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NEUROBEHAVIORAL GRAND ROUNDS

Contribution of right hemisphere to visual imagery: A visual working memory impairment?

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Abstract

Visual Imagery is the ability to generate mental images in the absence of perception, that is, "seeing with the mind's eye." We describe a patient, IM, who suffered from an acute ischemic stroke in the right anterior choroidal artery who appeared to demonstrate relatively isolated impairment in visual imagery. Her cognitive function, including her performance on tests of semantic function, was at ceiling, apart from a deficit in visual memory. IM failed in tasks involving degraded stimuli, object decision involving reality judgments on normal animals, and drawings from memory. By contrast, she was able to match objects seen from an unfamiliar viewpoint and to perform tasks of semantic and visual association. We hypothesize that IM has a visual working memory deficit that impairs her ability to generate full visual representations of objects given their names, individual feature, or partial representations. The deficit appears to be the result of damage to connections between the right thalamus and the right temporal lobe. Our findings may help to clarify the role of the thalamus in the cortical selective engagement processes that underlie working memory. (*JINS*, 2008, *14*, 902–911.)

Keywords: Visual imagery, Thalamus, Visual working memory

INTRODUCTION

Visual Imagery is the ability to generate mental images in the absence of perception, that is, "seeing with the mind's eye." As defined by Farah (1995), it *is the process by which knowledge of the visual appearance of objects or scenes stored in long-term memory is used to create a short-term percept-like image*.

Many studies have sought to understand the neural and functional bases for visual imagery, including its relationship to perception, the reasons for associations and dissociations with visual recognition (see Goldenberg, 1992), the general basis for modality specific capacities for imagery, and the basis for object and spatial attributes of visual imagery. Cognitive theories of mental imagery assume that visual perception and visual imagery can either share some cognitive processes or use modality-specific processes (Farah, 1984; Kosslyn, 1988). Both recognition, deriving from perception, and visual imagery would require knowledge about the visual properties of objects stored in long-term memory. In recognition, the visual input is matched to stored knowledge (long-term memories), and in visual imagery the content of the mental image is drawn from the same stored knowledge. However, whereas matching visual input to knowledge in long-term memory requires perceptual processing—a bottom-up process, image generation converts knowledge into a "quasi-perceptual" format through top-down engagement of the visual cortices supporting that knowledge—the presumptive basis for working memory.

Within this framework, associations and dissociations are equally possible. A deficit in both perception and imagery could be produced by a category-specific knowledge deficit (e.g., for living things) stemming from damage to visual association cortices. Impaired recognition and spared visual imagery could be produced by a deficit in the bottom-up perceptual processing that leads to knowledge access. Finally, spared recognition associated with impaired imagery would indicate a damage to the top-down visual image generation process (Farah, 1984).

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In most reported cases, deficits in visual imagery have been associated with lesions of the mesial temporal lobes, the left in particular, and adjacent parietal and occipital regions (for a review, see Bartolomeo, 2002). However, a predominantly left hemisphere basis for visual imagery is far from proven. For example, functional imaging studies have provided evidence that both hemispheres are involved in visual imagery (Ishai et al., 2000; Kosslyn et al., 1995; Mellet et al., 2000; Sergent, 1989). The emerging consensus is that visual imagery is subserved by distributed neural systems located in both hemispheres that are implicated in visual perception, visual working memory and in "top-down" control functions (Gardini et al., 2005; Ishai et al., 2000; Kreiman et al., 2000). A potential role for the thalamus in these processes has been posited (Beschin et al., 2000; Kosslyn et al., 2004; LaBerge, 2002).

To our knowledge, deficits in visual imagery stemming from isolated right hemisphere damage have not been described yet. In the present case-report, we describe a patient with a stroke involving the right anterior hippocampus and the posterior limb of the right internal capsule with selective impairment in visual imagery. We hypothesize that her problem reflects a working memory deficit, reflecting impairment in the capacity for top-down engagement of right hemisphere visual association cortices as a result of thalamo-cortical disconnection.

METHODS AND RESULTS

IM is a right-handed, 76-year-old woman with 13 years of schooling. Her past medical history did not reveal any significant cerebrovascular risk factors apart from untreated hypercholesterolemia. In May 2004, she experienced an acute ischemic stroke in the right anterior choroidal artery (AchA) territory (see Figure 1a–c). The infarct involved regions typically supplied by the AchA (Hamoir et al., 2004): the right anterior hippocampus and overlying cortex, and the posterior limb of the right internal capsule.

