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Research report

Selective deficit of spatial short-term memory: Role of storage and rehearsal mechanisms

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ABSTRACT

We report the neuropsychological and MRI investigation of a patient (GP) who developed a selective impairment of spatial short-term memory (STM) following damage to the dorso-mesial areas of the right frontal lobe. We assessed in this patient spatial STM with an experimental procedure that evaluated immediate and 5–20 s delayed recall of verbal, visual and spatial stimuli. The patient scored significantly worse than normal controls on tests that required delayed recall of spatial data. This could not be ascribed to a deficit of spatial episodic long-term memory because amnesic patients performed normally on these tests. Conversely, the patient scored in the normal range on tests of immediate recall of verbal, visual and spatial data and tests of delayed recall of verbal and visual data. Comparison with a previously described patient who had a selective deficit in immediate spatial recall and an ischemic lesion that affected frontal and parietal dorso-mesial areas in the right hemisphere (Carlesimo GA, Perri R, Turriziani P, Tomaiuolo F, Caltagirone C. Remembering what but not where: independence of spatial and visual working memory in the human brain. Cortex. 2001 Sep; 37(4):519–34) suggests that the right parietal areas are involved in the short-term storage of spatial information and that the dorso-mesial regions of the right frontal underlie mechanisms for the delayed maintenance of the same data.

1. Introduction

Short-term memory (STM) subserves the temporary retention of a limited amount of information for on-line processing and mental manipulation (Baddeley, 2003; Baddeley & Hitch, 1974). Results of intensive neuropsychological investigation of single cases (e.g., Basso, Spinnler, Vallar, & Zanobio, 1982; Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001; Darling, Della Sala, Logie, & Cantagallo, 2006; Shallice & Warrington, 1970; Vallar, Di Betta, & Silveri, 1997) and patient groups (De Renzi & Nichelli, 1975; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Wang & Bellugi, 1994), functional neuroimaging (Courtney, Ungerleider, Keil, & Haxby, 1996; Paulesu, Frith, & Frackowiak, 1993; Ungerleider, Courtney, & Haxby, 1998), transcranial magnetic stimulation (Oliveri et al., 2001;

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Romero, Walsh, & Papagno, 2006) and cognitive evoked potential (Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992; Shucard, Tekok-Kilic, Shiels, & Shucard, 2009) studies in healthy subjects have convincingly demonstrated that distinct neural networks underlie the short-term retention of verbal, visual-object and visual-spatial data.

In the verbal domain, there is ample evidence from healthy humans that distinct and complementary psychological mechanisms cooperate in the passive storage and on-line maintenance of incoming data (Baddeley, 2003). There is both neuropsychological (Baldo & Dronkers, 2006; Vallar et al., 1997) and functional neuroimaging (Paulesu et al., 1993) evidence that distinct cortical regions subserve the two mechanisms. Concerning visual-spatial STM, cell recording experiments in non-human primates (Chafee & Goldman-Rakic, 1998; Takeda & Funahashi, 2004) and functional neuroimaging data from healthy humans (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; Ricciardi et al., 2006; Ungerleider et al., 1998) have demonstrated a dedicated network including dorso-mesial and dorso-lateral areas of the frontal and parietal lobes. Nevertheless, the distinct and cooperative role of these areas in the storage and rehearsal of spatial information remains unresolved (Curtis, 2006).

Carlesimo et al. (2001) reported a vascular patient (MV) with a very selective disturbance of visual-spatial STM. On the Corsi test, he achieved a span of three, which was well below the range of normal controls. Pathological performances were also obtained on several STM tests involving immediate recall of spatial positions, irrespective of whether the response involved use of the arms. Conversely, his performance on tests of verbal and visual-object STM and tests of spatial long-term memory were in the normal range. This patient's brain lesion involved dorsal areas on the lateral and medial surfaces of the right frontal lobe and the medial surface of the right parietal lobe. Storage of spatial data in the STM buffer was likely precluded in this patient as he also scored poorly in recalling spatial positions at null delays.

