Chapter 2

THE ROLE OF IMAGERY IN NAVIGATION: NEUROPSYCHOLOGICAL EVIDENCE

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Abstract: In this chapter a brief review of studies analyzing the relation between disorders in mental representation of space and environmental navigation is reported. Most of the studies concern the role on navigation of unilateral neglect, that is the inability to represent and to attend to the contralesional side of the space, that often follows lesion in posterior regions of the right hemisphere. Different studies demonstrate that unilateral neglect does not affect the ability to use some basic navigational processes such as path integration, but it affects the ability to develop and use cognitive maps of the environment for navigation. A case is also described of a patient who never developed navigational skills due to a congenital brain malformation. The only remarkable deficits the patients presented concerned mental imagery, supporting the hypothesis that mental imagery plays a crusial role in navigation.

Key words: unilateral neglect; representational neglect; topographical disorientation; mental imagery disorders.

Navigation in the environment requires planning a trajectory to follow and using mental maps. However, up until now the role of mental imagery disorders in determining neuropsychological deficits in navigation has not been a popular research topic. Indeed, it is quite surprising that neuropsychological deficits of visuo-spatial imagery have hardly been investigated in the study of human navigation. In this context, the study of one disorder in particular, namely, spatial neglect, seems very promising to provide a better understanding of the relationship between mental representation and navigation. Spatial neglect is a unilateral disorder of space representation affecting the contralesional side of space that is usually produced by lesions of posterior areas of the right hemisphere (Bisiach, 1999). The inability to process contralesional stimuli may involve different visuo-spatial processing, from the perception and handling of visual, auditory and tactile stimuli to the mental representation of objects and scenes.

In particular, in daily life activities or during formal neuropsychological testing right brain damaged patients affected by neglect are unable to detect stimuli on the contralesional, left side of space. Patients may fail to answer the examiner if he/she is seated on their left side and may even fail to detect the examiner's presence. They eat only from the right side of a dish, bump into left-sided obstacles when walking, read only the right columns in the newspaper and sometimes read only the rightmost letters in a word.

During formal testing, they fail to cross out left-sided stimuli such as letters, circles, lines or bells, bisect horizontal lines with consistent leftward errors and are not subject to leftward optical illusions. In some patients, neglect affects personal space; thus, these patients do not comb their hair on the left, do not shave or make up their left cheek, do not pull on their left pant leg or the left arm of shirts and jackets. In some cases, mental imagery may also be affected. For example, patients may omit the left side of drawings from memory and may fail to describe the left side of familiar places from memory such as public squares, their own office or apartment. Neuropsychological tests assess representational neglect by asking patients to compare pairs of mental images that may differ on the left or on the right side (Slit test, Bisiach et al., 1979; Ogden, 1985) or asking them to imagine two analogical clocks showing two different times on the left or on the right side in order to judge which angle formed by the clock-hands is wider (O'Clock Test, Grossi et al., 1989).

It is well known that patients affected by unilateral neglect may show topographical disorientation (De Renzi, 1982). Indeed, patients who are unable to perceive landmarks on the left, to perform in the left hemispace, to measure lengths on the left side or to compare the length of leftward and rightward stimuli may be impaired in navigating in the environment. However, it is important to note that navigational impairment may not be present in some patients with representational disorders (see, for example, Passini et al., 2000). Due to the extensive range of disorders that comprise the unilateral neglect syndrome, it is plausible to hypothesize that topographical disorientation appears only when neglect affects some specific aspects of space representation. Identifying which specific neglect disorders affect navigational skills would help us to understand navigational processes on one side and the organization of space processing on the other.

To investigate what links specific neglect deficits to specific navigational processes, in the following paragraphs we will first analyze deficits in representing familiar places, which can be considered impairments in mentally mapping the environment, and then deficits in different navigational tasks.

Patients have been reported who neglect the left side of visual images of familiar places (Bisiach and Luzzatti, 1978; Guariglia, 1993; Coslett, 1997; etc) and maps (Rode et al., Bisiach et al., 1993, etc); however, very few attempts have been made to investigate their ability to describe pathways in detail. Bisiach et al. (1993) asked two patients affected by unilateral neglect to describe well-known pathways in their hometown. In both cases, the descriptions included complex detours to avoid left turns, and when the leftward turns could not be avoided the patients failed to reach the goal and were lost.