At clinical examination IM displayed a mild dysarthria, spontaneously recovered after few hours, and left hemiparesis. Fluid attenuated inversion recovery MRI failed to demonstrate any old infarcts, and diffusion-weighted MRI did not highlight any additional regions of acute infarction that might have accounted in whole or part for patient's neurological and cognitive deficits.

When discharged from hospital, IM displayed an almost complete recovery from hemiparesis. Visual acuity was normal and there was no evidence of hemianopia. Once at home, however, she started complaining of a subjective "feeling of unfamiliarity" with objects ("*It seems to me that the objects look odd, as if they were different than usual* . . ."). However, she had no difficulties with recognition, naming, or use of objects. She also had a good level of autonomy in daily living activities. In July 2004, we conducted detailed neuropsychological testing to characterize and identify the possible basis for her unusual visual complaint. Testing was done in three different 2-hour sessions to avoid fatigue. All data were obtained with IM's consent and in compliance with both the regulations of our institution and the Helsinki Declaration.

Neuropsychological Assessment

Cognitive performances are summarized in Table 1; raw scores were defined as normal or defective according to Italian or international normative data; the cutoff score indicated the outer nonparametric limit (5% of controls). IM was well oriented in both time and space, very co-operative and motivated. A moderate degree of anxiety was present, but disappeared during testing.

Memory

Auditory-verbal memory was assessed by means of a supraspan word-list to be learned over five trials of immediate free recall; delayed recall was assessed 15 minutes later (Carlesimo et al., 1996). Short- and long-term recall were above the cut-off scores, as was recognition.

Visual memory was evaluated by means of the immediate and 30-minute recall of the Rey-Osterrieth Complex

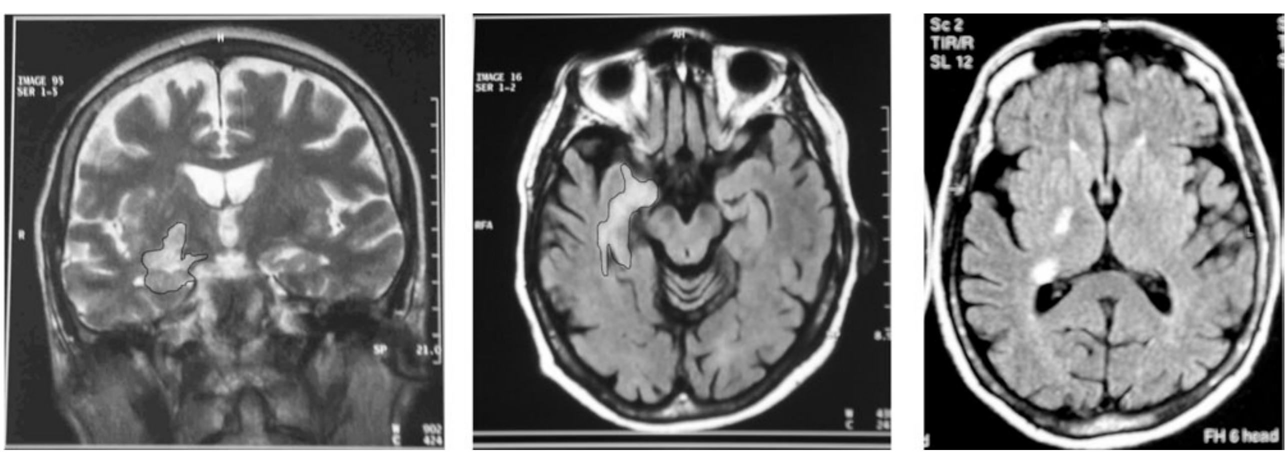

Fig. 1. MRI coronal and axial slices.

Table 1. Neuropsychological assessment

Test	Score	Normative values
Auditory Verbal Memory		
Short-term recall	46.4	≥ 28.53
Long-term recall	11.6	≥ 4.69
Recognition hits	12	13.2 ± 1.3
Visuo-spatial memory		
Rey Complex Figure—immediate recall	4.5	15.44 ± 6.51
Delayed recall	3.5	≥ 9.47
Trail Making Test:		
Part A*	35	<94
Part B*	129	<283
Stroop Test		
Word	92	>75
Colour	66	>58
Colour-word	41	>25
Coloured Progressive Matrices Language	19.5	≥18.96
Alphabetic fluency (F.A.S.)	32.5	≥17.35
Semantic fluency (Animal naming)	19	16.4 ± 4.3
Aachener naming subtest	113	>104
Visuo-spatial functions:		
Rey Complex Figure (copy)	32	≥28.87
Hooper Visual Organisation Test	8/30	>20
Street's Completion Test	5/14	>2.50
Unknown face recognition test	41	>39

*time in seconds.

