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Lateralization of spatial-memory processes: evidence on spatial span, maze learning, and memory for object locations

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Abstract

Spatial memory is one of the most important cognitive functions in daily life, enabling us to locate objects in our environment or to learn a route or a path. In the present study, we elaborated on the hypothesis that human spatial memory consists of multiple sub-processes, relying on different brain structures. Therefore, 50 patients with an ischemic stroke and 40 healthy participants underwent tests measuring spatial span and maze learning. By means of a computer paradigm the following aspects of memory for object locations were assessed: (1) object location binding; (2) positional memory; (3) a combination of these two aspects. The results clearly showed a double dissociation: the group of patients with an infarct in the left hemisphere (LH) was impaired on object location binding, whereas the group with an infarct in the right hemisphere (RH) was impaired on positional memory. Lesions in the RH resulted also in impairments on maze learning. Moreover, patients with lesions in the posterior part of the parietal or the occipital lobe performed especially worse on spatial-memory tasks. These findings extend the theoretical framework of categorical versus coordinate spatial processing in the human brain and corroborate previous findings on selective aspects of memory for object locations. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Spatial memory involves the encoding, storage and retrieval of information about spatial layouts, enabling us to remember the positions of objects in our environment, or to learn a route or trace a path [12]. There is converging evidence that spatial memory is not a unitary construct, but that multiple components can be distinguished [52]. An important distinction can be made between memory for routes or paths on the one hand, and memory for the location of objects on the other hand [8]. Moreover, recent findings suggest that the latter can be subdivided into three possible sub-processes [42]. First, there is the ability to form associations between object-identities and positions at item level, regardless of metric information, often referred to as object location binding [7]. Second, the precise, metric information (i.e. the co-ordinates) has to be processed, independently of the object-identity. This can be regarded as a form of Euclidean positional memory [34]. Third, there might be a mechanism integrating these two processes that might be applied in most everyday-life situations, in which positional information must be combined with the associations between object-identities and locations [43]. Support for this subdivision has come from studies using dual-task paradigms. For example, verbal suppression was found to suppress the performance on object location binding and the combined mechanisms, but not on positional memory [42]. Also, selective effects related to sex hormones on positional memory and the combined process have been demonstrated, but not on object location binding [44,46]. Moreover, dissociations have been found in patients with focal cerebral damage [18,20].

The fractionation of spatial memory is further corroborated by evidence for specialized involvement of different brain structures. Neuroimaging research, for example, has demonstrated that the prefrontal cortex is especially active during spatial working memory tasks, requiring active processing of information during a brief period of time [47,61]. In addition, the posterior part of the parietal lobe has been shown to play an important role in the formation of short-term representations of spatial information [28]. Neuropsychological studies have revealed that patients with frontal lobe lesions often show problems in maze learning [36]. Furthermore, the hippocampal formation has received much attention in spatial-memory research, both in humans

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[17,37] and in animals [40]. Patients with lesions in the temporal lobe including the hippocampus were impaired on place learning [53], maze learning [36], and object location memory [54,56]. Moreover, the hippocampal formation might be specialized in navigation and locating objects in everyday environments [33]. Finally, there is evidence that subcortical regions, such as the striatum and caudate nucleus, might contribute to spatial-memory processing [30,41].

There is also evidence for specialized involvement of the cerebral hemispheres. For example, Smith and Milner [54] found deficits in object location memory in patients with lesions in the right temporal lobe, but not in patients with left-temporal damage. This is in agreement with the idea of lateralization of function in spatial processing. Furthermore, it has been suggested that the right hemisphere (RH) is superior in processing precise, metric spatial information, whereas the left hemisphere (LH) is superior in processing relative spatial relations [6,25,26].

