio, Guariglia, Nico et al., 1996). The two patients had frontal and right parieto-temporal lesions, respectively. In interpreting these findings, Pizzamiglio et al. (1996) posited that a navigational (allocentric) strategy was required in the former imagery task, while the latter tasks could be performed within a body-centered framework (Pizzamiglio et al., 1996). Following the idea that the dissociation in imaginal neglect between different types of mental images is linked to damage of two different spatial systems, it can be hypothesized that a similar dissociation is found in neglect patients when they have to perform Hermer and Spelke's task with and without visual cues added to the environment.

In the present work, two unselected groups of right brain-damaged patients with and without hemispatial neglect and a control group were studied. Assuming the existence of two independent spatial systems, two dissociations were expected: (a) the first one concerns the possibility of identifying neglect patients with or without the ability to orient themselves in a rectangular enclosure without visual cues; (b) the second concerns the patient's ability to integrate the available visual cues (one colored wall in the room) with the information derived from overall perception of the room.

Materials and Methods

Subjects

The two brain-damaged groups included patients with unilateral right-sided lesions following a CVA, without history of psychiatric disorders or signs of mental deterioration.

Hemispatial neglect was assessed by means of a neuropsychological battery comprised of the following four tests: (a) Line Cancellation (Albert, 1973); (b) Letter Cancellation (Diller and Weinberg, 1977); (c) Wundt-Jastrow Area Illusion Test (Massironi, Antonucci, Pizzamiglio et al., 1988); (d) Sentence Reading Test (Pizzamiglio, Antonucci, Judica et al., 1992). Patients were included in the neglect group when they scored below the cut-off on at least two of the above-named tests (Pizzamiglio, Antonucci, Judica et al., 1992).

Size and location of the lesions were assessed with MRI (except for one neglect patient, who refused all radiological exams) and visual fields were assessed by Goldmann perimetry.

Fifteen right brain-damaged patients with hemispatial neglect (RBDN+), eleven right brain-damaged patients without hemispatial neglect (RBDN–) and eleven normal controls (C) of the same age, sex and education were examined. Clinical data of the RBDN+ group and demographic data of the other two groups are reported in Table I.

TABLE I

Demographic Data for the Three Groups and Clinical Data for the Neglect Group (RBDN+)

Patient	Age	Sex	Months from onset	Lesion site	Line Cancellation* (range: 0-21)	Letter Cancellation* (range: 0-104)	Wundt-Jastrow** (range: 0-20)	Sentence Reading* (range: 0-6)
RBD+1	64	F	2	FTPO	13	31	4	2
RBD+2	72	M	1	FTP	6	9	19	0
RBD+3	68	F	1	PO, Th	6	14	20	0
RBD+4	62	M	6	FTP, Th	10	22	8	1
RBD+5	63	M	2	Th, C, Pa, Put	12	38	14	0
RBD+6	65	M	9	FTPO	21	70	1	6
RBD+7	64	M	7	FTP	12	10	19	6
RBD+8	63	M	7	TP	20	20	17	2
RBD+9	71	F	3	FTP	17	92	18	6
RBD+10	70	M	3	FP	20	65	14	6
RBD+11	69	F	6	TPO	16	49	13	6
RBD+12	68	F	2	—	20	50	3	1
RBD+13	69	F	8	TP	21	59	13	5
RBD+14	64	M	10	Bg, Th	21	54	5	2
RBD+15	65	M	1	FTP	19	84	10	6
RBDN+ (N = 15)	66.47 (3.25)	6F 9M	4.53 (3.16)					
RBDN– (N = 11)	66.55 (3.72)	4F 6M	4.72 (3.77)					
Controls (N = 11)	63.82 (3.89)	7F 4M						

* = correctly crossed out or read items; ** = "unattended" responses to left oriented stimuli; lesion site: F = frontal lobe, T = temporal lobe, P = parietal lobe, O = occipital lobe, Th = thalamus, C = nucleus caudatus, Pa = nucleus pallidus, Put = putamen, Bg = basal ganglia.

