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The Impact of Right Subcortical Lesions on Executive Functions and Spatio-Cognitive Abilities: A Case Study

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Abstract

Deep-seated cerebral lesions have been known to cause various cognitive impairments. In order to study the impact of these lesions on cognitive functioning, in particular on executive functions and spatial abilities, an investigation was carried out on a right-handed patient with lesions in the subcortical structures of the right hemisphere. Findings revealed a complex pattern of neuropsychological impairments that included a memory deficit, neglect and anosognosia. In addition, there was a severe executive function syndrome. Finally, observations show impairments in spatial abilities, usually attributed to right parietal damage. There was no obvious language deficit. The pattern of deficits was interpreted as a disconnection syndrome.

Introduction

It is now well recognized that subcortical lesions can cause neuropsychological impairments (Hublet and Demeurisse, 1992; Aglioti, 1997; Filley, 1998; Peru *et al.*, 2000). However, the nature and severity of these deficits, which may vary according to site and size of the subcortical lesions, remain largely unknown. Many clinical studies concern cognitive dysfunctions following thalamic lesions (see Van Der Werf *et al.*, 2000). However, studies that involve lesions to subcortical structures with sparing of the thalamus are less frequently reported. Understanding the cognitive effects of subcortical lesions has been hampered by the small number of patients with such lesions. Moreover, the role of these structures in cognitive functions such as executive functions (EF) and the so-called visuospatial domain is as yet insufficiently understood.

Memory deficits have been frequently reported in the presence of subcortical damage. Several previously reported patients with thalamic lesions were noted to have a memory defect (e.g. Squire and Moore, 1976). The memory loss associated with such lesions received extensive attention and was described as “diencephalic amnesia” (Graff-Radford *et al.*, 1990; Wheatley and McGrath, 1997). In many cases, the patients had bilateral thalamic lesions. However, a number of studies have reported memory disorders following unilateral thalamic lesions. Several reports examined the relationship between right-sided thalamic lesions and memory deficits

(Metter *et al.*, 1983; Waxman *et al.*, 1986). Damage to the non-dominant thalamus has been associated with memory impairments that mainly involve visuospatial material (Speedie and Heilman, 1983; Bogousslavsky *et al.*, 1987; Van Der Werf *et al.*, 1999). However, observations made by Wallesch *et al.* (1983) on a series of patients who showed memory deficits after thalamic lesions did not support the notion that these functions are lateralized. They proposed a rostrocaudal dichotomy where the rostral thalamic lesions lead to memory deficits and caudal lesions to impairments of ‘abstraction’ and ‘categorization’. Memory disturbances following subcortical lesions, that do not involve the thalamus, were reported by Hublet and Demeurisse (1992). They observed deficits for visuospatial material in the posterior limb of the right internal capsule when it was damaged.

A number of prior clinical studies reported the existence of neglect syndromes of subcortical origin (Zeil and Von Cramon, 1979; Bisiach *et al.*, 1981; Kertesz and Dobrowolski, 1981). Hemi-inattention and neglect syndromes have mainly been observed following cortical lesions of the human right parietal lobe (DeRenzi, 1982; Young, 1983; Jewell and McCourt, 2000). Neglect syndromes have also been described with lesions of the frontal lobe (Heilman and Valenstein, 1972; Damasio *et al.*, 1980; Ogden, 1985), cingulate gyrus (Damasio *et al.*, 1980) and right temporal cortex (Samuelsson *et al.*, 1997; Karnath *et al.*, 2001). The majority of neglect cases involving

subcortical structures includes lesions to the thalamus (Bisiach and Vallar, 1988). This was labeled "thalamic neglect" by Watson and Heilman (1979; Watson *et al.*, 1981). It is generally accepted that lesions to the right thalamus are associated with multimodal neglect (Cambier *et al.*, 1980; Graff-Radford *et al.*, 1984). However, in some cases, the damage involves other subcortical structures such as the striatum (Damasio *et al.*, 1980), the putamen (Heir *et al.*, 1977; Bartolomeo *et al.*, 2000), and the caudate nucleus (Caplan *et al.*, 1990). According to Karnath (2001), the putamen, the pulvinar and, to a lesser degree, the caudate nucleus are the subcortical structures associated with neglect.

A number of patients with lesions confined to white matter have been so far reported (Heaton *et al.*, 1982; Cambier *et al.*, 1983; Ferro and Kertesz, 1984). However, lesions confined to white matter are less associated with neglect. In their group study based on 51 patients with RH lesions, Vallar and Perani (1986) observed that neglect was most frequently associated with extensive subcortical lesions involving the thalamus, the basal ganglia, and the subcortical white matter (100% incidence). Neglect was present in 50% of the cases when lesions were confined to the thalamus and in 28% of the cases when lesions involved the basal ganglia. However, neglect, after white matter damage only, was comparatively rare, that is, 5%. Fromm *et al.* (1985) had similar observations. In the series of Ferro *et al.* (1987), two-thirds of patients who had suffered damages to the basal ganglia and white matter had neglect. Clinical neglect following subcortical damage to the left hemisphere (LH) has rarely been reported. The common belief is that it is not involved in spatial attention. However, a certain number of cases of right-sided neglect following subcortical left sided lesions have been reported (Manabe *et al.*, 1999; Peru *et al.*, 2000).

Although memory deficits and neglect syndromes are among the most notable effects of subcortical damage, other cognitive effects have also been observed. In the last decade, a number of studies reported cognitive deficits following damage to subcortical structures that are generally associated with frontal (more appropriately prefrontal) lesions. EF impairments generate difficulties in sustained attention and effort, perseverations, impaired initiation of action, poor use of feedback and failure in planning and organization. Again, clinical studies have most often reported lesions in thalamic structures (see Van Der Werf *et al.*, 2000). Impairments in EF, whether or not accompanied by memory deficits, have been observed (Bogousslavsky *et al.*, 1986, 1991). However, as suggested by Van Der Werf *et al.* (2000), in many studies, the number of tests of EF administered to patients was insufficient. Thus, it is difficult to draw a solid conclusion about the presence of an executive dysfunction. Executive dysfunctions following subcortical lesions that do not involve the thalamus have much less frequently been reported (Pozzilli *et al.*, 1987). Conclusions concerning EF and its relation to these types of lesions can therefore be less readily drawn.