Some reports suggest that imagery deficits refer specifically to a representational system devoted to constructing mental maps of the environment for navigation. In these cases, in fact, there is an amazing dissociation between a full representation of visual events (objects, faces, written material, etc.) and a defective representation of the left side of the environment.

Guariglia et al. (1993) reported a patient with a fronto-temporal lesion who showed severe and persistent imagery neglect when required to describe familiar public squares from memory but not when required to process mental images of an object. Ortigue et al. (2003) reported a patient with a right temporo-occipital junction lesion who was unable to describe the left side of Place Neuve in Geneva from memory or to describe the left side of an imaged map of France. However, she was able to provide a fully detailed description of the left side of the interior of her car from memory and the left side of an array of objects she had just explored on a table a few minutes before. The authors interpreted these results as demonstrating that perceptual and representational neglect are supported by independent cortical systems and that inferior temporal areas might be important for the mental representation of far space when a viewer-centered reference is imposed. Alternatively, in this case it can be hypothesized that representational neglect affects a specific representational system devoted to constructing cognitive maps of environmental space; such cognitive maps, whose frame of reference is egocentric, should be used to drive the subject's navigation.

A recent fMRI study (Committeri et al., 2005) showed the segregation of the neural substrates involved in perceiving the spatial relationship between different items and the relationship of the same items to an environmental frame of reference.

Rode et al. (2004) described a patient with representational neglect who, when asked to describe France as it would appear from Marseille, was unable to report the cities on the left. However, when asked to name as many cities as possible, the patient reported the same number of cities on the right and left sides of France. Here also, this can be interpreted as demonstrating damage to a system representing space in egocentric co-ordinates for navigation.

Further support comes from Pizzamiglio et al.'s (1996) study of a double dissociation between perceptual and representational neglect. Their results strongly support the notion that the presence of representational neglect, not that of even very severe perceptual neglect, affects the ability to construct environmental cognitive maps. In this study, the ability of a patient affected by representational, but not perceptual, neglect (MC) to explore and mentally represent a novel environment was compared to that of a patient affected by severe and persistent perceptual neglect without any sign of representational neglect (BM). Both patients were brought into a room they had never seen before, placed in the centre and asked to describe the four walls in detail. The number of elements reported on each side of the room was recorded. Soon after, the patients were brought into a different room where they spent one hour performing verbal neuropsychological tests that did not tax either memory or visuo-spatial abilities. At the end of this time, the patients were asked to imagine entering the first room, standing at the door and describing all the objects they saw; a description from memory from the opposite vantage point was also requested. The number of elements reported on each side of the mental image was recorded.

When required to visually explore and describe the room from four different vantage points, MC correctly reported all features (furniture, objects, windows, etc.) in detail. However, after the one-hour interval he was unable to describe the contralateral side of the room from memory but correctly described the ipsilesional one. This demonstrates his failure to construct and store a mental map of the environment.

On the other side, BM described only the ipsilesional side of the same room while visually inspecting it. When required to describe it from a given vantage point from memory, he correctly reported both ipsilesional and contralesional features, thus demonstrating he had processed a complete mental map of the environment. These observations suggest that representational neglect involves damage to an imagery system devoted to processing environmental information for the construction of cognitive maps for navigation; in the case of perceptual neglect without representational neglect, this system is unaffected. Therefore, the system that guides visual exploration and directs visuo-spatial manipulation does not prevent tying up the partially perceived environmental elements into a correct cognitive map by means of the system representing space for navigation.

From the above-reported observations, it can be hypothesized that two different types of space representation exist that may be selectively affected by neglect and may be classified as topographical images and non-topographical images. Topographical images are the mental representations of stimuli such as rooms, cities, public squares, etc., the subject can navigate in and they can be transformed into (or correspond to) mental maps of the environment. Non-topographical images are mental representations of stimuli such as a desktop, the interior of a car (Ortigue et al., 2003), single objects or arrays of objects that can be manipulated but can never be navigated. Topographical and non-topographical mental images may share some common mechanisms but, based on the above-described dissociations, they are essentially generated by different processes.