Tasks

White Room

Patients and controls were blindfolded and brought into the room on a wheelchair. The four walls of the rectangular room (4 × 2.5 m) were completely covered by white vertical stripes from ceiling to floor; no meaningful visual cues were present on the floor or on the walls (including the door). The room was dimly lit by four identical lamps placed in the four upper corners.

Inspection phase: the subject was placed in front of one of the fours walls (see procedures), the blindfold was removed and he/she was asked to find an object (a yellow raincoat) located in one corner. The subject was blindfolded again and disoriented by at least two and a half complete clockwise and counterclockwise rotations of the wheelchair before being placed in front of one of the four walls; meanwhile, the raincoat was removed from the room.

Test phase: the blindfold was removed again and the subject was required to indicate, either verbally or by pointing, the corner where the raincoat had previously been located.

The patient always faced wall A during the inspection phase (see Figure 1). Two conditions were varied across trials: the location of the object during inspection (in the left or in the right corner in front of the subject) and the wall faced during the testing phase. There were 16 trials.

Visually-Cued Room

The subject's task was the same as in condition 1, except that during both the inspection and the test phase a 2 × 1 m red panel was clearly visible on one of the room's short walls. This condition included 32 trials.

Procedures

In both conditions (i.e. white room and visually-cued room), trials were randomized for both the target position and the wall faced during the test phase. In the visually-cued room, the panel position was also randomized across trials.

In order to ensure that no other cues were used except those provided by the experimental design, i.e. the shape of the room in the white room condition and the shape of the room plus the colored panel in the visually-cued room, the subjects were required to describe the room before testing began. If a subject reported the presence of extraneous reference points (such as a dirty spot on the floor that may not have been noticed by the experimenters), these were removed before the experiment began. Further, in order to avoid any suggestion of reorienting strategies (i.e., looking for an extraneous reference point that may not have been noticed by either subject or experimenters), the white room condition was always carried out before the visually-cued room condition.

Dependent Measures

Since the findings in normal adults described by Hermer and Spelke (1994) report an equal probability of "correct" and "rotationally equivalent" responses in task 1 and responses close to the ceiling effect for the correct corner, with no difference for the three other choices in task 2, two dependent measures were used in different analyses.

In task 1 both the objectively correct and the rotationally equivalent responses were considered "correct". Both corners on the crossed diagonal were considered "incorrect".

In task 2, where the colored visual cue was introduced, only the true correct response was accepted, while any of the other three responses was considered wrong.

The true correct response was also used to make a direct comparison between tasks 1 and 2 in the three groups of subjects.

