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Selective Space Transformation Deficit in a Patient with Spatial Agnosia

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Abstract

We studied the spatial processing abilities of a 55-year-old male patient, PAO, with a right perisylvian lesion. Although the patient showed no problems in performing object recognition tasks, he was impaired in visuo-spatial tasks. PAO's most prominent deficit was a marked inability to manipulate figures mentally in the absence of an impairment in visuo-spatial working memory. His deficit would surface whenever a non-predictable rotational change in the spatial frame occurred. In contrast, his perception of spatial location and his ability to cope with size transformations were in the normal range. These results suggest that the deficit described here is selective to the rotational operation. The results are discussed in relation to the model of Kosslyn *et al.* (Journal of Experimental Psychology: Human Perception and Performance 1992; 18: 562–77) proposing the existence of two separate, categorical and metric, spatial coding systems, only the former of which is held to be impaired.

Introduction

The ability to localize visually objects in our environment, both in relation to oneself and to each other, is essential for our daily activities. Not only have we to be able to store information about object locations, but we need to be able to transform the positions mentally in order to predict where the different objects and parts of objects will be located, both relative to us and relative to each other, if, for example, they move in a consistent fashion.

This ability can be selectively impaired after brain damage. In fact, lesions to the parietal lobes, most commonly the right one, induce, among a variety of other clinical manifestations, spatial agnosia. A number of different deficits of spatial operations are covered by this term. Although it has a number of components, it is nevertheless mainly concerned with the ability to compute, represent and use spatial relationships between and within objects. This disorder has been held to overlap various syndromes, including constructional apraxia, spatial dyslexia and acalculia, and disorders of locations and orientation of visual stimuli and impaired memory for location (Walsh, 1978). These various deficits do not necessarily co-occur in a single patient. However, in this study, we are concerned with disorders of the ability to transform spatial relationships between and within objects as they are manifested in a test like Block Design.

For this analysis, it is important to distinguish spatial agnosia from a deficit that can produce somewhat similar effects, but which is qualitatively distinct. When reporting object location with tasks like pointing, patients may have impaired ability to integrate information about the visually computed location of a stimulus and the somatosensory information about hand/arm position. This deficit, optic ataxia (Perenin and Vighetto, 1988), is potentially due to an impairment in cross-modal interactions and not only to impaired functioning of modality-specific components. Therefore, for an analysis of spatial agnosia related to visual perception, one should limit the study to patients who do not present with optic ataxia.

With regard to spatial agnosia, an important distinction first put forward by Paterson and Zangwill (1944) is that between a deficit in the visual localization of a single stimulus and that of spatial relationships between stimuli. In a number of group studies (e.g. Faglioni *et al*., 1971), right posterior patients were shown to be more impaired than left posterior patients in visual localization tasks that test the ability to make metric spatial judgements. Not necessarily linked to the process of localizing objects is the ability to perform transformations of the stimulus. One process involved is mental rotation. A large body of work has been carried out in characterizing the ability of normal subjects to perform mental rotation. Shepard and Metzler (1971) showed that the

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time subjects require to determine whether two views from different perspectives belong to the same, previously unknown, three-dimensional object increased linearly with the angular difference of their orientation in three-dimensional space (Shepard and Metzler, 1971). Their study started a new vein of research concerned with people's ability to perform transformation operations on objects. This type of work has, however, mostly focused on the interaction of this ability with object identification (Biederman, 1987; Tarr and Pinker, 1989; Bülthoff and Edelman, 1992) with little or no reference to the spatial representation used.

In addition to these studies on the normal population, disorders of mental rotation have been described in the literature, but little detailed analysis of these deficits has been conducted up to now. For example, the Manikin and the Flags tests have been used in order to supply psychometric measures of spatial agnosia for clinical purposes (Thurstone and Jeffrey, 1956; Ratcliff, 1979). However, these investigations have primarily been group studies concerned with the relationship of any impairment to the anatomical localization of the relevant lesions.

One study has been carried out which had the aim of analysing the underlying cognitive deficit of a patient with a selective impairment of image transformations, who at the same time had unimpaired visuo-spatial working memory and imagery (Morton and Morris, 1995). These authors showed that the patient's deficit was selective to image transformations and did not involve the coding of object representations. However, this patient was clinically somewhat unusual in having a left parieto-occipital lesion rather than the right posterior lesion that typically gives rise to the deficit. There is, therefore, a slight possibility that the patient's deficit, while apparently related to spatial difficulties, was observable in a patient with a left hemispheric lesion through being secondary to verbal reasoning or labelling abilities that might have been used by the patient to perform some of the tests.

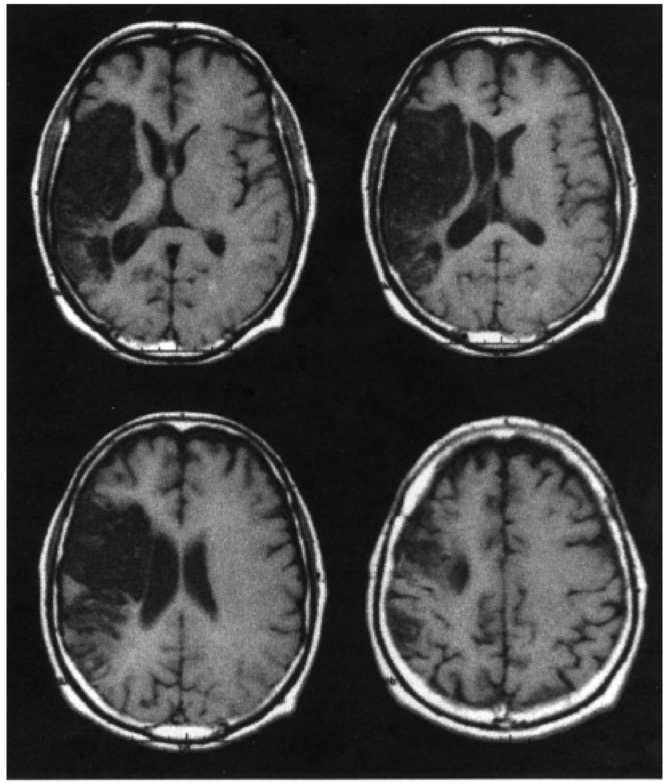
Spatial transformations are mental operations that change spatial relationships between pre-existing representations of objects. In their study, Morton and Morris analysed the above reported deficits of their patient in terms of a model proposed by Kosslyn *et al.* (1992). On the basis of computer simulations, these authors had proposed that two qualitatively different computational processes exist and are used in coding and manipulating visuo-spatial information. This proposal has been based on the hypothesis that the brain could represent spatial relationships in different ways due to the different requirements of various spatial operations. The authors suggest that at least two subsystems could exist: one named metric or co-ordinate, which codes space to the finest possible resolution useful for guiding action; and a second one, named categorical, which codes the space assigning a range of positions to an equivalence class (such as up/down, left/right) useful for coding the relative position of objects and their parts in scenes. In particular, they showed that networks that are divided so as to have two different sets of hidden units, which can contribute to different operations, performed better than undivided ones in processing categorical and metric information. On the basis of previous psychophysical work (Hellige and Michimata, 1989; Kosslyn *et al.*, 1989), they concluded that spatial relationships must be represented in two separate modes in relationship to the context in which subjects operate. This may be true not only for vision, but also for language comprehension, where dual encoding occurs in closed-class spatial forms (Hayward and Tarr, 1995). The working hypothesis that Kosslyn and his colleagues developed is that the module that processes the spatial properties of objects has two separate subsystems: one for categorical operations (in the left hemisphere) and one for co-ordinate operations (in the right hemisphere). The computational model has been criticized (Cook *et al.*, 1995; but see Kosslyn *et al.*, 1995). Morton and Morris (1995) interpreted their findings in terms of their patient having a selective impairment of categorical operations. In addition, there has been converging evidence from other neuropsychological studies (Bruyer *et al.*, 1997) for the basic functional distinction between categorical and metrical processing. However, while there is stronger psychophysical evidence on a left visual field/right hemisphere advantage for the computation of metric spatial relationships, only weak evidence has been found for the left hemisphere specialization for the computation of categorical spatial representations (Rybash and Hoyer, 1992; Michimata, 1997).