Figure (RCF). As expected, owing to the lesion in the right hippocampus, both performances were below average (Caffarra et al., 2002).

Executive functions

IM displayed a fast visual search in the Trail Making Test–A form, followed by a good performance in sequential shifting in the B form (Giovagnoli et al., 1996). Neither attentional slowness (Stroop Test; Golden, 1978) nor a deficit in conceptual thinking (Colored Progressive Matrices; Spinnler and Tognoni, 1987) were evident.

Language

Spontaneous speech was fluent and flawless, and there were no difficulties in comprehension. Verbal fluency task performance, including both letter fluency (F.A.S.; Carlesimo et al., 1996) and category fluency (Animal Naming; Tombaugh et al., 1999) was normal. Naming was assessed by means of the Italian version of the Aachener Aphasia Naming test (Luzzatti et al., 1996), which provides stimuli for naming of colors, objects, and actions; performance on this task was normal.

Spatial abilities

IM did not show any signs of neglect or topographical disorientation. The very good score on the RCF copy ruled out constructional disorders. Face recognition was also normal (Benton et al., 1983), as were processes of perceptual closure of incomplete stimuli (Street's Completion Test; Spinnler and Tognoni, 1987). By contrast, she was severely defective at the Hooper Visual Organization Test (VOT; Western Psychological Services, 1983). This test consists of 30 line drawings depicting common objects, cut into pieces like a puzzle; the subject is asked to identify the object through mental rotation and reorganization of fragments. IM correctly recognized only 8 items out of the first 14 (table, plane, ball, dog, cup, truck, scissors, and stick), regardless of the complexity of the stimuli (the number of pieces the image is made of). From the 15th to the 13th items, the errors pattern was characterized by partial (e.g., *hoe* instead of *hammer*; *pipe* instead of *mice*), bizarre (e.g., *shoe* instead of *key*, *blazer* instead of *lighthouse*), and *"I don't know"* answers.

Because, unexpectedly, IM failed in this right hemisphere sensitive test, we posited a perceptual deficit and administered a screening battery for agnosia. The cognitive framework of Humphreys and Riddoch (1987) was used to guide the experimental design.

Experimental Investigation

This section was designed to follow both the bottom-up and top-down processes involving visual perception (Table 2). Because normative values were not available for some tests that had been adapted for IM (Figure boundaries and the Top-down tasks), data from a matched control group (10

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Table 2. Experimental investigation for agnosia

Bottom-up Pathway		
Perception		
Efron test	17/20	15–20
Figure boundaries	3/3	3
Copy drawings	8/9	7.5 ± 1.5
Line orientation judgment	24/30	40^ %ile
Degraded Gestalt Perception		
Poppelreuter-Ghent overlapping figures	61.04	>51.5
Shape detection	18	>15
Incomplete letters	9	>14
Silhouettes	14	>15
Perceptual constancy (BORB)		
Essential features recognition	25/25	23.3 ± 2
Figures in perspective	23/25	21.6 ± 2.6
Visual matching	32/32	30 ± 2
Pre-semantic visual access		
Semantic matching	30/30	27.5 ± 2.4
Naming	70/80	>61
Object decision	65/72	>68
Top-down Pathway		
Drawings from memory	10/22	16.3 ± 3.2
Perceptual differences description	9/25	21.40 ± 2.3
Colour representation	19/20	19.3 ± .4
Alphabet letters curvature	24/24	24/24

females; age, 70–80 years; education, 8–13 years) were collected for comparison.

Perceptual analysis

Tasks are designed to assess the early stage of perception: shape detection and spatial judgment. To assess IM's ability to discriminate one-dimensional differences between shapes, the *Efron Test* (1968) was administered according to the procedure of Warrington and James (1988). It consists of 10 pictures which present pairs of two-dimensional stimuli, one 5-cm black square and one black rectangle controlled for total surface but progressively changed in height and width. The subject has to decide whether items in the pair are the same or different shape. IM's performance, 17/20 correct was in the normal range.