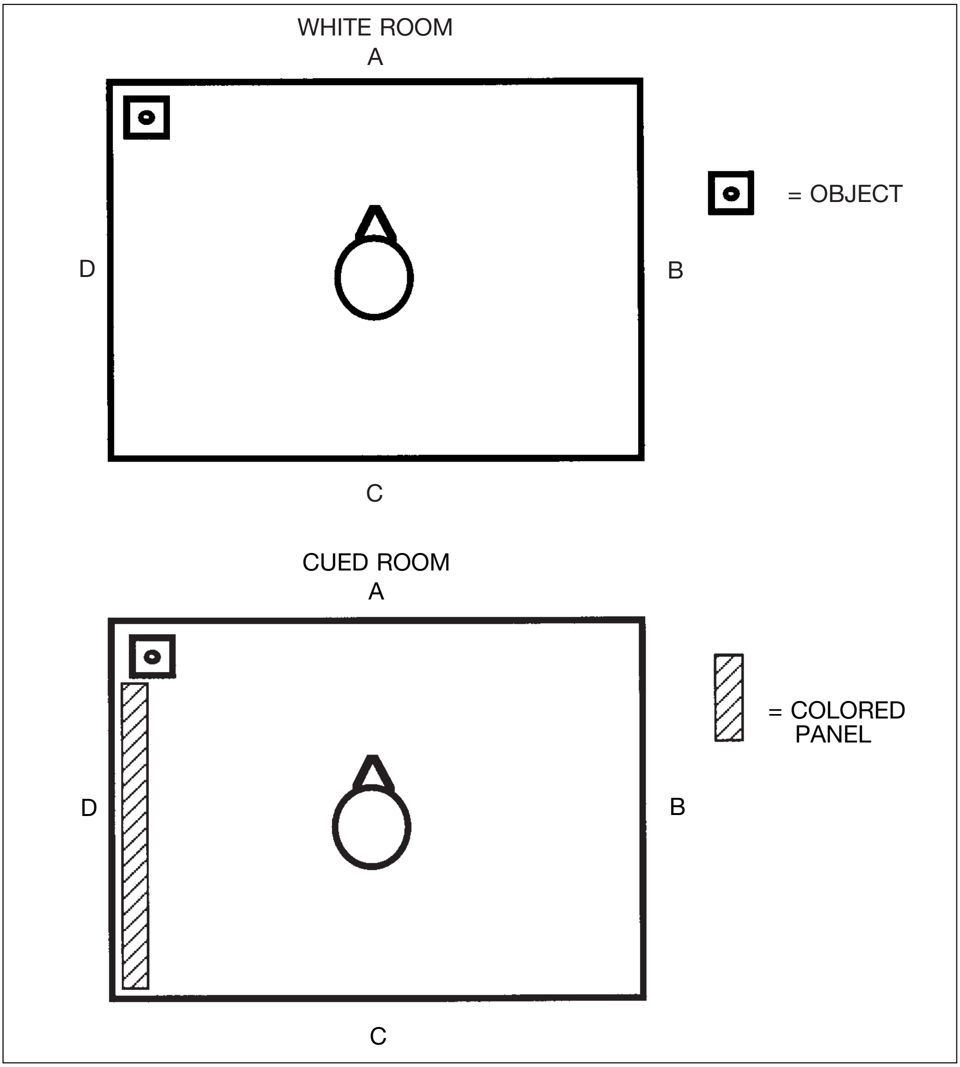

Fig. 1 – *During inspection, the subject always faced A; the object (O) was located either in the left (AD) or in the right (AB) corner. In task 2, the colored panel was always on one of the short walls. After being blindfolded and disoriented, the subject was tested facing one of the four walls.*

Results

A preliminary analysis showed no difference between the left and right presentation of the target object, so the two conditions were pooled together in the following analysis.

White Room

Means and standard deviations for the three groups of patients are shown in Table II. Correct and rotationally equivalent responses did not significantly

TABLE II

Means (and SDs) of Correct and of Rotationally Equivalent Responses for the Three Groups in the White Room and in the Cued Room

	White room		Cued room	
Group	Correct R	Rotationally equivalent	Correct R*	Rotationally equivalent*
Controls	8.45 (2.58)	6.09 (2.30)	15.00 (1.05)	.32 (.25)
RBDN–	7.63 (1.43)	5.36 (2.42)	12.59 (1.91)	.95 (.76)
RBDN+	5.80 (2.78)	3.80 (1.81)	7.35 (3.11)	2.30 (2.22)

* There were 16 trials for the white room and 32 for the cued room. In the table, the latter data are divided by two to facilitate reading of the results.

differ in the three groups. Therefore, these two responses (corners AD and AB, Figure 1) were pooled together for subsequent analysis.

A one-way analysis of variance was performed. The difference between the three groups was significant ($F = 13.9$, $p < .0001$). The neglect group performed significantly worse than the other two groups which, however, did not differ from each other (Scheffé's post hoc test).

In order to assess whether the subjects used geometric landmarks, the number of correct and rotationally equivalent responses was tested in each group against the expected chance value by means of a one-sample two-tailed t-test. In all groups, the difference was significant (C: $t = 11.65$, $p < .001$; RBDN–: $t = 8.02$, $p < .0001$; RBDN+: $t = 2.87$, $p < .01$) indicating that geometric information was used in this task.