Here we report a new patient with a selective deficit of visual-spatial STM. At variance with MV, this patient (GP) performed normally on immediate spatial STM tests but was impaired on tests performed after a short delay (ranging from 5 to 20 s). Anatomical reconstruction of the brain lesion on MRI images and its comparison with that of MV revealed almost complete preservation of the precuneus in the right parietal lobe in GP and, conversely, involvement of more rostral dorsal regions in the medial wall of the right frontal lobe. These data are discussed in the light of a neural model that attributes a role in spatial STM passive storage to the dorsal regions of the right parietal lobe and, conversely, a role in the active rehearsal of the spatial STM trace to the mesial areas of the right frontal lobe.

2. Case report

2.1. *History*

GP is a 50-year-old, right-handed woman with a high school diploma who was employed at the National Social Security Institute. We first observed GP two months after she suffered an ischemic stroke in the cerebral territory supplied by the right anterior cerebral artery. At that time, she was an alert, oriented and cooperative individual. The neurological examination revealed left limb spastic paresis, which affected moderately the leg and only mildly the arm and the hand. Visual field and voluntary ocular motility were intact. GP exhibited no disorder of spatial attention for either extrapersonal or peri-personal space. The neuroradiological and neuropsychological investigations described below were carried out from December 2011 to October 2012.

2.2. *Neuroanatomical investigation*

T1-weighted images of the brain were obtained with a Siemens 1.5 T Vision Magnetom MR system (Erlangen, Germany, MPRAGE sequence, 1 mm isotropic voxels) 60 days after the stroke. The patient's brain MRI was transformed into a standardized stereotaxic co-ordinate system using Collins, Neelin, Peters and Evans (1994) transformation algorithm. DISPLAY software provided by the Brain Imaging Center, Montreal Neurological Institute, McGill University was used to visualize the 3D images of the patient's brain. The sulcal nomenclature for the lesion description was taken from Economo and Koskinas' maps (Tomaiuolo & Petrides, 2010).

As to brain convexity, GP's lesion affected the medial portion of the superior frontal gyrus of the right hemisphere including part of Brodmann areas (BAs) 6, 8, 9, 10 and 11. Most of the central gyrus was spared (Fig. 1). Medially, it included the rectus and subcallosal gyri up to the olfactory sulcus (BAs 11, 12), the superior frontal gyrus, the cingulate and paracingulate gyri (BAs 10, 9, 5 ,6 , 32 ,33 ,24 ,31) and a small portion of the lobus paracentralis (BA 4). Most of the posterior part of the cingulate gyrus was spared. The corpus callosum was largely damaged.

When we compared the case of GP with that of MV (see Fig. 1), we found that the former had a much larger rostral lesion, which occupied the overall anterior medial wall of the frontal lobe but spared the posterior portion of it and did not involve the parietal lobe; conversely, in the latter we found that the anterior portion of the medial wall was spared, and that posteriorly the lesion extended to the parietal lobe and involved a large part of the precuneus. In MV, the cortex included in the superior frontal gyrus was completely damaged, but in GP the lateral portion adjacent to the superior frontal sulcus was spared.

2.3. *Neuropsychological examination*

GP was preliminarily evaluated on a number of cognitive abilities potentially able to interfere with performance accuracy on tests of visual-object and visuo-spatial STM. In particular, she received tests of Visual-object and Visual-spatial perception (Visual Object and Space Perception battery, Warrington & James, 1991; Benton's Facial Recognition test, Benton & Van Allen, 1968; Street Completion test, Spinnler & Tognoni, 1987; Judgement of Line Orientation test, Benton, Varney, & Hamsher, 1978; Copy of Rey's Figure A, Rey, 1968), Space exploration (Line cancellation test, Albert, 1973; Letter Cancellation test, Vallar, Rusconi, Fontana, & Musicco, 1994), Visual-spatial long-term memory (Immediate and Delayed reproduction of Rey's Figure A, Carlesimo