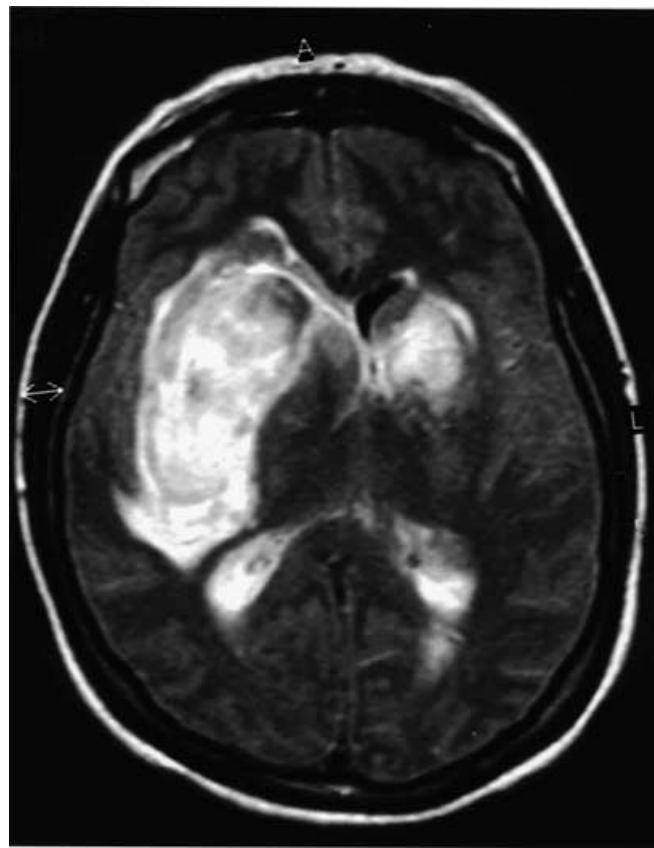
Spatial cognition concerns multiple processes necessary in the treatment of space, such as spatial perception, spatial

memory, and spatial representation. Lesions producing spatio-cognitive deficits are classically located in the RH, more specifically in the parietal region and/or in the right parahippocampal gyrus (Benton, 1982; DeRenzi, 1982). In light of the constellation of clinical deficits reported above, one might expect impairments in spatio-cognitive abilities in the presence of subcortical damage. Hublet and Demeurisse (1992) reported the case of a patient having a lesion in the posterior limb of the right internal capsule. They observed a severe topographical disorientation and a memory disturbance for visuospatial material. The topographical disorientation was attributed to a specific loss of topographical memory. Ricker and Millis (1996) reported impairment on tasks of visual and spatial synthesis following infarction of deep gray structures.

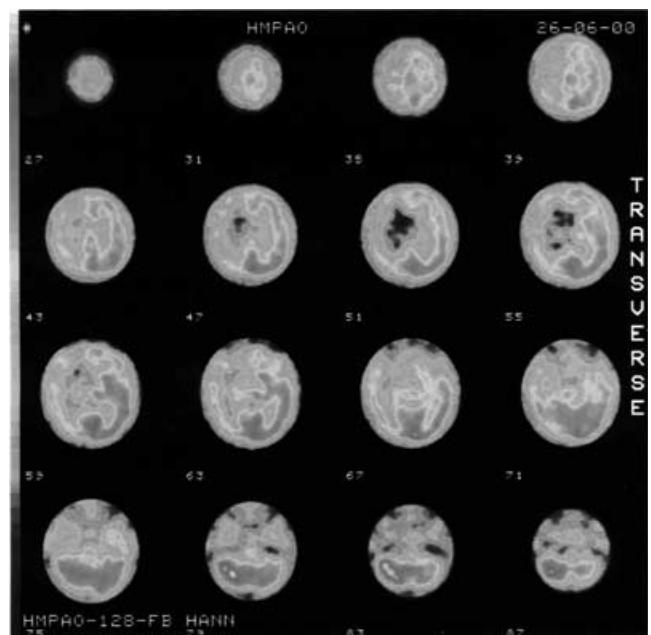
In sum, only a few studies involving spatial dysfunctions exist. Moreover, these studies particularly consider the processing and/or the memory of visuospatial material. The pattern of spatio-cognitive deficits remains to be shown as well as the extent to which subcortical damage might influence the outcomes in terms of cognitive incapacitation. The goal of this article is to provide a detailed description of a patient with a right subcortical lesion in order to have a better understanding of the impact of such lesions on cognitive functioning. More specifically, this article aims to study the impact of subcortical lesions on executive functions and on spatio-cognition (spatial abilities).

Case description

CP is a 32-year-old, right-handed (score of 90 at the Edinburgh Handiness Questionnaire of Oldfield (1971)) woman, with 13 years of education who worked as a salesperson in a shop. No history of psychiatric or neurological diseases was noted. She suffered a severe hemorrhagic cerebro-vascular accident in the right hemisphere (RH) during her second pregnancy. As she was close to her delivery date, an emergency cesarean surgery was performed due to a sudden and severe fetal bradycardia. Though surgery was completed without any complications, two hours following her surgery CP fell into a comatose state. A brain angiography performed on that same day showed neither aneurysm nor any sign of venous thrombo-phlebitis. Due to a dramatic increase in intra-cranial pressure with vital risk a right hematoma was surgically removed. The clinical status slowly improved and CP opened her eyes on the thirteenth day post-onset. Extensive assessments were undertaken, but failed to explain the cause of the cerebro-vascular accident. The blood pressure was not high. CP took some acetyl-salicylic during her pregnancy but had stopped more than one month before her stroke. Current blood tests were negative. No coagulation impairment was found. One has to note however that her first pregnancy was complicated by a retro-placental hematoma. During her stay in neurosurgery, CP suffered several severe seizures. One month after her stroke, she was transferred to a neurological rehabilitation unit. She had a severe left hemiplegia with spasticity. The Barthel Index was 45 on admission. CP was aware of