Visually-cued Room

Means and SDs for the three groups are presented in Table II. A one-way analysis of variance using the number of correct responses as dependent variable showed that the difference between the three groups was significant ($F = 17.04$; $p < .001$). The neglect group performed significantly worse than the other two groups, which did not differ from each other (Scheffé's post hoc test).

The correct responses within each group were tested against chance with a two-tailed t-test, which yielded the following values: $t = 34.79$, $p < .001$ for C; $t = 14.93$, $p < .001$ for RBDN– and $t = 4.35$, $p < .001$ for RBDN+.

Further, within each group the choice of the correct corner was significantly more frequent than that of the rotationally equivalent one (C: $t_{(two\text{-}tail)} = 40.25$, $p < .001$; RBDN–: $t_{(two\text{-}tail)} = 15.37$, $p < .001$; RBDN+: $t_{(two\text{-}tail)} = 4.17$, $p < .001$).

The choice of the correct corner was also significantly greater than that of the wrong corner nearest the red panel (C: $t_{(two\text{-}tail)} = 28.22$, $p < .001$; RBDN–: $t_{(two\text{-}tail)} = 13.53$, $p < .001$; RBDN+: $t_{(two\text{-}tail)} = 3.34$, $p < .01$), as well as that of the other wrong corner, i.e., the one that was neither the rotational equivalent nor the wrong end of the red panel (C: $t_{(two\text{-}tail)} = 36.85$, $p < .001$; RBDN–: $t_{(two\text{-}tail)} = 15.29$, $p < .001$; RBDN+: $t_{(two\text{-}tail)} = 3.7$, $p = .006$).

These results indicate that the three groups were able to use visual cues in addition to the geometric landmark; however, the patients with hemispatial neglect were less proficient in integrating the visual landmark with the environmental information.

Comparison between the Two Tasks

A group-by-task (repeated measure) ANOVA was performed: the dependent measure was the number of correct responses (divided by two in the cued condition). A significant effect was found for group ($F = 22.36$, $p < .000$) and for task ($F = 102.82$, $p < .000$): the RBDN+ group performed significantly

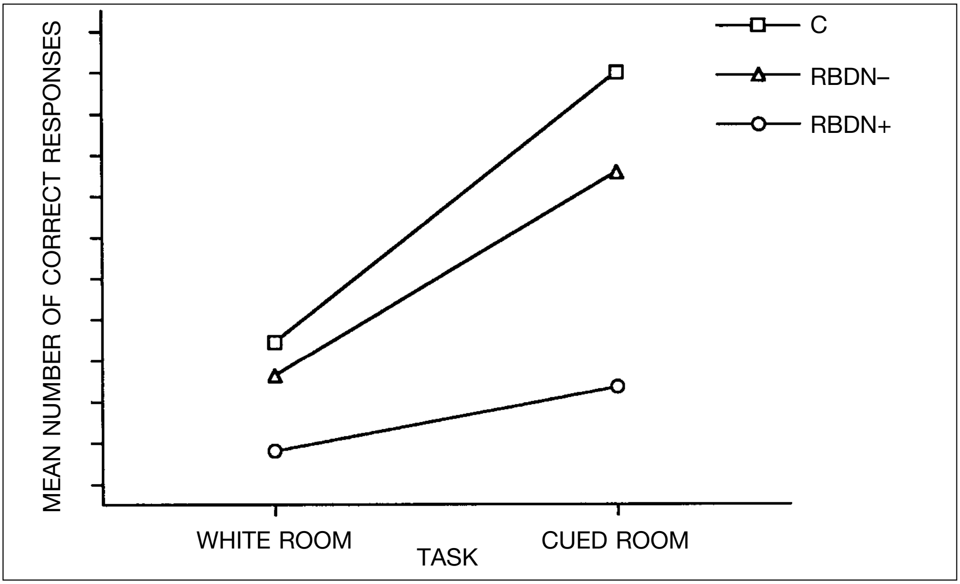

Fig. 2 – *Performances of the three groups of subjects in the two experimental conditions.*

worse than the other two groups, which did not differ from each other (Duncan's post-hoc test); there were significantly more responses in the visually-cued room. The group-by-task interaction was also significant ($F = 11.65$, $p < .000$); performance was greater in the colored than in the white room in the C (simple effect: $F = 76.94$, $p < .000$) and in RBDN– ($F = 49.07$, $p < .000$) groups (see Figure 2), while it was just short of significance in the RBDN+ group ($F = 3.92$, $p = .06$).