Additional support for the existence of separate processes subserving the generation of topographical and non-topographical visual images comes from a very recent study investigating the presence and the nature of imagery deficits in neglect (Guariglia et al., in preparation). In this study, the incidence of imagery disorders in a sample of 96 right brain damaged patients is 35.42%; 14.43% show only representational neglect in the absence of perceptual neglect. Twenty-five patients (that is, 70.59% of the patients with mental imagery impairments) show selective impairment in generating the left side of topographical mental images without any asymmetries in processing the left side of non-topographical images.

Very few studies have looked specifically for a link between disorders in representing visuo-spatial information and navigation. Bisiach and coworkers (1997) made the first attempt by submitting neglect patients and controls to an easy navigational task. Blindfolded subjects were passively moved through short paths with two or three 90° leftward or rightward turns. The subjects' task was to indicate the point of departure. Although the subjects made a broad range of errors, the neglect patients' performances did not differ from those of the controls.

Philbeck et al. (2001) obtained similar results in a group of 6 patients affected by unilateral neglect. These subjects were required to update the remembered location of a target during passive rotations of the entire body. The patients sat on a swivel chair on which a manual pointing device was mounted at the level of their median sagittal plane. The target was a flashing light located 25° or 65° to the left or to the right of the patient's initial body midline. Passive clockwise or counter-clockwise rotations ranging from 25° to 125° (25° increments) were used in the presence or absence of visual control. After the patients saw a lit target, they were passively rotated and then had to set the pointer in the centre of the previously seen target. In the absence of a visual control condition, the patients were blindfolded for both rotations and pointing.

In both visual control conditions, the neglect patients updated the target location equally well on either side of the body midline even though they generally underestimated the rotations.

At variance with these observations of intact navigational skills in neglect are Pizzamiglio et al.'s (1998) findings in a re-orientation task. Right brain damaged patients with and without neglect and healthy controls had to point to a previously seen target in a rectangular room in two different conditions. In the first condition, the walls were completely covered by homogenous curtains in order to mask any environmental cues. In this condition, the patients had to re-orient themselves by relying solely on the rectangular shape of the environment. In the second condition, a wall was covered with a red panel to introduce a salient environmental cue that could be used as reference for re-orienting. In the no visual cue condition, the normal controls and the brain damaged patients without neglect pointed with equal frequency to the corner where the target was located or to the diagonally opposite corner. In the same task, the neglect patients performed completely at random, that is, they pointed indiscriminately to all four corners of the room. These results suggest that neglect patients are completely unable to use the geometric information in the environment to guide their spatial exploration.

In the second condition, the presence of a landmark facilitated the responses of controls and non-neglect brain damaged patients who identified the correct location of the target at ceiling. The neglect patients' performances were improved but they still made a significant number of errors. Therefore, in this condition the latter group was impaired in processing geometric information as well as in integrating visual landmarks with the shape of the environment in order to reorient.

In neither condition was a difference found related to the target position (left or right of the subject's starting position). This suggests that neglect affects the possibility of representing environments in toto and not just in the contralesional hemispace.

The ability to measure the spatial linear translation of the entire body was investigated in a subsequent study (Pizzamiglio et al., 2003). Right brain damaged patients with and without neglect and matched controls without any neurological or psychiatric impairment sat on a robotized wheelchair that was linearly moved forward, leftward or rightward in a rectangular room stripped of all visual cues (landmarks). The subject's task was to reproduce the distance of the passive translation in the same or in a different direction by actively driving the robot with a joystick. The neglect patients' performances did not differ from those of the right brain damaged patients or the controls in any condition or direction. Thus, the conclusion may be drawn that the deficit in computing distances in contralesional space, which is typical of neglect patients in desktop tasks, does not involve the vestibular, motor and proprioceptive computation of spatial translations. In a second experiment, some visual cues were introduced that could be used to more accurately measure the extent of the passive displacement. In this condition, the neglect patients' performances differed significantly from those of both controls and brain-damaged patients without neglect.

