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Egocentric memory impaired and allocentric memory intact as assessed by virtual reality in subjects with unilateral parietal cortex lesions

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ABSTRACT

Present evidence suggests that medial temporal cortices subserve allocentric representation and memory, whereas egocentric representation and memory mainly depends on inferior and superior parietal cortices. Virtual reality environments have a major advantage for the assessment of spatial navigation and memory formation, as computer-simulated first-person environments can simulate navigation in a large-scale space. However, virtual reality studies on allocentric memory in subjects with cortical lesions are rare, and studies on egocentric memory are lacking. Twenty-four subjects with unilateral parietal cortex lesions due to infarction or intracerebral haemorrhage (14 left-sided, 10 right-sided) were compared with 36 healthy matched control subjects on two virtual reality tasks affording to learn a virtual park (allocentric memory) and a virtual maze (egocentric memory). Subjects further received a comprehensive clinical and neuropsychological investigation, and MRI lesion assessment using T_1, T_2 and FLAIR sequences as well as 3D MRI volumetry at the time of the assessment. Results indicate that left- and right-sided lesioned subjects did not differ on task performance. Compared with control subjects, subjects with parietal cortex lesions were strongly impaired learning the virtual maze. On the other hand, performance of subjects with parietal cortex lesions on the virtual park was entirely normal. Volumes of the right-sided precuneus of lesioned subjects were significantly related to performance on the virtual maze, indicating better performance of subjects with larger volumes. It is concluded that parietal cortices support egocentric navigation and imagination during spatial learning in large-scale environments.

1. Introduction

Currently, spatial navigation and memory is modelled as a process supported by allocentric (i.e., world-centred) spatial representations, being independent to the observer, and egocentric (i.e., body-centred) spatial representations, which relate to the body axes (O'Keefe & Nadel, 1978). Allocentric spatial representations include prominent and salient environmental features ('places') that may serve as navigationally relevant locations for the purpose of spatial orientation and memory storage. On the other hand, egocentric spatial representations include the sensorimotor representation of whole-body, head and gaze motion, the mental representation of distance, time and number of routes that have been travelled, and the temporo-spatial relationship of all information.

A number of studies have reported that individuals with medial temporal lobe damage are impaired in finding their way within their locomotor environment ('topographical disorientation and amnesia') (Abrahams, Pickering, Polkey, & Morris, 1997; Astur, Taylor, Mamelak, Philpott, & Sutherland, 2002; De Renzi, Faglioni, & Villa, 1977; Landis, Cummings, Benson, & Palmer, 1986; Maguire, Burke, Phillips, & Staunton, 1996; Spiers, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2001b). Single case studies provided evidence that bilateral hippocampal lesions are associated with allocentric memory impairment (Holdstock, Mayes, Cezayirli, Aggleton, & Roberts, 1999; Holdstock et al., 2000; King, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2002; Maguire, Nannery, & Spiers, 2006; Spiers, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2001a), whereas other studies reported the right parahippocampal gyrus as the common area of damage across cases (Bohbot et al., 1998; Epstein, DeYoe, Press, Rosen, & Kanwisher, 2001; Habib & Sirigu, 1987; Nyffeler et al., 2005).

Topographical disorientation and amnesia were also reported in the presence of parietal (Barrash, Damasio, Adolphs, & Tranel, 2000; Cogan, 1979; De Renzi et al., 1977; Suzuki, Yamadori, Hayakawa, & Fujii, 1998) and retrosplenial (Maguire, 2001) lesions. However, individuals with topographical disorientation or amnesia vary with respect to specific spatial deficits (Aguirre & D'Esposito, 1999).

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Bilateral parietal lesions seem to be frequently related to a form of egocentric disorientation or amnesia, implying deficits to localize visual space, to orientate properly towards objects in space, to track and reach objects in space, or to form new topographical memories (Cogan, 1979; Kase, Troncoso, Court, Tapia, & Mohr, 1977; Levine, Warach, & Farah, 1985; Stark, Coslett, & Saffran, 1996; Wilson et al., 2005). Functional imaging studies frequently reported parietal cortex activations in topographic navigation tasks, although to a larger degree in tasks demanding position judgments when compared with tasks demanding landmark recognition (Aguirre & D'Esposito, 1997; Aguirre, Detre, Alsop, & D'Esposito, 1996; Burgess, Maguire, Spiers, & O'Keefe, 2001; Epstein, Graham, & Downing, 2003; Maguire, Frackowiak, & Frith, 1997).