Findings on hemispheric specialization for generating different kinds of mental images have also been taken to be in support of this theory. It has been shown that when subjects memorized descriptions of how parts of figures were arranged (categorical descriptions), they could later form images of the overall pattern better when the cue was presented to the right visual field, and so presumably first analysed by the left hemisphere, than when it was presented to the left visual field. It was also shown that when subjects memorized the position of single segments (metric descriptions) and mentally formed an image out of them, they could later form images more accurately when the cue was presented to the left visual field (Kosslyn *et al.*, 1995). This hypothesis of differential hemispheric lateralization of the two processes has also received some confirmation from a neuropsychological population study on unilateral stroke patients with lesions in the posterior areas (Laeng, 1994). Moreover, a study of left hemisphere patients has reported impairments in shape matching and rotation explained by a loss in these patients of categorical spatial descriptions of the parts of multipart objects (Mehta and Newcombe, 1991).

On the other hand, the patient described above (Morton and Morris, 1995) is not entirely compatible with this theory in showing no impairment in some tasks involving categorical relationships. Further testing of this hypothesis is therefore needed. In particular, we will be concerned with whether an impairment in mental rotation can arise when only one of the two processes is impaired. Moreover, it has not been shown that mental rotation is a specific type of operation that can be selectively disturbed. To our knowledge, size and translation operations have never been tested separately in order to distinguish these operations from rotation and therefore no inferences have been made on what basic processes are selectively impaired in spatial agnosia. In addition, a possible explanation of an apparent rotation deficit could be that the original spatial coding is inaccurate and therefore the rotation operation, even though intact, leads to an incorrect outcome because it exacerbates a basically inaccurate initial representation. Only by showing a normal ability to code spatial position and perform other types of spatial operations will one be able to isolate the rotation deficit satisfactorily.

Case report

PAO is a 55-year-old right-handed man with 17 years of education, who worked until March 1997 as an executive in industry. He was hospitalized in March 1997 following a cerebrovascular accident (CVA). A cranial CT scan performed on the same day showed 'right parietal cortico-subcortical hypo-density, hyper-density of the trunk of the middle cerebral artery', with a diagnosis of 'right sylvian stroke from complete thrombosis of the internal carotid'. A second CT scan (4 weeks later) demonstrated that there was still infarctual hypo-density in the territory of the right middle cerebral artery. An MRI scan taken a year after the CVA (see Fig. 1) showed a large temporo-parietal lesion with presence of cerebrospinal fluid (CSF) involving the anterior temporal pole and in particular the perisylvian areas of the middle cerebral artery including Brodmann areas 21, 22, 38, 39, 40, 42 and 43. The lesion then extends upwards and backwards. Primary motor cortex (areas 1, 2 and 3) is not involved cortically, but since the lesion is deep the fibres are presumably damaged. Area 7 is not involved, but the lower part of area 5 may be touched by the lesion. The patient showed plegia of the left arm and paresis of the left leg. He developed seizures. His visual fields were intact and he had no language problems, as would be expected given the lateralization of the lesion.



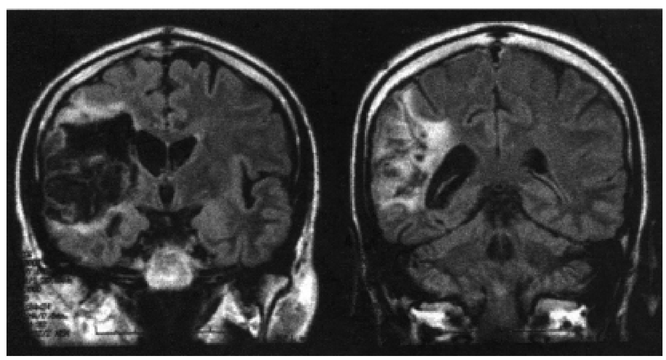


Fig. 1. MRI scans taken a year after the cerebrovascular accident. Four horizontal and two coronal slices depicting the right fronto-temporo-parietal lesion sustained by PAO are shown. Right–left is reversed.

A battery of tests was performed when the patient was at the neurorehabilitation centre in May 1997 and was repeated in June and September of the same year. PAO understood that the investigation was for research purposes and gave his consent. On the Italian version of WAIS (Ferradini and Vassena, 1974), PAO obtained a verbal IQ of 121 and a performance IQ of 101 (for scaled scores on subtests, see Table 1). A clinical neuropsychological assessment of the patient revealed no language or memory problems. He performed well within the normal range on the following tests: Attentive Matrices–Visual Search (PAO: 48.5/60; normal controls: 47.4 ± 9.8; Spinnler and Tognoni, 1987), Raven Coloured Progressive Matrices (PAO: 29.4/36; 5% cut-off: 20.75), Stroop (time interference: 18; 5% cut-off: 7.5; Venturini *et al*., 1983), Phonemic Fluency (PAO: 42; normal controls: 30.8 ± 11.4; Novelli *et al*., 1986), Semantic Fluency (PAO: 42; normal controls: 37.9 ± 8.1; Novelli *et al*., 1986) and Weigl (PAO: 15/15; normal controls: 11.8 ± 3.1; Spinnler and Tognoni, 1987). No sign of apraxia was observed. No evidence of neglect was found when PAO was tested with the Behavioural Inattention Battery (BIT) (Wilson *et al*., 1987), his scores being well within the normal range.