Two further tasks involving the ability to perceive figure boundaries and spatial arrangements of a model and its parts were administered. First, three black-line drawn figures were presented (a spoon, a mushroom, and a house) on separate sheets. IM had to follow their outlines with a pencil and performed well. Then, a *copy drawings* task was administered (Birmingham Objects Recognition Battery–BORB; Riddoch & Humphreys, 1993), consisting of nine line drawings (see Fig. 2): a triangle, a rhombus, a clock, a house with black trees, a cube, a cylinder, an overlapped triangle with a square, an overlapped circle with a hexagon and a table. IM performed within the normal range, only failing the cube copy.

The shape agnosic patient described by Milner and colleagues (1991) could neither decide the orientation of a slit, nor match two lines with the same orientation. Therefore, we administered a task of judgment of line orientation. The *Line Orientation Judgment Test* (Benton et al., 1978) consists of 30 figures, each showing a 180-degree angle divided into acute angles numbered from 1 to 11—the answer template. In the upper part, two lines of a given orientation are

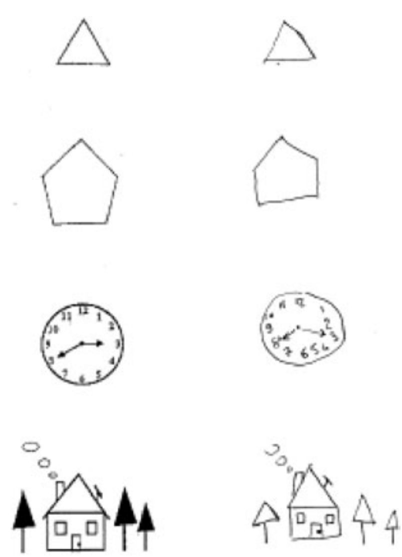

Fig. 2. Copy drawings.

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presented; the patient has to match their orientation to those of two of the lines in the template. IM's performance was good, falling at the 40th percentile.

These tests showed that IM had good perception of the stimuli: she was able to discern shape differences on the Efron test, reproduce the contour of a figure, copy two-dimensional figures, and judge line orientation in the space.

Degraded Gestalt perception

Patients with apperceptive disorders are often sensitive to conditions in which the identification of shapes is made difficult by a degraded background or by a reduction in the perceptual saliency of the stimuli. In this section, four types of test were used to examine IM's ability to segment visual information.

The Italian version of the *Poppelreuter-Ghent Overlapping Figure* test (Della Sala et al., 1990) consists in 71 figures: 36 meaningful stimuli (objects in any one figure belonging to a single category) and 35 meaningless stimuli (scrawls). Each figure has an upper part showing 3 to 5 overlapped black-line drawn stimuli and a lower part containing 10 single alternative stimuli (targets and distracters). IM was required to discriminate items in the overlapped pattern and match them to one of the 10 single alternative stimuli. Her performance was above average (61.04 *vs*. 51.5 for control subjects), without any difference in identifying meaningful (31.78/37) or meaningless (29.26/35) stimuli.

All three of the following tests are part of the Visual Objects and Space Perception battery (VOSP) of Warrington and James (1991).

The *Shape Detection test* consists of twenty figures depicting a fragmented X superimposed or not on a finely pixellated black-and-white background. Item difficulty varies depending on the ratio of black and white in both the stimulus and background. IM was not required to recognise the stimulus, but merely to detect its presence; her performance was above the cut-off scores for people over 50-year-old, thus ruling out any problems in figure/ground segregation.

The *Incomplete Letters test* consists of twenty alphabetic capital letters in a degraded condition, with 70% of each letter obliterated. IM performed very poorly, failing 11 items; the error pattern was characterized by targets with common perceptual features: B instead of E, H instead of M, and so on.

Warrington and James (1986) found that some subjects were able to identify an object from a minimal viewpoint, when only a few features were visible; for others, more distinctive features were necessary. The *Silhouettes test* consists of black silhouettes of 30 objects and animals, rotated through varying degrees from the lateral axis and ranging from very easy to difficult. Stimuli of both sets are arranged in order of difficulty (from easy to hard), and the subject has to identify them through naming. IM only scored 14 out of 30 correct and the error pattern appeared to reflect problems with imputed perceptual similarity (e.g., the front view of a bike became a coat-hanger, and the eyeglasses an eye-mask) rather than item difficulty.

Compared with the *Overlapping figure* and the *Shape detection* test, the *Incomplete Letters* and the *Silhouettes* tasks are characterized by an additional feature: degraded stimuli did not have to be detected, but recognized and named. This task requires a passage through visual memory to recall an analogous pattern for the visual matching.