So far, the majority of studies investigating topographical orientation and memory in individuals with brain damage relied on clinical descriptions, or used traditional neuropsychological paper and pencil tests. More recently, studies tried to assess topographical learning using complex real life surroundings (Barrash et al., 2000; Bohbot et al., 1998; Epstein et al., 2001; Maguire et al., 1996). The development of virtual reality technology has brought a major progress to the study of spatial navigation and memory. Virtual realities have a major advantage for the assessment of spatial navigation and memory formation, as computer-simulated first-person environments can simulate navigation in a large-scale space. There are now a large number of studies investigating allocentric memory in healthy individuals using virtual reality environments and functional imaging (e.g., Aguirre & D'Esposito, 1997; Aguirre et al., 1996; Burgess et al., 2001; Iaria, Petrides, Dagher, Pike, & Bohbot, 2003). However, studies on egocentric representation and memory of visual space using virtual reality environments are lacking.

In the present study, we studied neuropsychological and virtual reality task performance of 24 subjects with unilateral parietal cortex lesions due to infarction or haemorrhage and 36 healthy comparison subjects. Two virtual reality tasks affording the navigation in a virtual park (allocentric memory) and a virtual maze (egocentric memory) were applied. The goals of our study were (a) to test the suitability of virtual reality environments for the assessment of spatial memory in subjects with cortical lesions, (b) to assess whether subjects with parietal cortex lesions are impaired in learning the virtual maze, (c) to assess whether subjects with parietal cortex lesions are impaired in learning the virtual park, and (d) to analyse whether lesion characteristics such as size, laterality, and the exact location of lesions are related to virtual reality task performance of subjects with parietal cortex lesions.

2. Methods

2.1. Participants

2.1.1. Subjects with parietal cortex lesions

The study group comprised 24 subjects with focal parietal cortex lesions (14 left-sided, 10 right-sided), due to infarction or intracerebral haemorrhage within the territory of the medial cerebral artery (Tables 1 and 2). Screening the MRT records of the neurological department of the University of Göttingen identified subjects. Subjects older than 70 years, with a native tongue other than German, or with a history of psychiatric or other neurological disease were excluded. Only subjects with lesions covering substantial parts of the parietal cortex were included. Subjects were assessed at least 12 months after onset of clinical symptoms.

2.1.2. Healthy controls

Subjects with parietal cortex lesions were compared with 36 healthy control subjects recruited for the study by an advertisement in a local newspaper (Table 1). Only subjects without a history of neurological or psychiatric disorder were studied. Subjects were paid for their participation and matched subjects with parietal cortex lesions in terms of age, sex, and years of education.

After complete description of the study to the subjects informed written consent was obtained. The Ethical Committee of the Medical Faculty of the University of Göttingen had approved of the study design.

2.2. Lesion analysis

2.2.1. MRI acquisition and analysis

Subjects received MRI scanning using a 1.5-T Philips Gyroscan machine at the day of the assessment, including T_1, T_2 and FLAIR sequences. Scanning parameters of the T_1-weighted three-dimensional sequence were as follows: TE = 6.0 ms; TR = 24.0 ms; flip angle = 30°; FOV = 256; slice plane = sagittal; matrix = 256 × 256; slice thickness = 1.3 mm; slice number = 130; acquisition mode = three-dimensional. Volumetric analysis was done on the basis of 3D-MRIs. The images were transferred to a computer workstation and processed using the CURRY® software (version 4.5; Neurosoft Inc., El Paso, Tex.). Images were reformatted into continuous 1-mm thick slices. Intracranial volume and regional brain volumes were calculated with automated multistep algorithms and 3D region-growing methods that are limited by grey value thresholds. Simultaneous 3D visualization of brain structures and manual tracings allowed a precise identification and delineation of regions of interest. All regions of interest included grey and white matter volumes.