Individual Differences

Since individual differences were present in the neglect group, an individual data analysis was performed.

In the control group (C), no subject responded at chance level in the white room and all subjects reduced their error rate in the cued condition, except for three subjects who were already at ceiling level in the white room condition. The RBDN– group performed in the same way in the two experimental conditions, i.e., performances were above chance in the white room and the true correct responses increased in the cued room condition, with the exception of one patient who was close to chance in the white room, but not in the cued condition. In the RBDN+ group ten patients scored at chance level in the white room. Eight of them maintained the same performance level when the colored panel was introduced, and two patients (4 and 12) showed remarkable improvement. They scored 56% correct in the white room and 69% and 75% correct, respectively, in the colored room (Figure 3a).

The remaining five patients showed an above chance performance in the white room (from 75% to 94% correct responses). Three of them (5, 10 and 14) maintained the same level of responses with the colored panel, and the other two (3 and 8) clearly worsened their responses in the cued condition, falling from 75% to 41% and 53% correct responses, respectively (Figure 3b).

The neglect patients' scores in the white room and in the cued room were correlated with an index of neglect severity (average Z score of the screening battery for hemineglect). The r_s were – .30 and .10, respectively; both were non significant.

Lesion Site

Although the lesions of patients with stable neglect were quite variable and very large, they always involved extensive portions of the posterior-parietal cortical-subcortical areas.

The pattern of damage found in the three patients whose performances differed in the white- and the cued-room condition (the fourth one refused the radiological examination) is worth commenting on. Patient 4, who responded poorly to the geometric properties of the environment but made good use of the colored "cue", had a lesion involving the cingulate areas (BA 23 and 24) and partial sparing of the posterior parietal areas (BA 39 and 40; Figure 4a). On the contrary, the two patients (3 and 8) with good responses to the shape of the room but not to the cue had no involvement of the cingulate areas; however, they had massive damage in the posterior-inferior and superior parietal areas (BA 39 and 40, 5 and 7; Figure 4b, 4c).

Discussion

The first aim of the present study was to analyze whether neglect patients show individual variation in the capacity to use the overall configuration of the environment to orient themselves in space.

As a group, these patients were qualitatively similar to controls and RBDN– patients. However, single case analysis revealed that only some neglect patients made use of the geometric properties of the room, while others did not.

The observation that impairment in using the geometric properties of the environment does not essentially relate to the severity of neglect points to the