From May 1997 until mid-1998, the patient was tested in order to investigate his perceptual abilities using a series of standardized visual and spatial tests and, once his spatial difficulties became evident, tests especially designed to probe these operations. He showed no impairment at all in any of the subtests of the Birmingham Object Recognition Battery

Table 1. Summary of WAIS subtest scores

	1998
Verbal IQ	
Information	121
Digit Span	13
Comprehension	9
Vocabulary	18
Arithmetic reasoning	14
Analogies	11
Performance IQ	
Digit/Symbol association	101
Picture Completion	8
Block Design	13
Picture Arrangements	9
Object Assembly	4

Table 2. BORB results (April 1998)

Test	Score	5% cut-off
Length match A	24/30	24/30
Size match A	25/30	23/30
Orientation match	25/30	20/30
Position of gap	30/40	27/40
Overlapping letters		
Single	36/36	
Paired overlapping	36/36	
Paired non-overlapping	36/36	
Triplets overlapping	36/36	
Triplets non-overlapping	36/36	
Overlapping geometric		
Single	36/36	
Paired overlapping	35/36	
Paired non-overlapping	36/36	
Triplets overlapping	32/36	
Triplets non-overlapping	32/36	
Overlapping line drawings		
Single	40/40	
Paired overlapping	40/40	
Paired non-overlapping	40/40	
Minimal feature view	25/25	19/25
Foreshortened view	24/25	16/25
Drawing from memory	OK	
Object decision		
A: Hard	27/32	23/32
B: Easy	32/32	28/32
Item match	32/32	26/32
Associative match	28/30	22/30

(BORB) (Riddoch and Humphreys, 1993), as shown in Table 2. PAO was also tested on the Visual Object and Space Perception Battery (VOSP) (Warrington and James, 1991). This revealed no impairment in the object perception subtests (Table 3). By contrast, the patient showed a mild spatial agnosia with a deficit on the Position Discrimination and Number Location subtests. The deficit on the Position Discrimination subtest disappeared in later testing sessions, but his performance on the Number Location subtest remained impaired. In a test of constructional apraxia (TERADIC) (Angelini and Grossi, 1993), he showed borderline impairment in tests involving basic spatial judgements (see Table

Table 3. VOSP results

VOSP	May 1997	June 1997	May 1998	5% cut-off
Object Perception				
Screening test	19		20	15
Incomplete letters	19		19	16
Silhouettes	21		27	15
Object decision	18		17	14
Progressive silhouettes[a]	14		5	15
Space Perception				
Dot counting	10	10	10	8
Position discrimination	16*	16*	18	18
Number location	6*	5*	4*	7
Cube analysis	7	8	9	6

*Worse than 5% cut-off.
[a]Note that normal scores on this subtests are lower than the cut-off.

Table 4. Standardized score on the TERADIC subtests

TERADIC	May 1997	September 1997	Low schooling	High schooling
Line dimension	12*	16	14.69/20	16.1/20
Line orientation	6	8	3.36/10	8.37/10
Angle dimension	2*	5	2.08/10	5.32/10
Points position	7*	8	7.15/12	11.17/12
Mental rotation	5	8	3/10	8.42/10
Complex figures	6	10	5.98/10	9.44/10
Hidden figures	8	10	3.06/10	9.52/10
Mental construction	16*	16*	8.48/20	19.38/20

*Worse than 5% cut-off.

4). This impairment is apparent only with these more difficult tests. In fact, in similar and easier tests (e.g. BORB length match), he performed normally.

PAO was tested on the Corsi Block Span test (Milner, 1971), where the experimenter taps sequentially on blocks arranged in an array. The subject has to repeat the sequence immediately from memory. PAO's forward span was 4 blocks and his backward span 3 blocks. On later occasions, his Corsi forward span was 5; this is a low average score. He showed no impairment in judging line orientation. On the Benton Line Orientation Test (Benton *et al.*, 1990), he scored in the average or above average range [June 1997: PAO corrected score (CS) = 23/30, 76.7%; November 1997: PAO CS = 28/30, 93.3%]. His performance was borderline impaired (PAO: 39/54) on the long version of the Benton Faces test (Benton *et al.*, 1992).

The patient's attentional capabilities were tested with a serial and a parallel visual search task. The stimuli were coloured dots presented at pseudo-random positions on the display. In the parallel task, a single feature (colour) search task, the target was a red dot among blue and yellow distracter dots, while in the serial task, a conjunction (colour and form) search task, the target was a split red dot among split blue and complete red dots. We used a presence/absence design, in which the subjects had to detect the presence or absence of the target on any single trial. The dots depicted varied in number (1, 2, 8 or 16), and the target could appear randomly on the left or right side of the display. The subject was required to determine whether or not the target was present and instructed to respond as soon as possible after the decision by pressing one of two keys. We also tested three age-matched control subjects (mean age: 40.7 ± 12.9). Accuracy and median RTs were calculated for each condition. PAO's performance showed not only the normal serial pattern for the conjunction task, but more importantly the predicted parallel pattern for the single feature task even if his performance was slower than the normal controls, as could be predicted by a general slowing due to the lesion.

He was very good at copying both easy and difficult drawings. We tested PAO's perceptual organization and visual memory using the Complex Figure Test (Osterrieth, 1944). PAO's performance was at the 80th percentile level for both copy (34/36) and delayed recall (27/36) tasks (Osterrieth, 1944) of the Rey Figure on a first administration. On a second administration, the patient's performance had fallen, but still reached the 30th percentile on both copy (31/36) and delay recall (20/36) tasks. In a different session, the test was repeated using a different Complex Figure, the Taylor Figure, in order to eliminate possible memory interference in retesting. In this case, while the copy phase was normal (33/36, 60th percentile), in the recall phase the patient had a borderline performance (16/36, 15th percentile). Since we observed some suggestion of a decline in performance on the Complex Figures tests, the patient's visual memory was investigated further. His performance was normal on the copy version of the Benton Visual Retention Test (Benton *et al*., 1990), which is a more complex test of visual memory of drawings (number correct score: 7/10; number of errors score: 4/34) and he performed above average in the recall version of the test both for the number correct score (PAO: 6/10; average corrected for age: 4/10) and for the number of errors score (PAO: 5/34; average corrected for age and schooling: 9.1/34). However, although PAO's performance was above the average for his age group, he made a disproportionate percentage of errors involving incorrect positioning of the drawings (60% compared to the 10% average of normal subjects). This could point to a mild space-processing disorder with possible difficulties in 'relative' object localizations.

The Kohs Block Design Test (Roser, 1991) is a standard construction test related to the WAIS Block Design test in which the patient is asked to reconstruct using coloured blocks a number of designs printed on cards. The blocks are identical, each having four colours (red, white, blue and yellow) and with one side of each colour and the two remaining sides being one half-red half-white and one half-blue half-yellow with the colours divided along the diagonal. The patient had extreme difficulty in performing the task [I session (May 1997): 35/133; II session (December 1997): 31/133; III session (April 1998): 42/133]. He performed at the level of an 11-year-old. Compared to three age-matched (54.3 ± 8.1) controls (average score 104.7 ± 27.2), he was grossly impaired. He had great difficulty with a higher number of cubes. His problem manifested itself in an inability to rotate the cube in order to select the correct orientation of the top face. This was especially the case when a face, which was divided into two differently coloured parts by the diagonal, was critical. He was, for instance, unable to produce a 180° rotation of the face of the cube if the face was in the position where the upper left corner was red and the lower left was white, when it needed to be in exactly the opposite position. He could easily find the red/white face, but could not orient it appropriately. The patient would frequently pick up another cube, hoping to find it in the right orientation, even if he knew that all the cubes were identical and the examiner repeatedly pointed this out during the course of the testing.