Overall, the above-reported data suggest that neglect does not affect the simple computation of distances and angles in navigation when visual information is unavailable or unnecessary for the task. However, when visual information has to be taken in account to solve the navigational task, as in Pizzamiglio et al.'s (1998; 2003 - experiment 2) studies, the presence of neglect strongly affects performances by interfering with the construction of a mental map of the environment. In other words, it seems that neglect only interferes with the development of cognitive maps of the environment that tie up metric information about the shape and the dimension of environments with the presence and the relative position of landmarks.

Thus, the question is what happens in more complex navigational tasks that require the development of cognitive maps even in absence of landmarks, or when more complex navigational processes such as path integration or re-orientation have to be activated.

Guariglia et al. (2005; Guariglia et al., in preparation) developed a human analogue of the Morris water maze to test the use of different navigational processes in neglect. The first study (Guariglia et al., 2005) investigated path integration and re-orientation. To eliminate all environmental cues, the walls of a rectangular room (5 x 6m) were completely covered with homogeneous grey curtains. A photocell was mounted on the ceiling and directed toward a target location (TL) on the floor, and whenever a subject passed through the TL an acoustic signal was delivered. The subjects were brought into the centre of the room blindfolded. The curtain covering the door was closed and the blindfold was removed. The subjects' task was to explore the room to find the TL and then to memorize its location. Subsequently, they were blindfolded, disoriented and again placed in the centre of the room facing the same or a different wall. The blindfold was removed and the subjects had to reach the TL in the shortest and quickest way possible. After six trials, the blindfolded subjects were taken out of the experimental room; 30 minutes later they were brought back into the room; the blindfold was removed and they had to reach the TL. Three manipulations were introduced:

1. The subjects were placed in the centre of the room facing the same wall as in the exploratory trial,
2. The subjects were placed in the centre but facing a different wall,
3. The subjects were required to replicate the same task starting from the same position as in the exploration, but with a of 30' delay.

In the first condition, the task could be accomplished by relying on different processes; in the second and third conditions, just one process could be used successfully. In fact, in the first condition the participants could rely on both path integration and a mental representation of the environment. In the second condition, due to the change in the starting position, they could no longer use path integration and had to reorient themselves in the environment using a mental map or the geometric module. In the third condition, the subjects had to organize their navigation based on a stored map of the environment because path integration quickly deteriorates and is completely disrupted after such a long delay.

Five different groups of subjects took part in the experiment: control subjects with no history of psychiatric or neurological disease; right and left brain damaged patients without neglect; right brain damaged patients with perceptual neglect; right brain damaged patients with representational neglect. No differences in path integration were detected in the five groups of subjects. This finding confirms that unilateral neglect does not affect the ability to process idiothetic information. Instead, re-orientation was severely damaged in the representational neglect patients but not in the perceptual ones. This suggests that an impairment in representing the contralesional side of space affects the ability to construct cognitive maps based on the geometric shape of the environment. This was confirmed by the fact that representational neglect patients (but not perceptual ones) were impaired in performing the delayed reaching of the TL. In other words, the inability of representational neglect patients to construct a cognitive map of the experimental environment prevented them from storing the target position in long-term memory. The previous experiment shows that path integration is possible for perceptual and representational neglect patients, and that representational neglect patients fail to reorient themselves.

The next question is whether perceptual and representational neglect patients can integrate the relative position of various elements placed in the environment, that is, whether they can guide their navigation independently of the two above-mentioned processes.

In another very recent study (Guariglia et al., in preparation), this issue was further investigated in the above-mentioned, modified version of the human analogue of the Morris water maze. Two distinct elements (a lamp and a clothes hook), which were similar in size and general appearance but not in color and function, were brought into the room. Procedures and task were identical to those of the previous study (Guariglia et al., 2005). However, the presence of two landmarks allowed the participants to rely on the representation of the target position relative to the landmarks (that is, to use the view-dependent place recognition process), without necessarily relying on path integration or representation of the geometric information. Since perceptual neglect patients were able to orient their navigation using landmarks, their performances did not differ from those of controls and right brain damaged patients without neglect.

Instead, representational neglect patients were unable to use the landmarks. This confirms that the impairment of mental representation due to parietal lesions affects the ability to construct cognitive maps of the environment and, therefore, to efficiently store in long-term memory the location of the target relative to the configuration of the room or to the position of the landmarks.