2.2.2. Parietal cortex lesion size

2.2.2.1. Precuneus. The anterior border of the precuneus was defined by the postcentral sulcus, the posterior border by the parietooccipital sulcus, the ventrolateral boundary by the intraparietal sulcus and the inferior medial border by a line passing through the cingulate/subparietal sulcus that extended into the parietooccipital sulcus. Manual markings were made on coronal slices by drawing a straight line between the intraparietal sulcus and the cingulate/subparietal sulcus and its posterior extension. The resulting volume (Fig. 1) includes precuneus and related superior parietal cortices (Brodmann areas 5, 7 and 31).

2.2.2.2. Postcentral gyrus. The anterior border of the postcentral gyrus was defined by the central sulcus. On the medial surface, a line vertical to the AC–PC line was drawn between the central and cingulate sulcus. The posterior border was defined by the postcentral sulcus, the ventrolateral border by the Sylvian fissure and the inferiomedial border by the posterior cingulate sulcus. Manual markings were made on coronal slices by drawing a straight line between the central and postcentral sulcus. The resulting volume (Fig. 1) includes the primary somatosensory cortex (Brodmann areas 1–3).

2.2.2.3. Inferior parietal cortex. The anterior border of the inferior parietal cortex was defined by the postcentral sulcus, the dorsal border by the intraparietal sulcus and the ventrolateral border by the Sylvian fissure. A line passing through the Sylvian fissure was extended in the same orientation posteriorly and served as post-Sylvian ventrolateral boundary. An oblique plane orientated along the length of the parieto-occipital sulcus defined the posterior border. Manual markings were made on coronal slices by drawing a straight line between the Sylvian fissure/post-Sylvian boundary and the intraparietal sulcus. The resulting volume (Fig. 1) includes the supramarginal and angular gyri (Brodmann areas 39 and 40).

In a previous study (Irle, Lange, Weniger, & Sachsse, 2007), sufficient intrarater and interrater reliabilities have been obtained. The intraclass correlation coefficients for this procedure were $r = 0.99$ (intrarater) and $r = 0.95$ (interrater) for the precuneus, $r = 0.99$ (intrarater) and $r = 0.98$ (interrater) for the postcentral gyrus and $r = 0.96$ (intrarater) and $r = 0.93$ (interrater) for the inferior parietal cortex.

2.2.3. Parietal cortex lesion localization

Lesion territories were localized by one of us (E.I.) who was unaware of the results of the behavioural assessments. MR scans of the present assessment as well as MR and CT scans obtained at the time of the insult were used for lesion localization. Lesion areas were mapped onto appropriate atlas templates (Talairach & Tournoux, 1988), and involvement of cortical (Brodmann areas) as well as subcortical regions was assessed. Table 2 summarizes lesioned cortical areas for individual subjects, and gives the Talairach coordinates of the lesion centre. In three subjects with parietal cortex lesions, the T_1-weighted three-dimensional sequence could not be obtained. Parietal cortex size reduction in these subjects (Table 2) was estimated by calculating areas covered by the lesion in each slice using a standard grid, and by summing up these areas across slices.

2.3. Neuropsychological assessment

Subjects received a comprehensive neuropsychological assessment of intellectual, attentional and mnemonic performance with special emphasis on spatial functioning. A short form of the *Wechsler Adult Intelligence Scale-Revised* (*WAIS-R*) (Tewes, 1991) was given to derive an estimate of general intellectual capacity. Memory was assessed with the *Wechsler Memory Scale-Revised* (*WMS-R*) (Wechsler, 1987). Spatial performance was assessed with four subtests (dot counting, position discrimination, number location, and cube analysis) of the German version of the *Visual Object and Space Perception Battery* (*VOSP*; Beckers & Canavan, 1992; Warrington & James, 1991), one subtest (remembering a short route, immediate) of the *Rivermead Behavioural Memory Test* (*RBMT*; Wilson, Cockburn, & Baddeley, 1992), and one subtest (city map) of the *Lern-und Gedächtnistest-3* (*LGT-3*; Bäumler, 1974), which affords to memorize a complex route marked on a city map. Subjects had