In conclusion, despite his large right hemisphere lesion, the patient showed no impairment that could be traceable to an agnosic or neglect deficit, and had normal abilities in drawing and copying. However, he had grossly impaired performance on the Kohs Blocks Test, which suggested an inability to make an appropriate visual transformation. The investigation that followed addressed two main questions. (1) Is the patient's problem selectively restricted to visual rotations or does it include other visuo-spatial transformations? (2) If the deficit is restricted to mental rotation, can a basic process which is selectively damaged be isolated?

Tests of spatial processing: clinical investigations

Initially, we checked PAO's ability to perform mental rotations using a set of standardized tests.

Flags test

This is a simple test of mental rotation (Thurstone and Jeffrey, 1956). A white and black target flag is represented next to six other flags positioned to the right of it. The aim is to judge whether these flags can be obtained by simple rotation of the target flag in a plane or alternatively represent the opposite side of the flag. The subject is asked to make as many decisions as possible with a time limit of 5 min.

Results and discussion. PAO's performance was very poor on a number of testing sessions. In the first session (November 1997), he attempted only 33 items out of 126 with only 25 correct judgements (~76% correct). Compared to 10 control subjects (age 59.7 ± 5.4), he was not only very slow (controls attempted 52.6 ± 10.8 items), but also below the mean accuracy of the controls (controls correctly identified 45.9 ± 10.5 items, 87.1% correct). In further testing sessions, his performance did not improve: on a first session in December 1997 he made 33 attempts with 23 correct judgements (70%), while in the last session of April 1998 he attempted only 14 judgements, making 10 correct ones (72%). (Note that there was a difference in procedure between the first two times and the third. In the first two cases, the experimenter wrote down the response as soon as the subject uttered it verbally, on the third occurrence the subject, as did the controls, recorded the responses himself.). During the second testing session, we also checked his ability to judge identity using the same kind of stimuli; he was very fast and was 100% correct (6/6). His difficulty, therefore, did not arise from an inability to construct a good representation of the stimuli, instead his performance deteriorated drastically when the rotation operation was introduced.

The Manikin Test

This task was a computerized version of the Manikin Test (Ratcliff, 1979). On each trial, a stylized figure of a man holding a black ball in one hand and a white ball in the other hand was presented to the subject on a computer screen. The figure could be presented in one of four positions, either upright or upside down, and in both cases it could be either facing the viewer or facing away. The task was to decide whether the left or the right hand of the man was holding the black ball. The figure remained on the screen until the subject responded.

Results and discussion. In this test, right parietal patients show a clear impairment only when the stimuli are upside down (Ratcliff, 1979). However, PAO's performance was very inaccurate in all the positions (see Table 5), with many errors in the facing forward upside-down position (29.2% correct) and the facing away upright position (37.5% correct). It is interesting that the easiest position was the facing forward upright position (75% correct). This does not correspond to the patient's position, but to that of a person facing him. The easiest positions—the ones where the left hand on the screen corresponds to the left hand of the subject—are those where the subject makes more mistakes.

PAO is strongly impaired on this test compared to the right hemisphere control patients presented in the original study (Ratcliff, 1979). In fact, combining the two upright and the two upside-down conditions, PAO shows chance performance in both conditions (upright: 52.1% correct; upside down: 47.9% correct), a performance that is much impaired compared to the Ratcliff original control subjects (upright: 19.3% error; upside down: 11.3% error). Furthermore, we tested three age-matched controls (age 57.7 ± 4.6) who do not show any effect of rotation on error rates, which were below 6% in all conditions.

A control test was run where only the black and white balls, but no figure, were shown. The subject had to say on which side the black ball was. PAO performed flawlessly on this test (96/96, 100%), showing that he had no problem on simple left/right judgements.

Shepard and Metzler mental rotation

This is a more demanding three-dimensional mental rotation task (Shepard and Metzler, 1971) where the subjects have to judge whether two three-dimensional novel figures presented next to each other were of the same object or represented two different but similar objects. The stimuli were a subset of those originally devised by Shepard and Metzler; they were perspective line drawings of three-dimensional block objects (Marken, 1981). These stimuli were presented in pairs and subjects had to say, as rapidly as possible, whether a pair of drawings represented the same object ('same' condition) or two different objects ('different' condition). When the same object was presented in the pair, the two drawings could either be identical (0° difference) or differ in the perspective depicted. The difference in angle between the two drawings of the same object could be 60, 120 or 180°. When two different objects were presented, one was the mirror image of the other. Thus, the objects represented in the different pairs were sufficiently similar to force the subjects to compare them mentally in order to know that they were not the same. The original experiment showed a linear relationship between the angle of rotation of the drawings and response latency, suggesting that a mental rotation operation was being used. In our case, we will focus only on the accuracy measure.

Results and discussion. The patient's overall performance in this two-alternative forced-choice paradigm was not significantly better than chance [37/64 (57.8%); $P > 0.1$]. PAO

Table 5. Summary of clinical tests of spatial processing

	May 1997	September 1997
Rey figure		
Copy	34/36	31/36
Memory	27/36	20/36
Taylor figure		
Copy		33/36
Memory		16/36
Benton Visual Retention		
Copy		
Number correct	7/10	
Number of errors	4/34	
Memory		
Number correct	6/10	
Number of errors	5/10	
Imaging retrieval	OK	OK
Kosslyn Island		OK
Brooks Letters		
Control (h/v)		93/93 (100%)
Modified (l/r)		48/93 (51.61%)
Flags test		25/33/126
		23/33/126
		10/14/126
Shepard–Metzler		35/64 (57.8%)
Manikin		
Front 0°		18/24 (75%)
Front 180°		7/24 (29.2%)
Back 0°		9/24 (37.5%)
Back 180°		14/24(58.3%)
Kohs Blocks Test		35/133
		31/133
		42/133

performed flawlessly (8/8, 100%) when the two objects are not rotated with respect to each other, i.e. when the pair consisted of two identical drawings. As soon as they differed in perspective, the patient was incapable of performing the task, being at chance (4/8, 50%) in all three conditions (60, 120 and 180°).

Are these problems related to a deficit in mental rotation? A deficit of this kind could simply be related to difficulties in general visual scanning and processing. To investigate this possibility, we performed the following tests in order to ascertain PAO's ability to perform visual scanning.

The Kosslyn Island Task

In order to test the subject's ability to scan a visual image, a version of the Kosslyn Island Task was used (Kosslyn *et al*., 1978). The aim of this test is first to memorize the map of an island with various landmarks. After being shown the map and being given a description of the landmarks, the subject is asked to reproduce the location of each on a piece of paper on which only the outline of the island is marked. This procedure is repeated until the subject is able to reproduce the different locations to a previously specified precision. Once the map has been learned, the experimenter asks the subject to image the island and mentally trace a path between two of these landmarks. The subject had to report when he finished the task, which was repeated for many combinations of landmarks. The prediction is that the time taken between any two given landmarks should be proportional to the distance between the two if imagery keeps metric proportions.