(a)



(b)

Fig. 1. Computed tomographic scan showing CP's lesions. Hypodense lesions are apparent in the insula, the caudate and lenticular nucleus of the RH (a). The brain scintigraphy (HMPAO Tc 99) (b) shows a diffuse and heterogeneous hypoperfusion in the RH. The impairment is important in the insular white matter area, basal ganglia and in the right cortex, as a whole. A hypoperfusion is also present in the frontal cortex of the LH.

her motor and functional disability, but was nearly fully anosognosic of her cognitive impairment. The Galveston Orientation and Amnesia Test was 94 (Levin *et al.*, 1979) and Folstein's Mini-mental Status Examination (Folstein and Folstein, 1975) was 26 out of 30. During the course of her recovery CP developed unbearable pain and thalamic hyperesthesia on the left side of her body.

CP was evaluated 4 months after onset. The brain imagery (CT-scan and MRI) examination revealed the presence of a hypodensity, in the right hemisphere (RH), in the head of the caudate nucleus, the pallidus, and the adjacent white matter extending to the external capsule. The deep-seated lesion did not reach the cortex. The second hypodensity zone involved the head of the caudate nucleus in the left hemisphere (LH). No macroscopic lesion of the thalamus was apparent (Fig. 1a). A brain scintigraphy with HMPAO Tc 99 (Fig. 1b) showed a severe reduction of blood perfusion in the RH. The impairment was diffuse and heterogeneous, but the insular white matter area, basal ganglia and the cortex as a whole were the most impaired. In the LH, blood perfusion was reduced in the frontal cortex. Despite the fact that conventional imagery failed to show any impairment at this level, the scintigraphy showed a reduction of blood perfusion in the left cerebellum that might be interpreted as a crossed cerebellar diaschisis.

General assessment

The neuropsychological assessment involved standard global investigation of the cognitive functions and more specific tests for EFs and spatial cognition. CP was oriented and cooperative during the entire neuropsychological testing. She could adequately recognize the attending doctors and family members. No obvious difficulty in recognizing objects in the environment was observed. No hemianopia was reported. She was apathetic and easily distracted, but she collaborated well in the testing situation. There was a paucity of spontaneous movements. CP's spontaneous speech was not fluent but she presented with normal syntax and phonology. Oral comprehension, naming and repetition were considered normal. Phrase length and information content were also normal.

The global intellectual abilities of CP were evaluated with WAIS-R IQ test. Table 1 shows the age scaled scores to

Table 1. CP's age scaled scores on the subtests of the WAIS-R IQ test

Verbal subtest	Performance subtest	
Information	7/18	Picture completion 2/16
Digit Span*	5/19	Picture arrangement 2/20
Vocabulary	9/19	Block Design 1/18
Arithmetic	3/17	Object Assembly 1/19
Comprehension	11/19	Digit Symbol 3/19
Similarities	8/19	
Verbal IQ	83	Performance IQ 47
Total IQ:	64	

*Forward = 4; backward = 4.

Table 2. CP's scores on the subtests of the Revised Wechsler Memory Test

Verbal Memory	Visual Memory		
Logical Memory I	40/50	Figural Memory	3/10
Logical Memory II*	32/50		
Verbal paired Associates I	20/24	Visual paired Associates I	8/18
Verbal paired Associates II*	7/8	Visual paired Associates II*	4/6
		Visual Reproduction I	26/41
		Visual Reproduction II*	20/41
Digit Span	+	Visual Memory Span**	7/26
Verbal Memory Index	128	Visual Memory Index	66
General Memory Index	103		
Delayed recall Index	90		

*Delayed recall. +See Table 1. No Attention and Concentration Index were calculated.

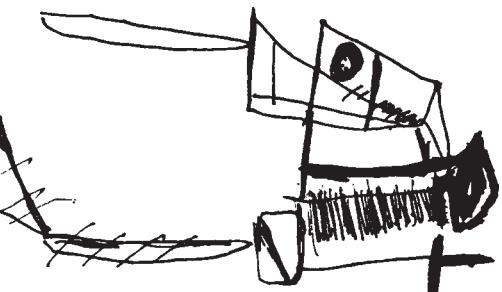
**Forward = 5; backward = 2.

different sub-tests. The performance IQ shows a clear deficit. Her results indicated a 36 points discrepancy between her performance and her verbal scores. Performance tests requiring imagery and spatial manipulations tests were poor.

Memory was evaluated with the Revised Wechsler Memory Test. The General Memory Index was 103. The scores to different sub-tests are shown in Table 2. The Verbal and Visual Memory Indexes differed by 62 points. The large discrepancy was in favor of Verbal Memory.

To assess visual-discrimination capacities (e.g. visual-agnosia), the four sub-tests of the Montreal-Toulouse test were used. In the visual-discrimination sub-test, the score was low (3/10). Qualitative analysis of the errors showed the presence of neglect. Only figures on the right side of the page were explored. Reaction time was slow (over 30 sec.) for 7 figures. The second sub-test consisted of a display of three overlapping drawings presented at the top of a page. Below these drawings, under a bold horizontal line, 8 figures are drawn in two columns. The patient is requested to choose the figures present in the target drawing from among the alternatives. This sub-test involves a) meaningful figures (i.e. usual objects) and b) meaningless figures (which does not require the ability to compare the figures with a stored structured representation, but to trace a proper form without being deceived by intersecting lines). CP solved 4 of the 12 problems (i.e. the recognition of the 3 figures). Considering all target figures (3 figures \times 12 problems), she recognized 24 of the 36 (66.6%). In the functional (belonging to the same functional category) and the categorical (belonging to the same category) pairing the scores were higher, that is, 9/10 on both tests. These tests showed no obvious sign of visual-agnosia. In sum, this test showed a mild impairment in visuospatial capacities, which cannot be entirely explained by the presence of neglect.