Perceptual constancy

A central requirement of object recognition processing is that objects be recognizable from different points of view (Humphreys & Riddoch, 1984). The following three tasks from the BORB were devised to assess this capacity. Each task uses a figure showing, in the upper part, a line-drawn object presented from a conventional view point and, in the lower part, two objects: the target and a distracter. IM was required to match the line-drawn and target under three different conditions: unconventional viewpoint, different perspective and different forms of the same stimuli.

In the first condition, the critical feature of the object (e.g., a double-decker bus) is obscured in the target by using an *unconventional viewpoint* (e.g., a bird's-eye view). The distracter is a different object with somewhat similar visual features. In the second condition, the main feature of the object is not obscured but the *perspective* is different (e.g., a rotation on the main axis). The third condition requires the visual matching of two stimuli having the *same identity but different specific attributes* (e.g., a grand piano and an upright piano). To perform the task IM had to access functional information about objects perceived through visual input. Tasks were correctly performed in all the three conditions, suggesting preserved ability to visually match shapes under both familiar and unfamiliar viewpoints and regardless of variations in specific attributes.

By this stage of testing, the nature of IM's difficulties had became clearer. She appeared to have particular difficulty when she had to match an extrapolation of a perceived stimulus (e.g., a silhouette of an unconventional view) with an internal stored representation, but she had no problems with perception *per se*, and when the stimuli to be matched reflected a difference in perspective, different forms of the same object, or when the stimulus corresponded to a stored representation, however unconventional the view. The next steps of our investigation were designed to test whether stored object representations were available for matching with top-down engaged visual representations.

Presemantic visual access

A semantic matching task was used to assess IM's ability to access stored knowledge of *functional or contextual relationships* between visually perceived objects. This test also belongs to the BORB and consists of pictures depicting three different stimuli, two of which are semantically related (e.g., a clown and a circus). IM's performance was flawless (30/30).

Although she did not display deficits in naming during the neuropsychological assessment, a further *naming task* was administered (Laiacona et al., 1993) to rule out any dissociation between identifying living and nonliving stimuli. The task is composed of 80 stimuli from Snodgrass and Vanderwart (1980): 40 figures of living stimuli and 40 of nonliving objects. IM's performance was above the cut-off score (70 *vs*. 61 of healthy controls). Performance was good for both categories (36 objects and 34 living stimuli). There were no visual misperceptions. Within the living stimuli she only confused a swan with a duck and an ostrich with a swan. The remaining errors mainly involved low frequency tools (wrench, chisel, and screw) and other nonliving stimuli, for which the "*I don't know*" response was given.

An *object decision* task requiring reality judgment was used to test IM's ability to manipulate images generated from stored representation and to judge an unreal object on the basis of extrapolation of knowledge of parts of that object (Bergego et al., 2002). According to Riddoch and Humphreys (1987), stored representation of objects' structure can be differentiated from semantic knowledge. The object decision task was specifically designed to assess structural knowledge about objects. The task consists in 36 figures of objects and animals and 36 nonobject figures with a high visual approximation to objects, all of them from the Snodgrass and Vanderwart series (1980) of objects and animal and 36 chimeric figures with a high visual semblance to real objects in the series. Chimeric figures were created by substituting a part of an object (or animal) with a part of another object (or animal) (e.g., a penguin with a horse head), or changing and/or adding a feature (e.g., a bus with airplane wings; a windmill with a flag). IM's performance was defective: she made seven errors, all belonging to "real" and "animal" classes (goat, kangaroo, rhinoceros, zebra, buck, snake, and ant). This suggested that she might have difficulties in generating mental images that could be manipulated to compare them with the test stimulus to judge its reality. Her consistent rejection of chimeric figures may simply reflect an ability to discriminate grossly distorted representations.

Patients with mental imagery deficits often show difficulties in other tasks requiring top-down generation of visual representations (Bartolomeo, 2002; Farah, 1988; Riddoch, 1990). We, therefore, tested our patient through the verbal modality.

Verbal access to the visual store

Four tests were administered to test the ability to generate a visual image from a concept representation.

Drawing from memory

Geometrical figures (7), objects (5), fruits (5), and animals (5) were named and IMS was asked to draw them. Spontaneous drawing may be affected by both constructional and executive deficits. However, IM had already shown intact constructional abilities during copy so that an executive deficit appeared to be unlikely. Despite this, only 10 of 22 figures were recognizable to three independent observers (Figure 3). IM had greater difficulty in drawing 3D figures, some artifacts and, above all, animals; this performance in particular was characterized by the loss of distinctive features between the stimuli: for example the dog, horse, mouse, and even the snake had a sort of beak instead of a muzzle; interestingly, some attempt was made to place the duck in its environment (the water). Deficits of this type may also be seen in subjects with semantic dementia (Bozeat et al., 2003), but as noted IM's semantic representations appeared to be substantially intact. Thus, this defective performance also suggested impaired capacity for visual imagery.