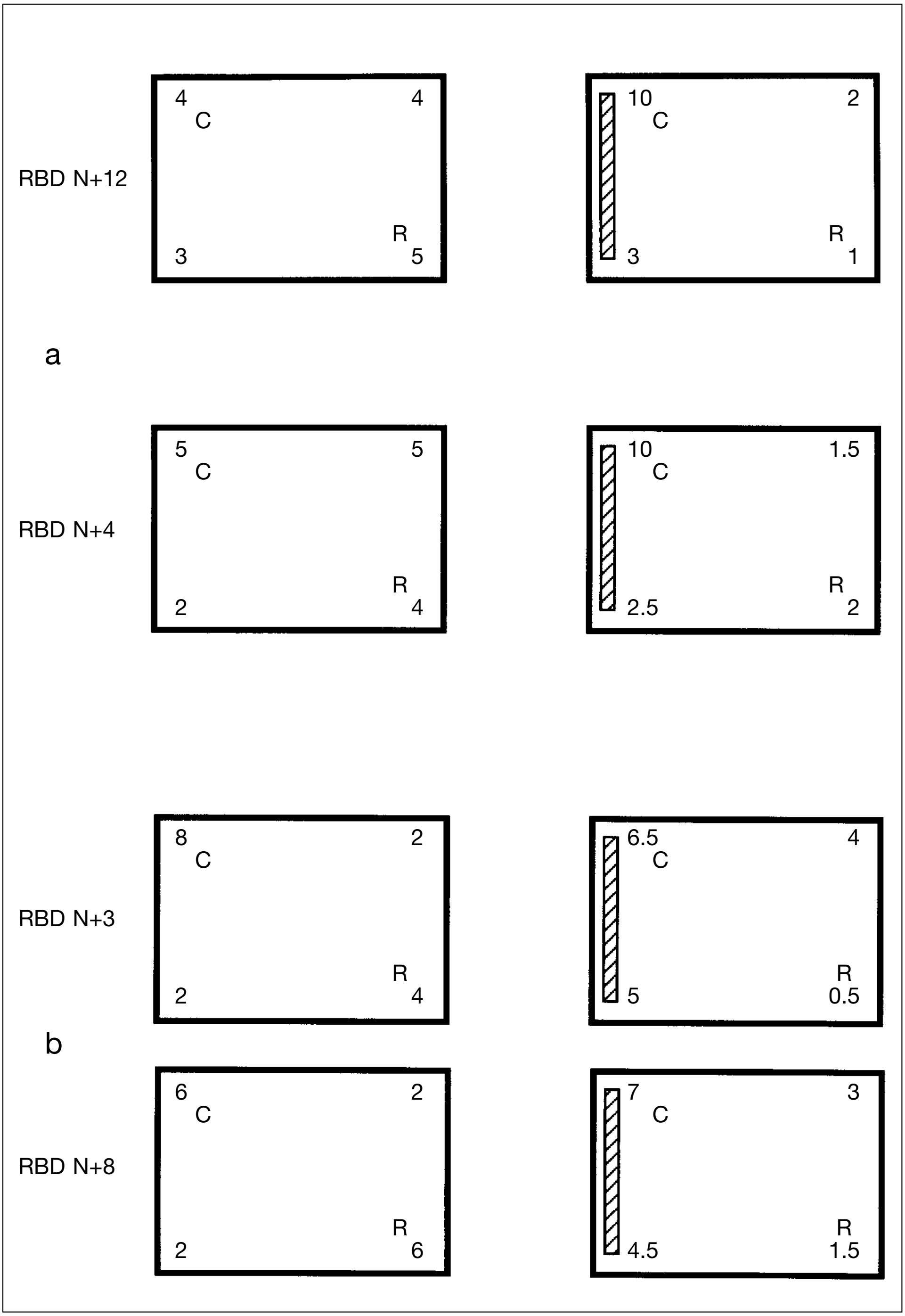

Fig. 3 – *Number of responses for each corner of the room in the white and in the colored condition for patients 4-12 and 3-8. In both conditions, the number of choices referred to 16 trials. C: correct response; R = rotationally equivalent response.*

