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Allocentric spatial memory in humans with hippocampal lesions

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Abstract

An immersive virtual reality (IVR) system was used to investigate allocentric spatial memory in a patient (PR) who had selective hippocampal damage, and also in patients who had undergone unilateral temporal lobectomies (17 right TL and 19 left TL), their performance compared against normal control groups. A human analogue of the Olton [Olton (1979). Hippocampus, space, and memory. *Behavioural Brain Science*, *2*, 315] spatial maze was developed, consisting of a virtual room, a central virtual circular table and an array of radially arranged up-turned 'shells.' The participant had to search these shells in turn in order to find a blue 'cube' that would then 'move' to another location and so on, until all the shells had been target locations. Within-search errors could be made when the participants returned to a previously visited location during a search, and between-search errors when they revisited previously successful, but now incorrect locations. PR made significantly more between-search errors than his control group, but showed no increase in within-search errors. The right TL group showed a similar pattern of impairment, but the left TL group showed no impairment. This finding

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implicates the right hippocampal formation in spatial memory functioning in a scenario in which the visual environment was controlled so as to eliminate extraneous visual cues.

Keywords: Immersive virtual reality; Allocentric memory; Hippocampus

1. Introduction

The hippocampus, as well as having a more general mnemonic role has been shown to be a key structure in supporting spatial memory, as indicated by a range of studies involving rodents (Aggleton, Hunt, & Rawlins, 1996; Morris, Garrud, Rawlins, & O'Keefe, 1982; O'Keefe & Burgess, 1996), non-human primates (Angeli, Murray, & Mishkin, 1993; Ono, Nakamura, Fukuda, & Tamura, 1991; Parkinson, Murray, & Mishkin, 1988; Rolls, 1999; Rolls & O'Mara, 1995) and humans (Burgess, Maguire, & O'Keefe, 2002; Morris, Nunn, Abrahams, Feigenbaum, & Recce, 1999; Morris & Parslow, 2003). The precise neural mechanisms supporting spatial memory have yet to be fully established, but one of the main theories is that spatial information is maintained in the hippocampus in the form of *Cognitive Maps*, which specify the directions and relative distances between locations in the environment (O'Keefe & Nadel, 1978; O'Keefe & Burgess, 1996). Spatial information is integrated into a viewer independent or allocentric representation and this is then maintained in long term memory. The allocentric representation contrasts with representing distances and direction specifically in relation to the body axis, termed egocentric memory, thought to be independent of hippocampal function.

In humans, spatial memory deficits have been found to occur following unilateral temporal lobectomy (TL), specifically when the operation is in the right hemisphere (right TL). This includes impairment in memory for location, as demonstrated in a landmark series of experiments by Smith and Milner (1981, 1989) in which participants were shown a layout of objects and subsequently had to place these objects from memory. More recently, this impairment has been found to be proportionately greater than that for recall or recognition of patterns or objects (Nunn, Graydon, Polkey, & Morris, 1999; Nunn, Polkey, & Morris, 1998) and to correlate with the degree of hippocampal damage (Graydon, Nunn, Polkey, & Morris, 2001; Nunn et al., 1999).

Many of the tasks used to initially to measure spatial memory in patients with hippocampal lesions have used static spatial arrays, with the possibility that spatial location can be encoded egocentrically, i.e. in relation to the bodily frame of reference. However, theories linking the hippocampus to spatial memory incorporate the notion of an allocentric representation (O'Keefe & Nadel, 1978; O'Keefe & Burgess, 1996; see also Neggers, Schölvinck, van der Lubbe, & Postma, 2005). Accordingly, some neuropsychological studies have used procedures in which the participant views three-dimensional arrays of objects or locations from different directions, or has to navigate through complex spatial environments (see: Burgess et al., 2002; Morris & Parslow, 2003). An early example of this is the development by Feigenbaum, Polkey, and Morris (1996) who showed a specific impairment in right TL patients on a computerized