In sum, the presence of neglect per se does not affect vestibular and proprioceptive (idiothetic) processes for the computation of linear and angular translation (Bisiach et al., 1997; Pizzamiglio et al., 2003 experiment 1). Instead the presence of representational neglect, even when perceptual neglect is absent, not only affects the possibility of memorizing environments and routes but also destroys the possibility of constructing environmental maps for navigation. This is true even in very easy tasks and in very modest and simplified experimental environments (Pizzamiglio et al., 1996, 1998; Guariglia et al., 2005; Guariglia et al., in preparation).

To our knowledge, very few attempts have been made to assess imagery components of topographical disorders and no attempts have been made to assess the possible presence of topographical and navigational deficits of patients affected by imagery disorders different from neglect.

A recent case of topographical disorientation due to a congenital brain malformation has been studied. The patient presents some specific imagery impairments directly linked to her navigational difficulties (Iaria et al., 2005). MGC is affected by a congenital cerebral malformation bilaterally involving the middle occipito-temporal regions. Despite almost complete absence of the right middle occipito-temporal cortex and the polimicrogyria of the left one, her development was quite normal (MGC successfully attended and completed high school) and her IQ within the normal range. Before coming under our observation when she was 22, MGC had never been able to learn pathways or to navigate in familiar environments by herself. An extensive neuropsychological assessment showed a moderate long-term memory impairment for visuo-spatial material and a mental rotation deficit. The assessment of MGC's navigational skills in ecological environments revealed the inability to select landmarks useful for orienting, a somewhat preserved ability to recognize familiar landmarks, but severe impairment in detecting their orientation and in using the recognized landmark to direct navigation. This impairment seems to be directly linked to her mental rotation deficit. In fact, her inability to detect whether a landmark has been reached from the left or the right or from the back corresponds well with her inability to recognize rotated stimuli on formal neuropsychological tests. Indeed, she was able to find the shortest path connecting two points on a map but was unable to follow the path even when she was allowed to rotate it. This deficit was linked to MGC's representational deficit on imaginal tasks where she was unable to imagine herself moving on the map and was unable to perform the mental transformation of her own body in mental rotation tests.

In conclusion, even though the role of mental visual imagery in navigation is not a matter of debate, thus far very few attempts have been made to assess the involvement of imagery deficits in navigation or to test visual imagery processes in topographical disorientation.

It should be noted that visual mental imagery and navigation are both complex cognitive functions in which several distinct processes and sub-processes can be recognized (see Farah, 1984, 1995; Kosslyn, 1984; Kosslyn et al., 1995; Redish and Touretzky, 1997; Wang and Spelke, 2002). Therefore, the demonstration of a generic link between visual mental imagery deficits and navigation impairments is not sufficient for understanding the nature and the relationship between these two functions. Indeed, several questions need to be answered before a model can be drawn of the interaction between mental imagery and environmental navigation.

At the moment, existing data indicate that an inability to mentally represent the contralesional side of mental images affects the construction of cognitive maps of environments and has specific consequences on some navigational processes. However, nothing is known about the effects of other imagery disorders, such as the inability to generate mental images or to perform different types of mental transformations, on specific navigational processes. Indeed, at this point we can make the following speculative hypotheses, which are as yet unsupported by neuropsychological data: 1) a deficit in generating mental images affects the ability to utilize verbal instructions for navigation; 2) mental rotation disorders affect the ability to return to the starting point in a new environment after pursuing a long path full of turns; 3) a deficit in visualizing colors or shapes affects landmark recognition. Different studies of navigational impairments suggest that specific impairments in mental imagery may affect some navigational skills. However, current studies analyzing the nature of navigational impairments include the assessment of several perceptual and memory functions (i.e., face and object recognition, verbal and non-verbal learning, etc.) but they very rarely investigate mental imagery specifically. The first question is whether only some types of visual mental images are generated defectively by patients affected by navigational disorders, more specifically whether their generation of skeletal or complex mental images of objects is intact while their generation of mental images of buildings, landmarks and views is lacking or defective. Further, the possibility that patients affected by navigational disorders may present specific impairments in specific mental transformation processes also needs to be analyzed.

In conclusion, we suggest that future studies of navigational disorders should assess representational abilities by referring to actual models of mental imagery.

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