CP was requested to copy the Rey-Osterrieth Complex Figure. This is a constructional task involving multiple cognitive components, visuospatial perception and the execution of a motor plan designed to duplicate a model. After completing a drawing, the material is removed. The subject is then asked to reproduce the same figure from memory. She is not



(A) Copy



(B) Immediate recall

Fig. 2. The Production of CP in the Rey figure task on copy (A) and immediate recall (B). One may observe the perseveration (overdrawing), in particular in copy.

forewarned that reproduction of the figure will be required. The time needed to copy the design as well as the accuracy of the copy are recorded. In copy, by reference to Osterrieth's method (Osterrieth, 1945), CP's reproduction score was 10/36 ($M = 35.37$, $SD = 1.44$, ≤ 1 percentile; see Meyers and Meyers, 1995). She took 8 min. to copy the model ($M = 3.12$ min, $SD = 1.22$ min, ≤ 1 percentile; see Meyers and Meyers, 1995). She used a type V copying strategy (Fig. 2A). That is, she copied parts of the drawing without any semblance of organization. She did not grasp the basic rectangular shape of the figure and copied subparts on the right hand side of the figure. Thus, her copying performance attests to an inability to adequately organize the drawing, relying on a time-consuming line-by-line approach. Her production further revealed a "slavish" approach betrayed by the exceedingly long time employed to execute the drawing. Her performance in immediate recall (Fig. 2B) was very poor. She was unable to give any of the details drawn earlier, except for the lozenge placed on the right hand side of the figure.

Neglect was obvious in a line cancellation test (Fig. 3). With the exception of 3 lines, the patient only cancelled lines placed on the right side of the sheet, in a more or less vertical pattern. The presence of neglect was further investigated with two letter cancellation tests (Diller and Weinberg, 1977). These tests are designed to evaluate visual attention and scanning ability. In the first test, a single letter has to be cancelled. It consists of a paper sheet with 6 lines, each of which contains 52 letters. The upper case H letter (4 mm high) is presented 105 times. The patient is asked to cancel all H's found on the page. The number of omissions is recorded. CP completed the task making 21 errors. Sixteen (76.2%) of these

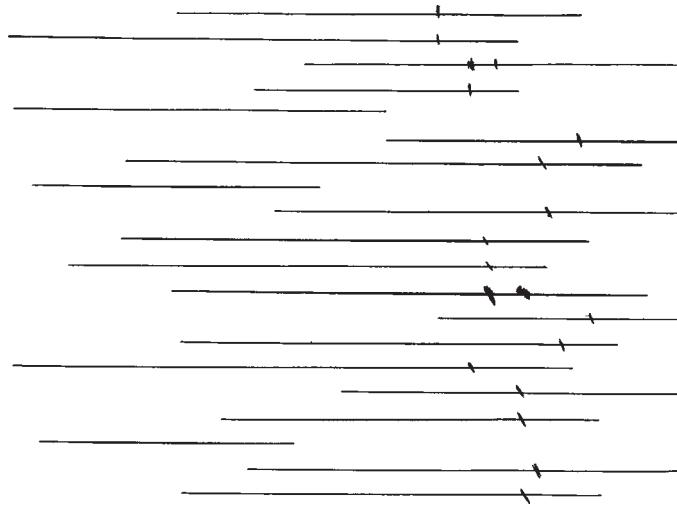


Fig. 3. Performance of CP in the line cancellation test.

were on the left-hand side. The second test is a double letter cancellation task. It is similar to the former task as the patient is asked to cross out 104 upper-case E and B letters, also printed in 6 horizontal lines on a sheet. Of the 28 letters forgotten, 25 (89.3%) were on the left hand side. Finally, the presence of neglect was also evaluated with the Bell Test (Gauthier *et al.*, 1989). The Bell Test is a complex task of selective attention and visual scanning. The test sheet contains 35 bells embedded within 264 distractors. Subjects are asked to circle each bell. The score is based on the total number of bells circled and the time taken to complete the task. CP had a score of 20/35. Ten were not circled on the left side (including the 5 bells in the further most column on the left), and 5 on the right sided. This performance reflects left side neglect (see Gauthier *et al.*, 1989). Time taken was 1 min and 47 s. Scanning was disorganized, that is she did not scan systematically up and down and right to left.

CP's EFs were assessed with the Tower of London (TOL) test, originally developed by Shallice (1982). The TOL is well recognized for the measurement of planning abilities (Anderson *et al.*, 1996; Levin *et al.*, 1996). A modified version (Rainville *et al.*, in press) was used. The protocol consists of 3 series of 5 problems requiring from 1 to 5 moves. Moreover, the protocol follows a hierarchical design, that is, simpler problems are embedded in more complex, subsequent problems (operationally, in each series, this means that a problem of level L includes all aspects of L-1 problem, and "something more"). CP successfully completed simple problems (1 and 2 moves). This suggests a good rule comprehension. It also suggests that her neglect did not influence her ability to complete the task. She also performed well in two other problems requiring four and five moves respectively. Qualitative analysis showed that in the large majority of cases, problems were failed due to rule breaking. By reference to a control group (Rainville *et al.*, 2002), her performance suggests an impairment of the supervening planning pro-

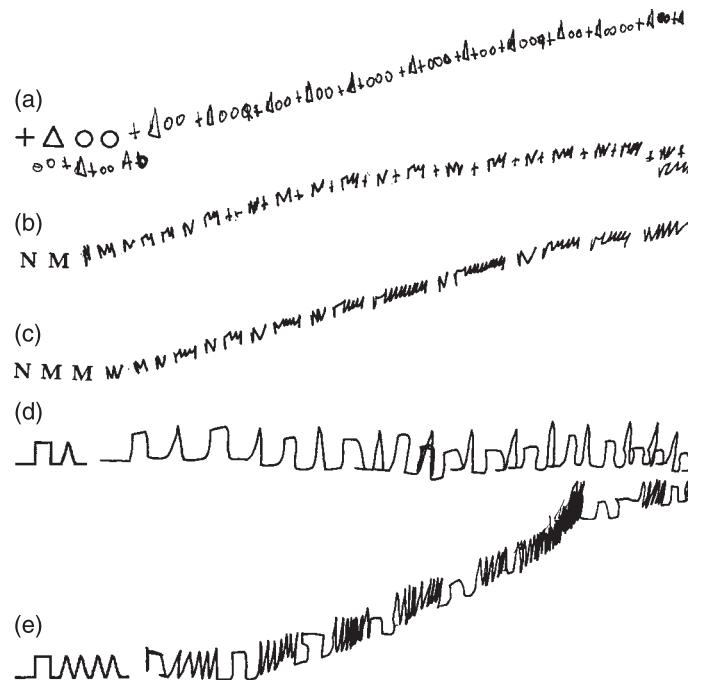


Fig. 4. Performance of CP in the graphical seriation test. (a) In the fourth sub-task the circle was repeated. Perseverations of the "hyperkinetic" type were frequent (in b, c, and e). In the series, where she had to copy letter N M, there was an intrusion from a previous series, that is a cross (in b).