Results and discussion. PAO was able to learn the map in one attempt, showing that his mild spatial agnosia did not interfere with this kind of task, i.e. with learning visuo-spatial metric information. In contrast to the patient of Morton and Morris (MG), who was able to learn the map only after four attempts, he showed good, faster learning of spatial representations. Moreover, MG was completely unable to carry out the instructions, stating that she could image destinations individually, but could not transfer her attention to a new destination. However, PAO was able to shift attention from one element to the other in the map without difficulty and with the time taken to shift attention between two given landmarks being in general proportional to their distance on the map.

Brooks Letter Task

As a second test of mental scanning, we used a version of the Brooks Letter Task (Brooks, 1968). The subject has to scan around a capital letter mentally in a clockwise direction from a prescribed starting point. The subject was trained with the letter T in view and then tested with the letters L, F, E and H. He was shown the letter with an arrow on the starting position, and then the letter was removed and the subject had to start responding. In one version, to test the subject's ability to image this type of stimuli, the subject had to decide, in one case, whether each line in the order he encountered them was vertical or horizontal. In the other version, the subject had to proceed around the letters instead, indicating whether they had to take right or left turns. Each letter was tested three times per session using a different starting point.

Results and discussion. In the paradigm where he had to judge whether the lines were vertical or horizontal, he made no errors on all of the letters starting from different positions (93/93, 100%). When the alternative version of this test was used (Morton and Morris, 1995), where the subject had to proceed around the letters, indicating whether they had to take right or left turns, PAO was impaired on all the test letters and was at chance (first session: 48/93, 51.6%). Not only did he make mistakes on the direction of the turns to take, but also he did not stop when he reached the starting position again, giving more responses than those that were appropriate in three out of 12 trials. He was asked to stop and restart the trial whenever he got lost. He took advantage of this option only once.

The results confirm those of the previous tests showing that mental image capabilities are intact (see the results on the Kosslyn's Island Test), but the patient is severely impaired on left/right decisions when this involves a relationship to a baseline that is not fixed.

Image retrieval

We also investigated PAO's ability to retrieve images from long-term memory and inspect them to retrieve the requested information (Farah and Hammond, 1988).

Results and discussion. PAO showed no impairment in a group of tasks where he had to judge whether an animal had a long or short tail (17/18, 94%), which of two objects was larger (15/15, 100%), which was the characteristic colour of an object or an animal (25/25, 100%), and how many lines were needed to make a letter (25/25, 100%).

Geographical orientation

The ability to locate geographical landmarks on a map is considered one of the components of the processes involved in spatial representation. We tested PAO's geographical orientation using a standardized test: Map of Italy (Spinnler and Tognoni, 1987). In this test, the subject is presented with an outline of Italy. The task is to indicate the location of 10 Italian cities on the map. Exact localization is not required and the score depends on localization with respect to the coordinates north/south and east/west.

Results and discussion. PAO's performance was in the normal range (raw score: 15; age-corrected score: 13; normals:

14.28 ± 1.38), showing an intact ability to locate geographical landmarks.

Left–right orientation

Another component of the processes involved in spatial representation is the ability to judge personal and extrapersonal orientation. In this test, the patient is asked verbally by the examiner to point to body parts that could be the patient's own ('point to your left shoulder') or the examiner's ('point to my left shoulder').

Results and discussion. The patient showed an interesting dissociation in these two subtasks. He performed flawlessly in the test of personal orientation (24/24), while he was strongly impaired in the test of the examiner's (reversed) orientation (2/24). This dissociation shows an understanding of handedness and an ability to judge absolute left and right with respect to oneself, but a marked incapability to transform this information and to use it when the frame of reference is different.

Tests of spatial processing: experimental investigations

Point localization: translation and expansion

PAO's performance in all the previous tasks points to a difficulty in transforming a visual representation rather than in creating or holding it. In the following experiments, we aimed to separate the visual perceptual component from the spatial component and so to isolate his particular problem. We reduced the visual stimulus to the minimum possible so as to analyse the different types of transformations separately in order to isolate PAO's deficit. We generated various versions of the same general task. To investigate this syndrome quantitatively, we used a technique similar to that often used in visual disorientation studies (i.e. pointing to a light stimulus presented in various positions in the visual field).

Method. In this task, the subject needs to map a stimulus between two different reference frames. In this first version, a trial is started with the presentation of a reference frame (a 138 × 138 mm square with its centre indicated by a small dot) on the screen. After 500 ms, a small filled square (11 × 11 mm) appears inside this frame for 150 ms while the frame itself continues to remain in view. Subjects are asked to fixate the central dot of the reference frame and once the small square has appeared they are required to reproduce its position as accurately as possible on an A4 piece of paper placed on the desk in front of them. Each subject is required to give the position of the square in the same relative position in which it had appeared on the screen with respect to the reference frame. The frame (a 185 × 185 mm square) and the centre point are already drawn on the paper. At the beginning of each trial, a new A4 sheet is placed in front of the subjects. There are 48 possible positions where the target square can appear. They are defined by a 7 × 7 grid with the same centre point as the frame and with neighbouring points positioned on the grid 24.5 mm apart. The centre point of the grid is not tested. Each position is tested once in a block and each subject is tested over two blocks for a total of 96 trials. Five practice trials are given before each block so that the subject can become familiar with the test. To create the impression of a randomly appearing point, a jitter of ±5.8 mm was added in a random direction to the computed positions on each trial. Therefore, the only transformations required were a translation from the reference frame on the screen to the reference frame of the paper and a scaling (34% increase in side; 80% increase in area).

Results and discussion. In order to evaluate performance, the position of each estimated dot was measured for each trial with respect to the frame on the paper. For a given trial, the actually presented dot and the estimated position were considered as the end points of two vectors, which we will call x_{act} and x_{est}, respectively, starting at the centre of the frame. Relative differences in length and angle between the two vectors were computed in order to evaluate errors. For the length, we used two types of measures: the difference between the length of the estimated position vector and the actual position vector [$x_{dl1} = l(x_{act}) - l(x_{est})$; where $l(x)$ is the length of vector x] and the absolute value of this difference [$x_{dl2} = |l(x_{act}) - l(x_{est})|$], which we will call modulus error. The first value, x_{dl1}, measures whether there is a bias in underestimating or overestimating the distance of the point from the centre. The presence of a bias of this kind would indicate an inability to scale the stimulus appropriately and therefore a deficit in the expansion operation. The second value, x_{dl2}, measures the subject's ability to estimate the position correctly. Regarding the difference in angle, we used only the absolute value of the difference of the angles, since the sign of the difference had no interpretable meaning, given the experimental design.