IM was then asked to verbally *describe physical dissimilarities* between pairs of objects, animals or fruits that share a common shape (e.g., a button and a coin) (De Renzi & Lucchelli, 1993). Instead of perceptual differences, she mainly described semantic differences (attributes and/or functions) (see Appendix), and despite cueing questions she only scored 10 out of 25. Six errors involved living things and nine objects.

The third task required IM to indicate *the colors* of named objects, fruits and animals. She scored 19 out of 20, only failing the color of the zebra ("*black and yellow*"). Her performance on this task was considered normal, however it is possible that at least some of her responses were drawn from semantic knowledge and did not require imagery (Bartolomeo, 2002).

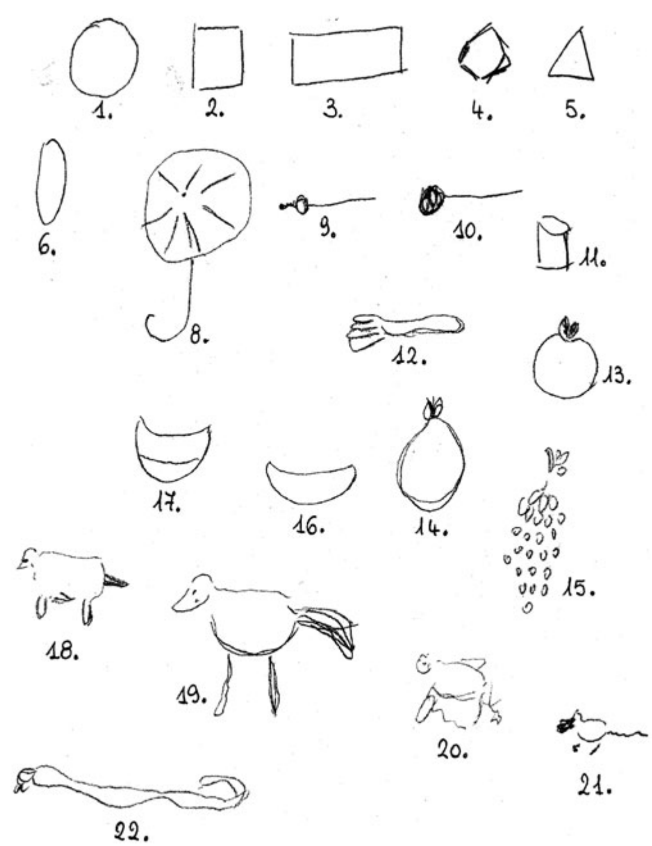

Fig. 3. Drawings from memory.

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Finally, IM was asked to *imagine the upper case letters* of the alphabet and to decide whether they had curved or straight lines. Twenty-four letters were given in random order. In contrast to her poor performance on *the Incomplete letters test*, IM's performance was perfect on this task

DISCUSSION

In this study, we have described a patient, IM, who showed good executive and constructional abilities, language functions, semantic knowledge, and verbal memory. By contrast, at the perceptual level she showed impaired recognition of degraded stimuli in some tasks (*Incomplete Letters* and *Silhouettes*), whereas she performed normally in other tasks of perception, figure-ground segregation and matching objects portrayed from different viewpoints.

The apparent incongruence between the well-maintained and defective abilities on different levels of perceptual analysis led us to suspect a deficit in visual imagery. This suspicion was born out in further studies

First, the error pattern in the *Incomplete Letters* task ruled out that IM's slight visual disturbances could have caused a disruption of the fine-grained processing involved in perception. This pattern did not seem to reflect the effect of item difficulty, but rather that of shapes similarity. She failed in those stimuli that were ambiguous because their distinctive feature were partially degraded, whereas unmistakable letters (W, Z, X. . .) were correctly recognized. The same occurred in the *Silhouettes* task, where IM mixed up stimuli sharing similar features independently on their perceptual difficulty. Also in this case, unmistakable silhouettes were recognized

Second, in the *Object decision* task IM failed to make a correct reality judgment for seven stimuli, despite the fact that she only failed to recognize two living stimuli during the *Naming* task. Stimuli of both tasks were taken from the Snodgrass and Vanderwart series, so that a bias in perceptual complexity can be excluded. IM's performance on the other tasks in which she experienced difficulty—*Drawings from memory* and *Perceptual description*—rule out the possibility of a category-specific impairment in semantic knowledge as well, because she failed in the verbal and pictorial description of objects regardless of the class of the stimuli.