cesses, that is, an incapacity to plan the moves in complex problems.

CP was submitted to a graphical seriation test, inspired by Luria's studies (1966, 1973). The patterns were selected to elicit different features of graphomotor skill such as establishment of rhythmicity, ability to generate a smooth flow of movement, and ease in changing directions. The test includes 12 patterns distributed in three series, each presented on a different page. In the first series, a set of simple and well-known geometric figures (e.g. a circle, a square) must be copied. In the second series, the subject must copy patterns, that entail generating units of written language (e.g. N, M, V or W). The third series requires the subject to copy repeated continuous patterns that represent no real script. In the last series, the patterns are relatively independent of linguistic demands or prior education.

In the *first series*, we observed a number of perseverations. This was particularly noted in the second and fourth sub-tasks where the circle was repeated (Fig. 4a). In some instances, CP was conscious of her errors and attempted to correct them by placing an X over them. In the *second series*, perseverations were massive. The most frequent of these were of the "hyperkinetic" type. That is, the patient was unable to terminate the production of a portion of a response and incorporated a piece or segment of that response into the production of the figure (for example, adding an additional segment on the letters 'M' or 'W'). As shown by the Figs. 4b and c, CP began to draw a letter, but could not stop at the right time and repeated the movement over and over again. Interestingly, in the first sub-task (Fig. 4b) there was also the intrusion of a unit of a

previous series (i.e. a cross). In the third series the production was relatively good in simple drawings (Fig. 4d), but there were massive perseverations of the "hyperkinetic" type in complex continuous patterns (Fig. 4e).

In Trail Making-A (Reitan, 1971) only one error was observed, performance was slow (90 s; percentile 10; see Spreen and Strauss, 1991). The performance in Trail Making-B (TMT-B), which involves shifting abilities and inhibitory processing, was very poor. Her test was stopped after 245 s (percentile < 10). A few letters and numbers were connected, without order. In the Stroop Test (Stroop, 1935), CP made no errors in both the reading task and the color naming task. The times used were, respectively, 30 s and 36 s. Surprisingly, she had a score of 48/50 in the interference Stroop task. The time taken was 1 min 23 s. There was no deficit in this test. The Ruff Figural Fluency test (Ruff *et al.*, 1987) consists of five sheets of paper, each containing 35 contiguous squares in a 5×7 array. The patient is asked to make as many different figures as possible within 5 min by connecting the dots with straight lines. On the second and third sheets, in addition to the dots, there are interference patterns. In the two last sheets, the dots are asymmetrically positioned with all squares alike on each page. The time allotted for each sheet is 5 min and the patient is requested not to repeat any of the figures. CP had a score of 16, which is impaired by reference to a control group ($M = 53$, $SD = 18$).

CP was submitted to the Isaac's Set Test of Verbal Fluency (Isaac and Kennie, 1973), which evaluates EF with verbal material. In this test, the subject is asked to name as many items as possible from four successive categories: colors, animals, fruits and towns. The subject must name items in the first category until no more are remembered (or for a maximum of 60 s). Then the next category is announced, and so on. The score is based on the total number of items recalled. CP produced only 7 items in the fruit category and 3 items in the animal category. Her verbal fluency was obviously impaired (see Lezak, 1995).

Spatial abilities were evaluated with three tests originally developed by Piaget and Inhelder (1948): a) Right-left discrimination; b) Topographical relations (Landscape test); c) Perspective relations ("three mountains task"). These tests have been described elsewhere (Passini *et al.*, 2000). These three tests involve projective relations between objects, that is, right/left and front/back relations. According to developmental studies (Laurendeau and Pinard, 1968; Piaget and Inhelder, 1948), the required skills are acquired in adolescence. Thus, there is no reason to believe that CP could not have successfully performed them prior to her stroke.

Right-left discrimination test

Right-left discrimination was measured in the following four conditions: (a) designation of the subject's body parts; (b) designation of the examiner's body parts; (c) relative position of three objects according to the subject; (d) relative position of three objects according to the examiner. Conditions (b) and (d) involved 180° rotation. Each condition consists of 6

questions. In the first three conditions, CP made no errors. However, in the fourth condition, she failed to respond correctly to 4 questions.

Topographical relations (landscape test)

The topographical relations test assesses the subject's ability to establish projective relations between objects and to maintain them through conditions of mental rotations. It also involves topological relations (e.g. the relations of enclosure, such as being 'on the road', or the relations of neighborhood, such as being 'near the yellow house') and to some extent metric relations (i.e. distance). The experimental apparatus consists of two miniature landscapes (35×47 cm) that are identical in all respects. The landscape features a road and railroad tracks. Five toy-houses, which distinguish themselves by size and color, are placed on each landscape (see Passini *et al.*, 2000 for a description). The examiner and the subject are seated across from each other. In the *first condition*, the landscapes are placed side by side and in the same direction. The examiner places a doll on his landscape, and asks the subject to place his doll "at exactly the same place" on his landscape. The examiner successively places his doll at 12 different points. In the *second condition*, the examiner turns his board by 180 degrees, directing the subject's attention to this rotation. He then proceeds as in the first condition. He successively places the doll at the same 12 points, but this time in a different order.