PAO's performance was reasonably good in localizing the position of the square, with an average modulus error in estimating the length of the vector being 5.91 mm and that in estimating its angle 6.66°. Three other subjects were also tested as controls (mean age 51.6 years; schooling 16.3 years); the average length estimation modulus error and average angle estimation modulus error are shown in Table 6. The patient was marginally worse than controls, being 35% worse than the average of the controls in estimating length and 31% worse in estimating the angle. There was a trend for him to be worse at the length aspect ($P < 0.1$) and he was significantly worse at the angle aspect ($P < 0.05$). The distribution of errors for the patient and the three controls was similar, as shown in the histogram in Fig. 2. Regarding the average length error, as seen from the table, PAO is no different from controls, which implies that his responses

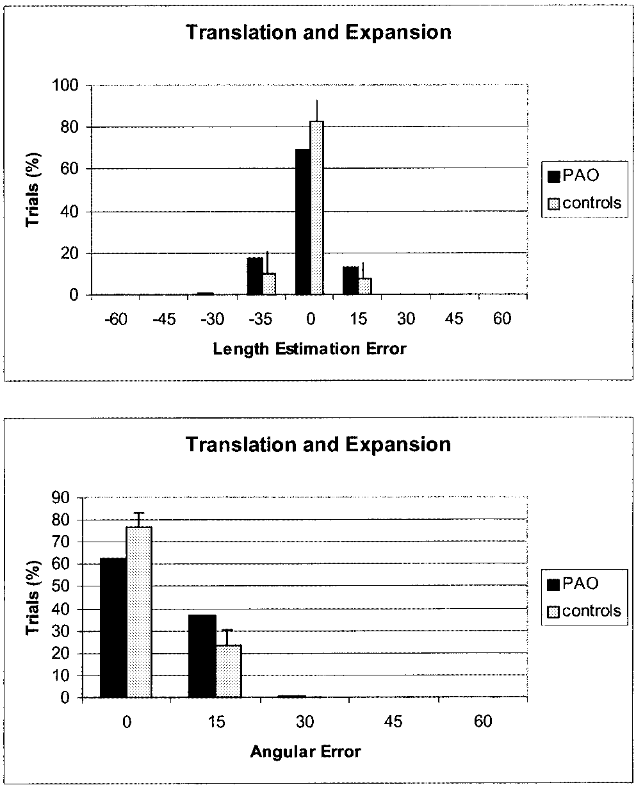


Fig. 2. Angular error distribution for translation and expansion transformation for PAO and control subjects.

Table 6. Average errors for patient PAO and three control subjects in the translation and expansion experiment

	PAO	Controls	
Length error			
Average	–0.86 mm	–0.15 ± 2.22 mm	$Z = 0.32$; $P > 0.1$
Modulus	5.91 mm	4.35 ± 0.95 mm	$Z = 1.64$; $P > 0.05$
Angular error			
Modulus	6.66°	4.90 ± 0.91°	$Z = 1.93$; $P < 0.05$

were not biased toward a systematic expansion or contraction of the space. These results suggest that PAO has a mild deficit in making the translation/expansion spatial transformation.

Point localization: rotation

Method. This test is a modification of the previous one. A reference frame (a 98 × 98 mm square with its centre indicated by a small dot) is presented on the screen in one of three possible orientations selected at random (0°, +45°, –45°). In order to identify the orientation of the frame clearly, the top side was drawn as a thick line, which was easily visible. After 500 ms, a smaller filled square (11 × 11 mm) appears inside this frame for 150 ms. The frame remains in view continuously. The subject is required to reproduce the position of the small square on A4 paper positioned in front of him on the table, marking a single dot with a thick felt pen (Fig. 3). The frame and the centre point were already drawn, but they were always in the upright position on the paper. On each trial, a new piece of paper was positioned in front of the subject. The filled square point could appear in various positions inside the frame; the possible positions were arranged in a circular grid, centred on the centre of the square, giving eight equally spaced points in each of three concentric circles. Then, to give the impression of a randomly appearing point, we added a jitter of ±5.8 mm to the computed positions. In this case again the subject was required to reproduce the position of the square in the same relative position with respect to the frame. The transformations required were a translation from the reference frame on the screen to the reference frame of the paper (a 110 × 110 mm square), a scaling as in the previous version of the test, and, in addition, on two-thirds of the trials, when the frame presented on the screen was tilted, a 45° rotation was also needed.

Results and discussion. In order to evaluate performance for each trial, the position of each estimated dot was measured, as in the previous case, with respect to the frame on the paper. For a given trial, the actually presented dot and the estimated one were considered as the end points of two vectors starting at the centre of the frame. Relative differences in length and angles between the two vectors were computed in order to evaluate errors, as in the previous experiment. PAO did not show any overall bias, with his average estimate of the length of the vector being only –0.45 mm from the real average and the average angle being only –0.408° from the real average. However, the results are very different if we consider the absolute error on each trial. As shown in Table 7, the pattern of results differs between length and angle. First, consider briefly the average modulus errors in estimating the length of the vector. In the case of no rotation, there is no significant difference between the length estimated by PAO and the controls. In the case of rotation, the difference does become significant, but the patient is better than the controls!

A different pattern of results is found when we analyse the angle estimation error in the two conditions: rotation and absence of rotation. The patient is grossly impaired. Even in the case of an upright frame, we see that in contrast to the result of the previous experiment, there is also a significant error in the estimation of the angle of the vector when the frame is not rotated. Since the three conditions, upright and left and right rotated frames, were presented intermixed in random order, it would appear that the effect is due to confusion induced by the task itself.

Finally, consider in detail the angle estimation in the case of rotation. An interesting difference is to be found in the pattern of errors shown in Figs 4 and 5. PAO's errors have a much wider distribution than the errors of the control subjects, with 20% of his errors being about 90° in the two-tilted frame conditions (see Fig. 4). In fact, for PAO, errors greater than 50° make up 31% of the trials in the leftward

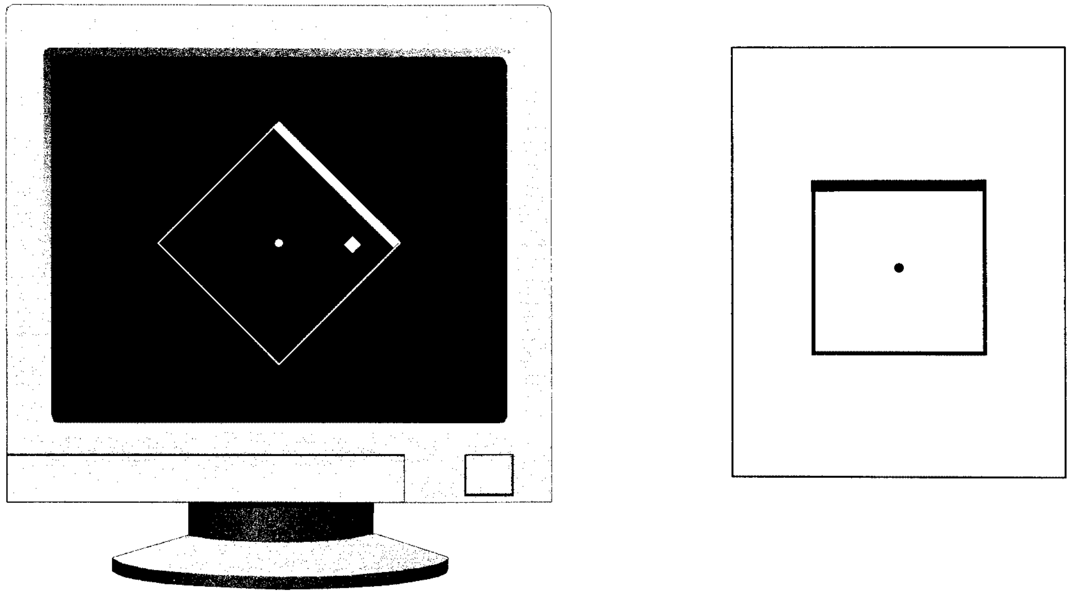


Fig. 3. On the left is an example of a display in the rotation experiment. The small square visible on the display stayed on the screen for only 150 ms. The subject had to reproduce its position relative to the frame on a piece of paper containing the frame (shown on the left). In this example, the point should have been placed in the top-right corner of the frame reproduced on the paper.

