Evidence of a topological map of the environment in the left inferior parietal lobule

P. Brotchie[1,2], S. Ip[3], G. Jackson[3]

[1]Brain Sciences Institute, Melbourne, Victoria, Australia, [2]MRI Department, Geelong Hospital, Geelong, Victoria, Australia, [3]Brain Research Institute, Melbourne, Victoria, Australia

Background

Spatial navigation is a vital function for the survival of most animal species. The human brain has evolved in such a way that navigation is performed effortlessly, usually at a subconscious level. The complexities involved in spatial navigation are therefore hidden from our awareness unless there is a breakdown of one or more components of the system. Clinical data from patients with various brain lesions provides valuable insights into the processes involved in navigation. Deficits in spatial navigation (called topographical disorientation) have been associated with lesions in at least three regions of the brain (Aguirre & D'Esposito, 1999). Clinical studies have identified the posterior cingulate and parahippocampus as being responsible for orientation and landmark identification respectively while the posterior parietal cortex integrates this information to allow identification of the location of landmarks relative to the subject. The importance of the hippocampus in navigational tasks in humans is more controversial. To understand the neural mechanisms underlying spatial navigation it is necessary to determine the computational processes required for this task. There are a number of computational models of vision based navigation systems in the robotics literature. These can be divided into those which generate topological maps of the environment and those which use map-less navigation. Since a topological map of space has never been discovered in the human brain, both map based and map-less models of navigation are biologically plausible. However, clinical observations of patients with posterior parietal lobe lesions causing egocentric disorientation have been attributed to damage to a cognitive map that represents space in an egocentric coordinate system (Stark et al., 1996). Support for a map of space within the parietal lobe also comes from single cell recordings of posterior parietal neurons in primates which demonstrate retinal receptive fields which are modulated by the animal's orientation to its environment, possibly representing a distributed topological map (Brotchie et al., 1995; Snyder et al 1998). Therefore, clinical data and neuronal recording data from primates provide some evidence for the existence of a topological map of the environment within the posterior parietal cortex. The purpose of this study was to attempt to detect the existence of such a map by causing perturbations in the subject's perceived spatial location. If an egocentric spatial map exists in the human brain, this perturbation in subject location would require the map to be updated, allowing detection by functional MRI.

Methods

Functional MRI data was collected on 10 subjects during the performance of a simplified navigation task consisting of the presentation of a single landmark within a 3D virtual environment. The task was presented as a delayed response task. After a delay of 3 to 6 seconds, the subjects were required to move to the target destination by pressing the button box. During training, the subject's initial location relative to the visual landmark was always the same (Figure 1A), creating a familiarity with that position within the virtual environment. However, during the recording of functional MRI data, the subject's initial position within the virtual environment was occasionally shifted in orientation by small amounts, between 10 and 45 degrees (Figure 1B). This required an adjustment in the response by the subject to accurately move to the target destination.

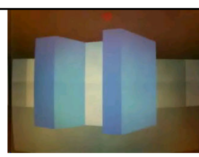


Figure 1A. Initial viewpoint for training and control task.

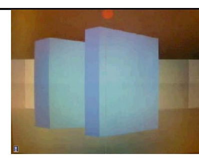


Figure 1B. Initial viewpoint for shifted landmark condition.

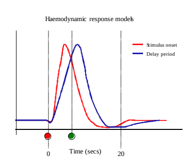


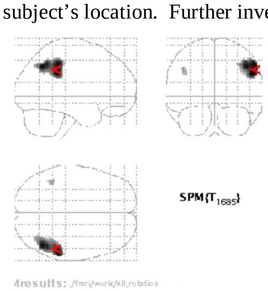
Figure 1C

The study was performed as an event related paradigm on a 3 Tesla GE scanner with BOLD sensitive echoplanar images acquired in the sagittal plane. Whole brain imaging was performed with a 128X128 matrix, 5mm thick slices and a repetition time of 2.5 seconds. Imaging data was analysed with SPM99 software (www.fil.ion.ucl.ac.uk/spm) using 2 separate models of the BOLD signal. The first model was a short event convolved with the canonical haemodynamic response function (hrf) in SPM99, aligned to the onset of each presentation of the visual landmark (Figure 1C, red dot). The second model was also aligned to the presentation of the landmark and convolved with the hrf, but the specified duration of the event was taken from the onset of the presentation until the cue to move (Figure 1C, green dot).

Results

Comparison of the shifted landmark condition with the control condition for the group of 10 subjects shows increased activation within the left inferior parietal lobule during the delay period of the task (Figure 2). The data demonstrated consistent activation within the left parietal lobe for both left and right finger press movements and left and right perturbations of the subjects location. The presence of this activation after perturbation of the subject's location within the virtual environment suggests that this may be the location of a topological map or cognitive map of the environment. If an egocentric topological map of the environment exists in the human brain, then this perturbation of the subject's location would require that the map be updated to allow for the change in position. The activity we observe in the left parietal lobe may well represent this updating of the topological map. However, another possibility is that the activity represents the subject's intention or plan to move towards the target. This motor plan would also need to be updated with perturbations of the subject's location. Further investigations will help differentiate between these possibilities.

Figure 2
Regions of significant activation for group data of 10 subjects comparing shifted landmark condition minus the control condition during the delay period of the task. A large area of activation is situated within the left inferior parietal lobule (red arrowhead) (p<0.05, corrected).



References

Aguirre GK & D'Esposito, *Brain*. (1999) 122:1613-1628.
Brotchie, P. R., Andersen, R. A., Snyder, L. H., Goodman, S. (1995). *Nature*, 375, 232-235.
Snyder L.H., Grieve, K.L., Brotchie P.R. and Andersen R.A. (1998) *Nature*, 394, 887-891.
Stark M, Coslett HB, Saffram EM. (1996). Cognitive *Neuropsychology*. 13:481-523.