In the *first condition*, CP correctly performed 10 of the 12 problems (83.3%). The two errors observed were of a metric order. In the *second condition*, CP succeeded in only 7 of the 12 problems (58.3%). According to Laurendeau and Pinard (1988), CP reached the sub-stage 2B in the first condition (by solving at least 5 of the first 7 problems, and 4 of the 5 next problems). In the second condition, she also reached the sub-stage 3A, but failed to reach the criteria of stage 3B (by not solving 4 of the 5 problems). This suggests that CP had no difficulty with the topological relations, but was incapable of establishing topographical relations in rotated conditions, at least when topological relations were absent. Thus, she had deficits in projective relations that led her to reproduce the egocentric perspective offered by the model and caused her to answer according to her point of view.

Perspective relations (three mountains task)

The perspective relations test involves the ability to visualize a configuration of objects from different points of view. The experimental material consists of a plain green cardboard square (52 cm) on which three paper cones (called "mountains"), varying in size and color, are placed. The examiner shows the subject a doll (about 3 cm high) and explains that the doll could take different positions around the table and 'take pictures'. Nine painted scenes of these cones complete the material. The examiner explains that the subject's task is to find, among 5 pictures, the one corresponding to the doll's view. A task is successfully completed when the subject selects the picture corresponding to doll's perspective and rejects all others. The test itself includes three tasks.

According to developmental studies (Longeot, 1978; Laurendeau and Pinard, 1988), it is the most difficult of the three tasks evaluating spatial abilities. The cognitive abilities needed are not completely acquired before the teens; only a small proportion (28.0%) of twelve-year-old children are able to cope with this task (Laurendeau and Pinard, 1988).

CP failed all three tasks. In the first task, her reasoning for accepting and rejecting the 5 'pictures' was exclusively based on characteristics of the composition seen from her own perspective (egocentrism). In the second task, CP chose two views that she considered "good". In both views, right/left relations were correct, but she had difficulties in manipulating front/back relations. Finally, in the third task, as in the first one, she made a choice that reflected her own point of view. In sum, CP was unable to understand the transformations induced by changes in the position of the observer. Justifications in the second task suggest that she was still anticipating, or mentally constructing the doll's perspective. But, such an attempt did not produce a good and consistent co-ordination of the various left/right and front/back relations. At best, only one dimension could be anticipated.

The Money standardized Road-Map Test of directional sense (Money *et al.*, 1965) is a right/left directional orientation test (Lezak, 1995). It also measures the subject's ability to rotate the person's frame of reference (Kritchevsky, 1988; Rainville *et al.*, 2002). The subject is shown a street map of a "small town" on which is drawn a route taken by a hypothetical traveler. The route shows 32 turns at as many intersections. The subject is asked to indicate whether he/she would be taking a right or a left turn at each intersection.

Condition 1: The Subject (S) is seated facing the Examiner (E). The subject is not permitted to turn the test sheet. The examiner follows the traced route with his pencil and at each intersection asks the subject "Now, at this corner would you be turning right or left?" There is no time limit.

Condition 2: To control the impact of the graphic material, the test is done again with the following modification. This time, at each intersection, the examiner turns the test sheet to align the route according to the subject's frame of reference.

In the first condition, CP's performance was 20/32. Most of the errors involved a mental rotation. In the second condition, she made just one error.

Discussion

An investigation was carried out on a patient with a lesion of the basal ganglia and deep white matter of the RH in order to study the impact of these lesions on EFs and on spatial abilities. CP had a complex neuropsychological profile with an intellectual deterioration, as suggested by the global score of the WAIS-R. The score on verbal subtests was within the lower average range, whereas the score in performance clearly showed the presence of a deficit. Her language comprehension was good and the overall verbal expression and ability to communicate were in the normal range although the performance remained poor.

Memory dysfunction

CP's memory skills were in the normal range, at least in reference to her global score on the Weschler Memory Scale. However, although her verbal memory was good, her performance with visual material was poor. This heterogeneity in scores is consistent with a deficit of the RH, which is "specialized" in visuospatial material. As stated earlier, memory deficits reported in the presence of subcortical damage are most often related to a thalamic lesion (Metter *et al.*, 1983; Wallesch *et al.*, 1983; Bogousslavsky *et al.*, 1986; Waxman *et al.*, 1986). The pattern of memory loss associated with such lesions has been described as "diencephalic amnesia". When it involves the fiber system of the mammillo-thalamic tract, it has been thought to take the form of an amnesic syndrome (Van Der Werf *et al.*, 2000). An amnesic syndrome is typically associated with an encoding deficit of new information, resulting in impaired anterograde memory with intact short-term memory and normal intelligence (Weiskrantz, 1985). The pattern of CP's memory disturbances does not correspond to this formal definition as intelligence was affected, as well as some aspects of short-term memory. There is evidence that the pre-frontal system participates in memory processes, i.e. in the retrieval of information and the use of search strategies in the memory store (Kapur *et al.*, 1995). Thus, memory problems may arise as a consequence of EF impairments, for instance, attention disturbances. In line with this hypothesis, CP's memory deficit was likely to be the result of an inability to use strategies, which is consistent with her executive dysfunctions (Hirst and Volpe, 1988; Van Der Werf *et al.*, 1999). Therefore, it might be that her strategy deficit led to a defective organization of memory, leading to retrieval deficits for visual-spatial material (Milner and Petrides, 1984).

Perceptual impairments

Perceptual skills were affected. CP had severe left-sided neglect. This deficit has mainly been reported after cortical lesions of the right parietal lobe in man (DeRenzi, 1982). However, as reported above, neglect has also often been associated with a variety of subcortical lesions (Henderson *et al.*, 1982; Decroix *et al.*, 1986; Graveleau *et al.*, 1986; Laplane *et al.*, 1986; Barrett *et al.*, 2000; Karussis *et al.*, 2000). Performances on the Montreal-Toulouse test suggested a mild visuo-perceptive integration deficit since the performance was poor in both the visual-discrimination and in the identification of overlapping drawing sub-tests. This is consistent with the observations made by Ricker and Millis (1996) and Bogousslavsky *et al.* (1986) who reported impairments on tasks of visual synthesis following infarction of deep gray structures. However, the impact of neglect cannot be ruled out. In the former test, it was clear in 5 errors although it was less apparent in the second subtest. Moreover, her knowledge of the visual characteristics of line drawing objects (belonging to the same category) was well preserved.