In sum, spatial memory is a multicomponential concept, both in terms of function and cerebral structures. As such, it was the purpose of the current study to compare different forms of spatial memory in a group of neurologically impaired subjects, namely stroke patients. Although cognitive dysfunction after stroke is well documented [13,58] and deficits in spatial orientation have been frequently reported [15,35,38], little attention has been paid to spatial memory in this group of patients. Hence, a group of patients with a cerebral infarct was examined using a number of tasks measuring a variety of spatial-memory processes, such as the Corsi Block-Tapping Task to assess spatial span memory, and the Oxford Stylus Maze Test for maze learning. Moreover, a computer task (Object Relocation) was included, measuring selective aspects of object location memory, i.e. object location binding, positional memory, and a process combining these two. Also, visuo-spatial perception and construction was assessed, as well as object-identity memory. The results were compared to the performance of a control group of healthy volunteers. Standard neuropsychological tests assessing verbal and non-verbal overall cognitive functioning were also administered in the patient group. The data were analyzed with the control group as a reference, subsequently focusing on hemispheric differences (comparing patients with lesions in the LH or RH or with bilateral (BIL) damage), differences between anterior and posterior regions of the brain, and between cortical and subcortical stroke.

2. Material and methods

2.1. Participants

Fifty patients who suffered from an ischemic stroke between 1991 and 2000 were selected from the Stroke Database of the University Medical Center Utrecht. Inclusion criteria were: (1) age between 25 and 75; (2) no history of previous neurological or psychiatric disorder; (3) at least 5 months after the onset of the stroke; (4) lesion visible on CT or MRI scan; (5) no hemispatial neglect or severe hemianopia. Informed consent was obtained from each patient. The control group consisted of 40 healthy, age- and education-matched participants, who were selected from a database of volunteers who responded to an advertisement in the local newspaper.

Mean age of the patients was 52.4 years (S.D. = 13.0; range 28–72); 50% was male and 50% was female. For the control group, mean age was 52.3 years (S.D. = 8.2; range 39–72), 52.5% of the healthy volunteers was male and 47.5% was female. Education level was scored using seven categories, one being the lowest and seven the highest education [13]. Mean education for the patient group was 4.3 (S.D. = 1.3; range 2–7; median = 4), mean education for the control group was 4.6 (S.D. = 1.3; range 1–6; median = 5). Handedness was assessed using the Dutch version of the revised Annett Handedness Inventory [2,5], with scores between −24 (left-handed) and +24 (right-handed). In the stroke group, six participants were left-handed (score <-9), one patient was mixed-handed (score between −9 and +9), and 43 were right-handed (score $>+9$). In the control group, seven participants were left-handed, one was mixed-handed and 32 were right-handed. There were no significant differences between the patient and control group with respect to age ($t(88) = 0.04$), education ($t(88) = 0.83$), or handedness ($t(88) = 0.82$).

Lesions were classified on the basis of the description of the CT or MRI data by an experienced neuroradiologist. Twenty-eight patients had an infarct in the LH, 16 in the RH, and six had BIL lesions. The cerebral cortex was affected in 45 patients, whereas in five patients the lesion was limited to subcortical areas. Of the patients with cortical lesions, 13 had frontal lobe lesions, 18 had a lesion in the temporal lobe (of which the hippocampus was affected in only one), 22 in the parietal cortex, and 18 patients had occipital lobe damage (note that one single patient can have lesions in multiple brain areas). Five patients had motor aphasia, but were able to communicate. Mean duration between the onset of the stroke and the time of testing was 26.2 months (S.D. = 22.1; range 5.2–92.8).

2.2. Materials and procedures

Standard neuropsychological tests were administered to the patient group only to obtain measures of overall cognitive impairment and general memory function. The 12-item short form of the Raven Advanced Progressive Matrices [50] served as a measure of non-verbal intellectual functioning. The Wechsler Adult Intelligence Scale (WAIS) [60] subtest Vocabulary was used as an estimate of premorbid verbal intelligence, and the subtest Digit Span as a measure of verbal working memory. The Rey Auditory Verbal Learning Test [51] was included to assess word-list learning. For these tasks, the percentage patients that could be classified as “impaired” was determined on the basis of the available