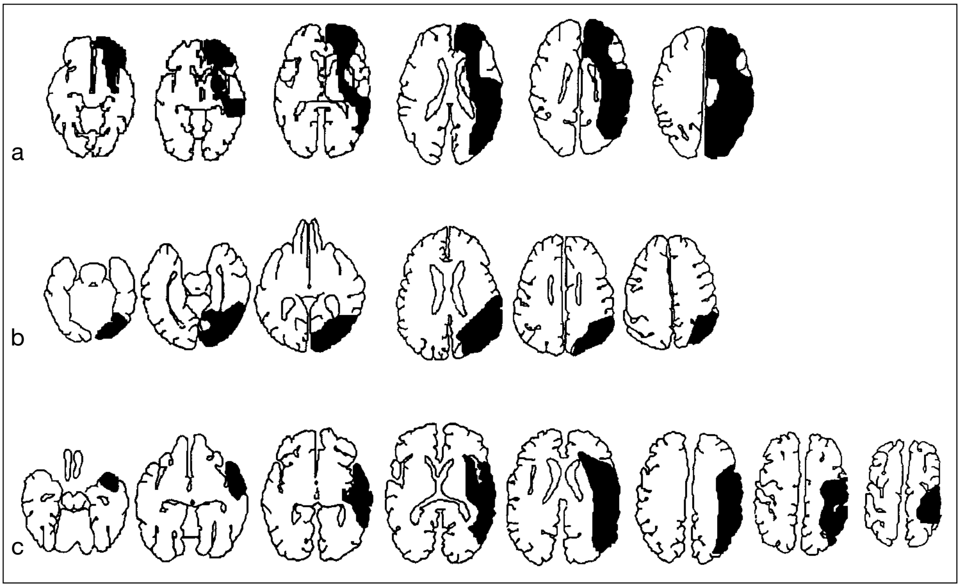

Fig. 4 – *Templates of the lesions in patients 4 (a), 3 (b) and 8 (c), according to Damasio and Damasio (1989).*

possible independence of the perception of the spatial properties of objects in space from the perception of the self in the surrounding environment.

The present data, which concern selective impairment of one of those perceptual systems, are compatible with the finding that early in development children predominantly rely on the shape of the environment without integrating any other non-geometric information present in it (Hermer and Spelke, 1994).

As for the second question addressed in this study, concerning the integration of geometric and non-geometric (the colored cue) information, the group data show that the facilitation of the colored cue consistently improved the performance of the control and RBDN– groups, but was less effective in the RBDN+ group.

Further, the dissociation shown by the four patients with neglect provides additional evidence about separate processes in spatial cognition. In spite of their great difficulty in abstracting information from the shape of the enclosure, patients 4 and 12, with very severe neglect, had the ability to extract visual cues, such as color, and to associate them with some geometric information (for instance, the short side of the room) in order to improve their orientation in the environment. On the contrary, patients 3 and 8 exhibited a completely different pattern showing fairly good orientation on the basis of the shape of the room, similar to young children, but severe impairment in integrating this overall perception when a strong and highly informative cue was presented. It is important to note that clinically these two patients showed a hemineglect syndrome of moderate severity, indicating that their perception of the properties of objects per se and their relation to extrapersonal space were only moderately impaired. The discrepancy between their performances in the room with and without the red panel suggests that their main problem may be the integration of perceptual information of a different nature.

The lack of flexibility in using separate kinds of information at certain levels of development and the opposite possibility of associating geometric and non-geometric properties of space observed in the two kinds of patients strongly suggests both the existence of different codes and representations of spatial information and the need for a neural system that integrates separate channels. Unfortunately, although the neural basis of these different spatial systems is partially known in lower mammal, no information is presently available in humans. The clinical dissociations we found provide some behavioral evidence in support of the existence of separate systems, but very little about the underlying neuroanatomy.

Few speculations can be drawn from the present data. The cingulate lesion, found in patient 4, directly affects the connections to and from the subiculum (Lopez Da Silva, Witter, Boeijinga et al., 1990), thus disconnecting some basic parahippocampal structures which, in animals, are involved in the shape-base coding of the space. On the other hand, the patients who failed to integrate environmental shape with other visual cues showed predominant involvement of posterior areas, possibly tuned to integrating multimodal information relative to the space.

It might be of interest to observe that the experimental situation used in young children and in brain-damaged patients primarily involves "perception" of the interaction between the self and environmental characteristics. This task did not involve any active movement of the subjects in the enclosure, minimizing the possibility of studying the second component of the ability to navigate in space. In order to more closely match the experimental situations used in studies on rats, other paradigms involving the subject's active or passive movements in a given space must be used.

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Luigi Pizzamiglio, Department of Psychology, University of Rome "La Sapienza", Via dei Marsi 78, 00185 Roma;
e-mail: pizzamiglio@uniroma1.it

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