Executive function deficits

CP also had a number of features of executive dysfunctions in tasks known to be standards of EF. These tasks involved verbal or visuospatial material. For instance, she showed impairments in the TOL task, indicating a difficulty in planning ahead and effective implementation of plans of action. Disabilities in organizing a structurally adequate course of action were also obvious in drawing tasks, in particular in the copy of the Rey Complex Figure Test. The constructional impairments presented by CP suggest a dysfunction of planning abilities. This is consistent with the observations of Ricker and Millis (1996) who reported a strong correlation between performances in visual synthesis and spatial analysis tasks and performance on neuropsychological tests of executive control. Abnormalities in CP's production included a "piecemeal strategy", omission of internal details, broken configurations, and repetition of individual elements (over-drawing). Grossi *et al.* (1996) reported similar observations in a patient affected by a subcortical lesion of the RH. The drawing disturbances of CP are in line with the results of Kirk and Kertesz's (1993) study that showed drawings with altered spatial relationships in patients with right subcortical lesions.

In the graphical tests, CP showed a severe tendency towards perseveration. In these tasks, perseverations are viewed as a particularly conspicuous consequence of an inhibition deficit. However, the perseveration type of errors noted in CP's performance may be analyzed at different levels, as suggested by a number of studies that distinguished several categories (Freeman and Gathercole, 1966; Sandson and Albert, 1987). These categories may result from diverse pathogenic sources as suggested by the works of Goldberg *et al.* (Goldberg, 1986; Goldberg and Costa, 1986) that distinguished four types of perseverations. Luria (1966) distinguished two main categories of perseveration, a form resulting from a planning deficit and a "hyperkinetic" type. As stated earlier, the second type was the most frequent. It was termed by Luria (1966, 1973) as "inertia of motor stereotypes", which he associated with a lesion to the basal motor ganglia. According to Luria (1973), it corresponds to a loss of the inhibitory and modulating function of the premotor cortex relative to the lower subcortical structures. With respect to the phenomenology and the nature of the underlying neuropathology, this interpretation is plausible. However, when considering the presence of the intrusion of a unit from a previous series (a cross), with regards to the impairments in the other tasks, it is not clear whether the perseverations simply result from an inability to terminate an automatic motor activity (as suggested by the label "hyperkinetic"), or from a "higher" level of integration, that is planning. Our data suggest that both forms are present. The combination of neglect and perseverations has also been previously reported, though not frequently (Na *et al.*, 1999). For instance, in cancellation tasks, Rusconi *et al.* (2002) observed that patients with unilateral neglect, in addition to failing to respond to contralesional stimuli, might show perseverative behavior. Interestingly, in these patients,

they reported that perseverative responses were more frequent in patients with damage in subcortical structures.

The performance in TMT-B, which was particularly low, also suggests an impairment in inhibitory processing. In sum, many observations are consistent with a dysfunction in inhibitory processing. However, this conclusion must be tempered by the performance observed in the Stroop test, which, surprisingly, did not indicate an interference deficit. CP showed no major difficulty in inhibiting the tendency to read the word instead of naming the color of ink. It might be that the Stroop test, although designed to evaluate "inhibition", involves other cognitive skills not impaired in this patient.

The presence of apathy and anosognosia observed are consistent with a number of clinical studies. Anosognosia has been associated with both superficial and deep lesions and with damage confined to deep structures. Anosognosia has also been reported in the presence of a frontal syndrome (Eslinger, 1996; Stuss, 1991). With damage to deep structures, apathy and anosognosia have frequently been reported after a lesion to the right thalamus (Bogousslavsky *et al.*, 1986; Kumral *et al.*, 1995; Van Der Werf *et al.*, 1999; Karussis *et al.*, 2000). Ellis and Small (1997) found a high incidence of lesions in deep white matter and the basal ganglia. To some extent, the observations done on CP are in line with the conclusions of these authors. However, interestingly, she was aware of her motor and functional disability. She presented no anosognosia for her left hemiplegia. There were no delusions or confabulations about the affected side.

Spatial deficits

Taken together, the pattern of impairments of CP in spatial tasks showed a deficit in spatial cognitive functions that is, again, consistent with a right parietal hemispheric lesion (see DeRenzi, 1982). She failed on the three piagetian tasks and there was no reason to believe that neglect had any impact. Clinically, she did not present any problems with left-right discrimination in respect to her own body, or with respect to the examiner. However, the findings suggest disturbances in the co-ordination of the plurality of the projective dimensions and in the co-ordination of different perspectives produced by the diversity of the potential positions of an observer (involving a mental rotation). More specifically, since these tasks involved projective relations between objects, that is, right/left AND front/back relations, this strongly suggests a dysfunction in the capacity to coordinate these spatial relations in a "whole system" (i.e. the coordination of many spatial relations at the same time), as proposed by Piaget and Inhelder (1948).

CP's performances also suggest impairments in mental rotation. Rotational difficulties were present in the localization of topographical positions (landscape test), perspective rotations (three mountains task), and in the left/right discrimination task, at least in the last sub-test that involved 180° rotation. For instance, in a case study of a patient having

circumscribed right superior parietal lesion, Passini *et al.* (2000) observed a deficit in all tasks involving mental rotation. This deficit was clear in the same piagetian tasks used in the current study. Butters *et al.* (1970) had similar observations. Moreover, in the Money route map test, she failed most problems involving a mental rotation while succeeding in a majority of the others (in both conditions). This test was assumed to involve the capacity to perform right-left discriminations (Lezak, 1995) as well as mental rotations (Kritchevsky, 1988), both of which are important spatial abilities. Concerning the former aspect, our findings do not suggest disturbances in right-left discrimination, at least with respect to parts of her own body. The hypothesis of a right-left confusion *per se* as the origin of the difficulties in these tests could not be supported.