Table 7. Average modulus errors for patient PAO and three control subjects in the rotation experiment

	PAO	Controls	
Length error			
Up	4.19	4.69 ± 1.04	$Z = -0.48$; $P > 0.1$
45	3.98	5.11 ± 0.58	$Z = -1.93$; $P < 0.05$
–45	3.38	4.80 ± 0.38	$Z = -3.76$; $P < 0.005$
Angular error			
Up	21.14	4.57 ± 1.11	$Z = 14.90$; $P < 0.0001$
45	41.66	14.72 ± 2.35	$Z = 11.44$; $P < 0.0001$
–45	28.65	16.03 ± 4.63	$Z = 2.72$; $P < 0.005$

rotation and 27% of the trials in the rightward rotation, while for the worst control subject these two values were an order of magnitude less (4.2 and 8.8%). This is in strong contrast with his ability to make a more precise localization, where he is roughly correct, i.e. less than 45° (see Fig. 5). If we consider only the average angle errors in the range –50° to 50°, we see that PAO is significantly better than the controls for both frame rotations (leftward rotation: $z = -2.45$, $P < 0.01$; rightward rotation +45: $z = 2.77$, $P < 0.005$).

General discussion

PAO has no major problems in visual domains other than space. Thus, he performed normally on clinical tests concerned with the processing operations underlying object recognition (BORB, VOSP), except where unusual orientations were used. He showed no sign of neglect either in the clinical tests of the Behavioural Inattention Test battery or in experimental situations, where no left/right bias was found. His visual attention systems seemed to be intact, as he showed the typical serial/parallel pattern of performance on a conjunction and single-dimension visual search task of the Treisman type. He was in the normal range on the standard visuo-spatial short-term memory task (Corsi blocks) and showed an excellent ability to image visual representations, as shown by his performance on the Kosslyn Island Task and other image-retrieval tasks.

If one turns to spatial operations, one can divide his ability into two contrasting parts. First, if one considers clinical tasks where the same frame of reference is used throughout (e.g. Cube Analysis, Brooks horizontal/vertical version, pointing to left/right on self, Manikin control balls procedure), his performance is normal. Similarly, if the same transformation of the frame of reference is required on all trials (VOSP position disorientation, TERADIC points position), his performance is at the lower end of the normal range, except for VOSP number location test, where he is below the normal range. By contrast, in all clinical tests where a part of a figure had to be localized with respect to a frame of reference that was subject to a transformation that was not predictable prior to the trial, PAO was severely impaired. This occurred in many clinical tests such as Kohs' Blocks, Object Assembly, the Flags tests, Ratcliff's Manikin test, Shepard and Metzler's mental rotation test, the left/right version of the Brooks Letter Task and pointing to left/right on the examiner's body.

We attempted to devise experimental tests that isolate what we view as the key components of these tasks. In one type of task, the subject had to make a transformation that was fixed across trials and where the frames of reference involved were those that corresponded to the natural top/bottom, left/right co-ordinates of the planes (for transformations or from monitor screens to desk top). In a second type of task, the transformation was unpredictable and natural top/bottom, left/right frame co-ordinates were not respected. In both these

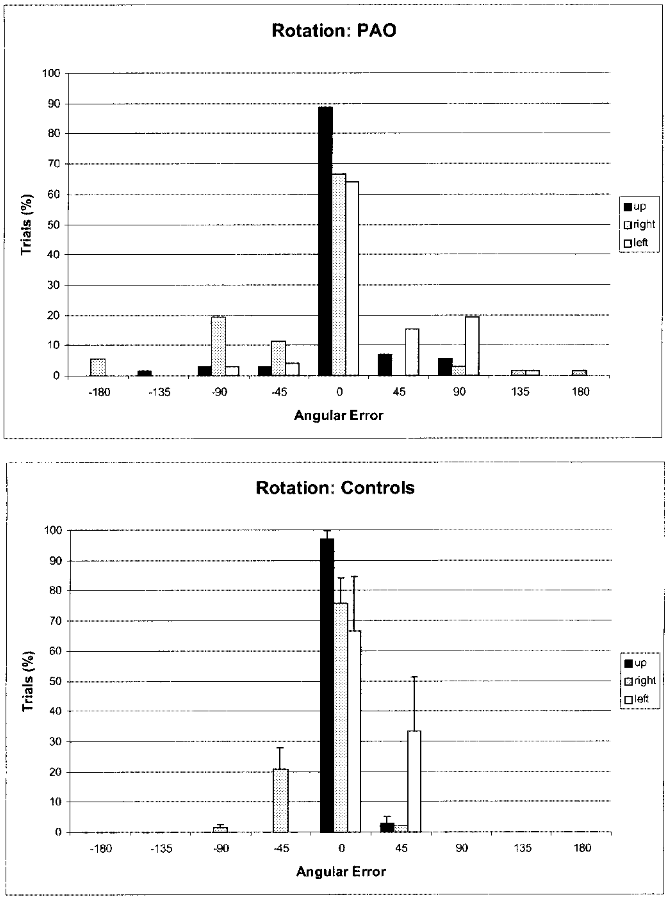


Fig. 4. Angular error distribution for the rotation transformation for PAO and control subjects.

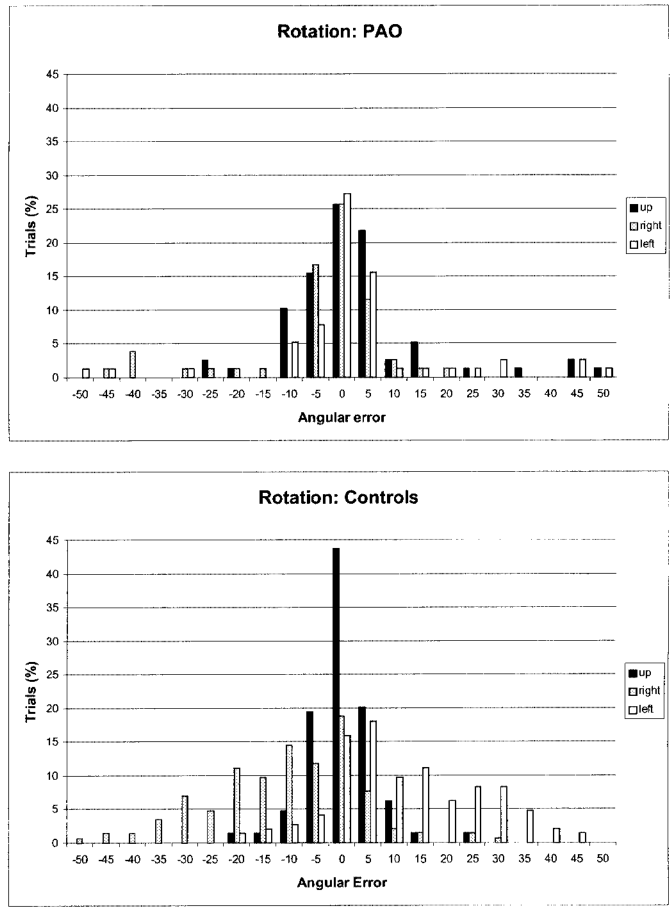


Fig. 5. The central part of the angular error distribution for rotation transformation for PAO and control subjects.

tasks, PAO was within the normal range on length estimation. On the fixed transformation task, which involved a major size change and a move from screen to desktop, he was just outside the normal range on the angle measure with an average modulus error of roughly 30% greater than matched controls.