The common feature to all the tasks on which performance was impaired is that they required the retrieval of mental representations in long-term memory store: that is, IM had to access a visual representation in long-term memory to mentally maintain it or inspect it (*Object Decision, Drawing from memory, RCF recall* and *Perceptual Differences Description*), or to manipulate it in the visual working memory system during attempted matching (*VOT, Incomplete Letters* and *Silhouettes*). Indeed, no problems arose when she had to identify objects, drawings or forms through a direct matching; this condition required that stimuli be visually present, even if with a degraded, embedded or atypical pattern. This was the case with the perception tasks, the *Overlapping Figures* and *Shape detection* tests, and all tasks of perceptual constancy.

As in others cases of a deficit in visual imagery (Farah et al., 1988; Riddoch, 1990), IM was unable to draw from memory despite her very good performance at copying, and showed difficulties generating vivid mental images to describe them.

On the other hand, IM showed problems with certain tasks such as the *Silhouettes test*, the *Incomplete Letters test* and the *Hooper test*, that were difficult to account for solely in terms of defective visual imagery. Therefore, we have posited that impairment in visual working memory could account for her defective performance on these tasks. The model proposed by Kosslyn (Farah, 1984; Kosslyn, 1980) conceptualizes a single visual working memory buffer, presumably based in visual association cortices. Top-down engagement of this buffer is used to generate mental images and bottom-up engagement to represent perceived visual stimuli. As an instantiation of the working memory system, the visual buffer would allow the subject to retain and examine internal images and/or a visual percept, and to manipulate and transform it.

During tasks like the *Silhouettes test*, the *Incomplete Letters test* or the *Hooper test*, the subject has to make a mental comparison between the visual percept and a series of selected mental images, to decide which one fits better what he sees. In addition, these tasks require a mental manipulation of the visual percept because they are degraded (letters), ambiguous (silhouettes), or rotated (Hooper). The sum of these operations is certainly more demanding than simple perceptual matching tasks, and involves a heavier load in the working memory system.

On the other hand, during the more conventional imagery tests (*Object Decision* and *Drawing from memory*, *RCF recall* l), the subject is engaged in a task demanding the maintenance of a vivid and detailed mental image in the visual buffer.

This pattern of difficulties, therefore, suggests that IM's problem may specifically lie in this visual component of the working memory system, necessary for the maintenance and manipulation processes of mental images generated from the visual long-term memory store.

Two points of interest are the discrepancies between performances apparently testing visual imagery: *Incomplete Letters* versus *Alphabetic letters curvature*, and *Perceptual differences description versus Color representation*.

Orthographic material (letters and words) represents a particular class of stimuli in visual imagery tasks, which typically require to state their physical appearance. IM was asked to state whether uppercase alphabetic letters contained curved or straight lines and her performance was at ceiling. There have been many reports of dissociations between visual recognition and visual imagery of alphabetic letters, particularly in agraphic and pure alexic patients (for a review, see Bartolomeo, 2002). In 1993, Goldenberg pointed out that to solve such kind of tasks two different codes may be used by patients, one visually based (mental reading) and one motor-based (mental writing). For example, patient VSB (Bartolomeo et al., 2002) significantly improved his capacity of revisualizing letters by tracing their contour with his finger and the same occurred in patient JB (Sirigu & Duhamel, 2001). In the present case, IM's good level of education and daily habit in reading suggest a mastery for letters and words and a *quasi*-automatic ability to perform the task so we cannot exclude that having a difficulty mentally seeing the letters, IM had solved the task using a writing-based strategy.

As concerns color processing, neuropsychological studies have provided evidence of an association between perception and visual imagery (Damasio et al., 1980; Farah, 1988), thus suggesting that the same neural representations are involved in both processes. However, the lesions in these cases invariably affected the mesial part of the left temporal lobe, which was spared in IM. It is also likely that questions about the typical color of objects were too easy for our patients, and semantic memory may have been sufficient to enable a correct response without recourse to visual imagery (Bartolomeo et al., 1997).

Anatomical Considerations

How can our findings be explained from an anatomical point of view? Neuroimaging studies have shown a distributed network of posterior and prefrontal cortices underlying visual working memory (Finke et al., 2006; Sala et al., 2003; Wager & Smith, 2003), with visual association areas involved in both object and spatial working memory and inferior temporal regions having a mainly perceptual role. None of these regions were damaged in our patient.