In sum, one may conclude that the damaged subcortical structures in the RH impaired specific rotational cognitive ability. This is in line with some studies that reported that mental rotation is sensitive to RH dysfunction, in particular the parietal lobe (Corballis and Sergent, 1989). However, this conclusion can be refuted by the fact that CP succeeded in some sub-tests requiring mental rotation (i.e. success in the designation of the examiner's body parts in the "Right-left discrimination test", and in at least 5 of the first 7 problems in the "Topographical relations test"). Taken together, the observations suggest a disturbance in the capacity to process spatial projective relations in a "whole system", in particular when a mental rotation is involved, but not restricted to it. Obviously, these tasks are a composite of different cognitive processes. In other words, these tasks do not measure a unitary "rotational function" or a right/left discrimination ability.

The pathogenetic mechanisms

Findings from this patient show a complex neuropsychological picture. The spectrum of dysfunctions was mixed and involved different types of mental operations. These impairments were probably related to decreased neuronal activity caused by damage, or dysfunction, in one of the sub-cortical structures and/or the tracts linking them to the cortex.

Several ascending and descending pathways run through the internal capsule or are in close anatomical relation to it. These include the pyramidal, corticorubral, auditory, visual and thalamic radiations. The cortico-thalamic fibers connect different nuclei of the thalamus to specific regions of the cortex. Non-specific thalamic fibers project from the nucleus reticularis to the multimodal parietal cortex. The retrolecticulic portion includes efferent connections from the pulvinar to the multimodal parietal cortex (Cummings, 1993, 1995).

With regard to the neuronal organization and the imagery findings, the deficits might be interpreted as a functional disconnection syndrome. Considering the time between the subcortical infarct and the evaluation of the patient, the hypothesis of hypoperfused cortical tissue to explain the clinical picture can be ruled out (see Hillis *et al.*, 2000, 2002). A number of authors (Viader *et al.*, 1987) proposed that

right subcortical pathways, and especially the thalamus, play a part in the activation of both cerebral hemispheres. It has been suggested that connections between the pulvinar and the parietal cortex play a critical role in modulating shifts of attention. Sakashita (1991) concluded that the basal ganglia and deep white matter in each hemisphere is involved in directing visual attention into both hemi-spaces. According to Ferro and Kertesz (1984), a pulvinar-parietal disconnection, that deprives the right parietal cortex from relevant visuospatial information from the contralateral hemisphere, is the cause of left hemispatial neglect. Samuelsson *et al.* (1997) suggested that a simultaneous damage to the cortico-thalamic system for regulation of arousal and to the neural systems mediating visual orientation is likely to be followed by persisting neglect symptoms. These conclusions are consistent with the presence of neglect in our patient. In this vein, the impairment of the spatio-cognitive abilities, in particular spatial abilities, observed in this patient might be interpreted as a global decrease of neural activity in the right parietal region, which is probably the consequence of the destruction of the reciprocal connections between the parietal cortex and the thalamus. This is corroborated by the finding of decreased blood flow in the right parietal cortex, and by evidence from the neuroanatomical literature.

Accordingly, the dysexecutive symptoms of CP are thought to be the consequence of functional disconnection of the prefrontal cortex from subcortical structures. Cummings (1993, 1995) provides comprehensive reviews of five neuroanatomical circuits connecting regions of the frontal lobes with subcortical structures. Three of them are involved in cognition, emotion and motivation and are therefore most relevant to the current case. Indeed, the SPECT data of our patient showed a hypoperfusion of both the frontal and parietal cortex, which is most probably the consequence of damage to the cortico-thalamic system for regulation of arousal. Bogousslavsky and colleagues (1988) reported similar observations in a SPECT study in the presence of subcortical lesions.

In summary, these findings confirm the crucial role of the connections in the subcortical structures as part of an integral neuronal network concerned with cognitive functions, in particular in EFs and spatial abilities. This is consistent with Filley (1998), who concluded that the periventricular white matter is likely to play a general "cognitive" role. The data also support the central role of the thalamus and basal ganglia although their relative contribution cannot be distinguished in the present study. Indeed, they probably do not merely play the role of transmission of information to various representative areas of the cortex (Aglioti, 1997; Karussis *et al.*, 2000).

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The impact of right subcortical lesion on executive functions and spatio-cognitive abilities: a case study

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Abstract

The presence of deep-seated lesions has already been considered to be responsible for different cognitive impairments. In order to study the impact of these lesions on cognitive functioning, in particular on executive functions and in space representation abilities, an investigation was carried out on a right-handed patient having lesions in the subcortical structures of the right hemisphere. Findings show a complex pattern of neuropsychological impairments, which includes a memory deficit, a syndrome of neglect and anosognosia. In addition, there was a severe executive function syndrome. Finally, observations show impairments in spatial processing, more specifically in space representation abilities, usually attributed to right parietal damage. There was no obvious deficit of language. The pattern of deficits was interpreted as a disconnection syndrome.

Journal

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Neurocase Reference Number

NC503/02

Primary diagnosis of interest

Executive function impairments and spatio-cognitive deficits after lesions in the subcortical structures of the right hemisphere

Author's designation of case

CP

Key theoretical issue

- The impact of a deep-seated lesion on Executive function and Spatio-cognitive abilities

Key words: right subcortical lesion; memory deficits; neglect; executive dysfunctions; spatial cognition impairments

Scan, EEG and related measures

CT brain scan, brain scintigraphy

Standardized assessment

WAIS-R IQ, Revised Weschler Memory Test, Line Cancellation Test, Letter Cancellation Test, Bell Test, Rey-Osterrieth's figure, Graphical Seriation Test, Trail Making (A and B), Stroop Test, Money standardized Road-Map of directional sense

Other assessment

The Ruff Figural Fluency Test, Rule Governed Drawing Test, Right-Left discrimination Test, Landscape Test, Perspective Relations Test, Tower of London

Lesion location

- Right subcortical lesion

Lesion type

Vessel ischaemic disease

Language

English