The most interesting result, however, was on the unpredictable transformation task. In this task, the subject must reproduce the position of a dot in a square, which has a marked top, when that square is subject to a +45°, –45° or 0° rotation. PAO, while normal on the length measure and showing no overall bias, was grossly impaired on the angle measure. In particular, he produced about five times the number of grossly deviant responses (>50° error) than did the worst normal control. These 'far-out' errors had not been observed in the fixed transformation experiment. Moreover, they occurred even in the 0° conditions, which when treated in terms of single trials alone, were easier than in the fixed transformation experiment as no major size change occurred. Most interestingly, if one examined the central part of the error distribution (<50° error), where the great bulk of the responses of normal subjects occur, PAO shows the same peaked distribution as the normal controls and is more accurate than they are!

This strongly supports the processing dissociation claimed by Kosslyn *et al.* (1989) between metric and categorical spatial operations. If a remapping between different spatial frames of reference has to be made, then on this theory, two types of operation have to take place. First, qualitative assignments of the remapped space must occur, for instance the non-verbal specification of quadrants, relative to axes or to points such as top/left, top/right, bottom/left, bottom/right. In addition, directionally categorized axes must be assigned as corresponding to (formerly) horizontal left-to-right and vertical top-to-bottom ones. Secondly, there are metric operations corresponding to the determination of distances and angles of target points in polar or (x, y) co-ordinates in a structure determined by the above points, axes and quadrants. PAO appears to have a severe deficit of the first type of operation, while the second is intact.

One surprising aspect of the results concerns the site of the patient's lesion. Of course a right parietal lesion, which PAO had sustained, is often found in spatial agnosia (De Renzi, 1982). However, imaging studies of mental rotation typically involve not the inferior areas 39 and 40 of the right hemisphere affected by his lesion, but the superior area 7, which was spared in PAO (Cohen *et al.*, 1996; Alivisatos and Petrides, 1997; Tagaris *et al.*, 1997). There seem to be at least two ways of explaining the discrepancy. As the lesion went deep into the right parietal lobe, the connections of area 7 with the prefrontal region, area 8, may have been affected. Alternatively, as area 7 is critical for visuo-spatial attention processes (Corbetta *et al.*, 1993), the right parietal activation in the imaging studies may arise from visuo-spatial attention processes necessarily involved in the rotation tasks. Moreover, it is not clear that categorical spatial operations such as those stressed in the key experimental conditions necessarily involve rotation *per se*. However, it should be noted that PAO was impaired on the Shepard–Metzler object rotation task.

Our functional interpretation of the impairment of the patient is similar to that provided by Morton and Morris (1995) for their patient, MG, who also had a specific problem in tasks involving a change of spatial reference frames. Morton and Morris (1995) investigated their patient's difficulties using clinical tests only. However, the pattern of disorders they obtained is similar on such clinical tests to those of PAO. One striking exception is the Kosslyn Island Test, which does not require a change of spatial reference frames. MG performed badly on the test, which Morton and Morris speculate may be related to a rotation deficit and due in some way to the size of the image required. However, PAO's performance on the test is good, as was that of ELD (Hanley *et al.*, 1991), who also had a problem in tasks requiring rotation. Thus, it seems simpler to assume that MG's problem with the Kosslyn Island Test is an additional deficit unrelated to her problem in tasks requiring a change in spatial reference frame, and possibly related to the imagery generation deficit noted by Farah and Hammond (1988) in another left posterior patient who had an intact ability in rotation tasks.

We would therefore argue that PAO's dissociation supports the isolatability of spatial operations from other aspects of visual processing and purely locational operations, with PAO having an impairment generally in categorical operations, rather than just in rotation operations. More critically, it supports Kosslyn *et al.*'s distinction between metric and categorical operations. However, in contrast to claims made by Kosslyn *et al.*, we would suggest that the principal locus of categorical operations, at least in operations where there needs to be remapping of frames of reference, is in the right hemisphere. Clearly, a strong case for localization cannot be made from a single patient. However, PAO's deficit is clinically typical of milder patients with right parietal lesions and in particular with respect to their performance in tests such as Kohs Blocks.

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Selective space transformation deficit in a patient with spatial agnosia

E. Bricolo, T. Shallice, K. Priftis and **F. Meneghello**

Abstract

We studied the spatial processing abilities of a 55-year-old male patient, PAO, with a right perisylvian lesion. Although the patient showed no problems in performing object recognition tasks, he was impaired in visuo-spatial tasks. PAO's most prominent deficit was a marked inability to manipulate figures mentally in the absence of an impairment in visuo-spatial working memory. His deficit would surface whenever a non-predictable rotational change in the spatial frame occurred. In contrast, his perception of spatial location and his ability to cope with size transformations were in the normal range. These results suggest that the deficit described here is selective to the rotational operation. The results are discussed in relation to the model of Kosslyn *et al*. (Journal of Experimental Psychology: Human Perception and Performance 1992; 18: 562–77) proposing the existence of two separate, categorical and metric, spatial coding systems, only the former of which is held to be impaired.

Journal

Neurocase 2000; 6: 307–19

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O196

Primary diagnosis of interest

Visuo-spatial difficulties

Author's designation of case

PAO

Key theoretical issue

- Dissociation between good performance in tasks comprising categorical space transformations and bad performance in tasks comprising metric spatial transformation associated with a right temporo-parietal lesion

Key words: visuospatial agnosia; space transformation deficit; metric and categorical spatial coding system

Scan, EEG and related measures

MRI

Standardized assessment

WAIS, Attentive Matrices, VOSP, BORB, TERADIC, BIT, Raven Coloured Progressive Matrices, Complex figure, visuo-spatial span, Kohs Block Design

Other assessment

Flags test, Manikin test, Shepard and Metzler mental rotation test, Kosslyn Island Task, Brooks Letter Task, and ad hoc designed experiments testing spatial transformation abilities

Lesion location

- A large temporo-parietal lesion with the presence of cerebrospinal fluid involving the anterior temporal pole and in particular the perisylvian areas of the middle cerebral artery including Brodmann areas 21, 22, 38, 39, 40, 42 and 43. The lesion then extends upwards and backwards. Primary motor cortex (areas 1, 2 and 3) is not involved cortically, but since the lesion is deep the fibres are presumably damaged. Area 7 is not involved, but the lower part of area 5 may be touched by the lesion

Lesion type

Vascular

Language

English