Two major structures were damaged in IM: the anterior hippocampus and the posterior limb of the internal capsule. Either lesion, or the combination of these two lesions, appears to account for the neuropsychological impairment demonstrated.

Hippocampal systems are involved in the encoding and consolidation of fact memories to be held in long-term stores. However, hippocampal function may play a role in short-term processes that are sometimes viewed as engaging exclusively working memory mechanisms. For example, in testing of immediate recall on supraspan memory test, the primacy effect disappears in subjects with hippocampal lesions (Baddeley & Warrington, 1970; Kesner & Di Mattia, 1984; Milner, 1978). Thus, to the extent that visual imagery task require engagement of representations that is sustained over periods of time, perhaps as little as 5–10 seconds, hippocampal mechanisms might plausibly come into play. Gazzaley and colleagues (2004) showed that the hippocampus may contribute to stimulus maintenance, probably by engaging the long-term memory network of associated context representations. Other neuropsychological studies have suggested that medial temporal lobe damage can affect short-term memory for objects (Ranganath & Blumenfeld, 2005) and that "portions of the long-term memory, possibly the hippocampus, are critical for accurate visual working memory" (Olson et al., 2006).

The lesion of the posterior limb of the internal capsule produced by AchA distribution infarcts tends to extend along the entire rostro-caudal extent of the capsule, and thus, has the capacity for disconnecting the thalamus from overlying cortices. The effect has been most clearly demonstrated with left AchA infarcts, which produce thalamic aphasia (Goldman-Rakic, 1990; Nadeau & Crosson, 1997). The lesion in IM (Figure 1b) was confined to relatively ventral regions of the internal capsule, plausibly disconnecting the thalamus only from the temporal lobe (visual association cortices subserving the "what" visual pathway; Mishkin & Ungerleider, 1982). The fact that IM's paresis recovered so well indicates that damage to motor fibers descending in the internal capsule was modest. However, more medially or laterally placed thalamocortical fibers may have sustained more severe and persistent damage.

Because thalamocortical disconnection could directly impair the visual working memory processes implicated in our patient's deficit, we favor this as the primary cause. However, it is not possible on the basis of available evidence to rule out a contribution from the right hippocampal system.

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APPENDIX

Verbal description of physical dissimilarities

Stimuli	Answers
1. The blade of a saw and that of a knife	*That of a sow is much more jagged*
2. A nail and a screw	*The screw is not smooth (gesture), the nail is*
3. The back of a horse and that of a camel	*The camel has the hump*
4. An artichoke and a fennel	*The artichoke has big flakes, the fennel looks like a pine cone. It's closed*
5. A pig's tale and that of a horse	*Pig's tale is a little curl, that of a horse is long and thick*
6. A bottom and a coin	*The bottom can be patterned, the coin is smooth*
7. A chestnut and a nut	*The chestnut is a bit round with little hairs in its centre; the nut is light brown coloured*
8. A match and a toothpick	*The match has a little head that one fires*
9. A pot and a pan	*The pot is a bowl, the pan is flat*
10. A brush and a toothbrush	*The brush is big, the toothbrush is little*
11. A fly and a bee	*The bee is yellow and pricks. The fly is dark and it only bothers*
12. A shoe and a slipper	*The shoe is a thing to wear, the slipper is for home*
13. A pot and a colander	*The pot is closed and the colander has holes*
14. A needle and a pin	*The needle has the eye for the thread and the pin has a little head*
15. The wheel of a bike and that of a car	*That of a car is enormous and bigger*
16. A tie and a scarf	*The tie is put under the shirt and the scarf wraps the neck*
17. An almond and a hazelnut	*The almond is into the confection. The hazelnut is round and light brown coloured*
18. Spaghetti and fettuccine	*Spaghetti are smooth and long, fettuccine are a sort of long rectangles*
19. A cigar and a cigarette	*Cigar is big and cigarette small*
20. Branches of a pine and those of an oak	*Those of a pine are not regular*
21. The skate and the shoes	*The skate have the rollers*
22. A pear and an apple	*The pear is long, the apple round*
23. A spoon and a dipper	*The spoon is to eat the soup, the dipper to supply it*
24. A bean and a pea	*The bean is three times bigger than the pea*
25. Ears of a horse and those of a sheep	*Those of a horse are up and those of a sheep down*