Perception, memory, and action in frontal and parietal cortex

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Abstract

Visually guided behavior engages posterior parietal and lateral prefrontal cortex, yet the unique contributions of these brain regions are strongly contested. Recent experiments by Curtis and D’Esposito use fMRI to differentiate the roles of parietal and prefrontal cortex with respect to visual working memory and movement planning.

Main Text

The notion of functional specialization in the visual system has a long if not uncontroversial history (Trevarthen 1968; Scheider 1969; Ungerleider & Mishkin 1982; Goodale & Milner 1982). One current area of contention is the division of labor between posterior parietal (PPC) and lateral prefrontal cortex (PFC). Both are involved in visual-motor transformations, but is one inherently more “visual” and the other more “motor”? A functional imaging study by Curtis and D’Esposito (2006) shows that PPC and PFC perform a kind of dance during visual-motor behavior with first one area taking the lead and then the other. Their results suggest that PPC is more active during the encoding and storage of visual stimuli in working memory, but PFC becomes more active during response preparation and execution. These results lend support to the view that parietal cortex contains a general purpose visual map (Gottlieb et al 1998) while prefrontal cortex is more action oriented.

Curtis and D’Esposito’s experiment used a delayed response task that evoked activity in a region of the precentral sulcus likely to be the human frontal eye field (FEF), and a region in the intraparietal sulcus (IPS) likely to be the human equivalent of monkey lateral intraparietal area (LIP). Subjects were required to remember an array of four stimulus locations during an extended delay period. At the end of this delay, a cue identified one of the four locations as the saccadic goal. A second delay interval required the maintenance of the target location until a movement execution cue was given. IPS and FEF showed opposite patterns of BOLD activation during the two delay intervals. During the “visual memory” delay, activation was stronger in IPS than in FEF. However, during the “movement preparation” delay, the pattern of activation reversed. These results support the idea that neural activity in IPS is primarily...
influenced by the processing and storage of visual stimuli, while FEF is more heavily recruited during the preparation of the motor response. A previous study (Connolly et al. 2002) showed that motor set modulated activity in FEF but not IPS.

Other interpretations are possible, but the most likely of these are ruled out by the data. For example, one can imagine that during the first delay, subjects covertly prepare all four movements instead of (or in addition to) simply remembering the stimulus locations. In this case, one might infer that IPS is more closely involved in movement planning because it has the greatest activation during the first delay. This explanation can be rejected since IPS activation fell to baseline levels during the second delay despite the continued need for motor response preparation. FEF activation remained significantly above baseline. A reduction in the number of planned movements from four to one might account for the reduced activation seen in both FEF and IPS, but not the observed inversion in the relative strength of activation between the two areas.

The fact that the number of locations to be remembered changes once the target is cued raises the issue of whether an overall reduction in the level of BOLD activation between the first and second delays is due to response selection, per se, as opposed to the corresponding reduction in memory load. To address this, Curtis and D'Esposito looked for lateralized activation in IPS and FEF. It is well-known that the majority of neurons in the parietal and prefrontal cortex prefer contralateral stimuli and/or contraversive movements (Funahashi et al. 1990; Blatt et al. 1990). Because the initial stimulus array covered both visual hemifields, the first delay interval showed bilateral brain activity that was equal across the two hemispheres. However, after presenting the target cue, activity in the second delay interval became strongly lateralized in the hemisphere contralateral to the position of the target. The lateralized IPS activation was short-lived, but FEF activation was sustained and the degree of lateralization increased over time until the response was executed. Thus, the lateralization of activity in FEF increased even though there was only a single item in memory. More importantly, lateralized FEF activation just prior to the motor response predicted the direction of the eye movement; IPS activation did not.

Neurophysiological studies in monkey FEF and LIP support the visual-motor distinction. These studies have revealed neurons with visual, movement and mixed visual-movement activity (Bruce & Goldberg 1985; Andersen et al. 1990; Barash et al. 1991). Visual and visual-movement neurons are found in both areas (Chafee & Goldman-Rakic 1998), however pure movement neurons without visual responses are common in FEF but rare in LIP. Movement-related activity in parietal cortex tends to evolve slowly and is best demonstrated in delayed-response tasks. If monkeys are required to make an immediate “anti-saccade” (a saccade directed away from the visual stimulus) when a target
appears, FEF neurons are able to reliably signal the direction of the movement (Everling & Munoz 2000), but LIP neurons are not (Gottlieb et al 1999). Finally, while eye movements can be elicited by stimulating either FEF or LIP, stimulation thresholds in FEF are much lower than LIP (Bruce et al. 1985; Shibutani et al. 1984).

FEF and LIP are key components of a fronto-parietal network that is involved in spatial attention, working memory, and eye movements (Posner & Petersen, 1990). Different labs have come to almost diametrically opposed views on the role of parietal cortex in this circuit. One group has proposed that parietal cortex represents the attentional salience of visual objects (Goldberg et al. 2002), while others have emphasized its role in motor planning (Snyder et al 2000). The view that FEF is primarily “motor” has likewise been called into question by studies showing the involvement of FEF in attentional tasks (Moore et al 2003; Thompson et al. 2005). Electrophysiologically, FEF and IPS show as many similarities as differences. The value of the Curtis and D’Esposito study is that it clearly shows, at the level of fMRI, a movement planning signal in FEF that is not present in IPS, thus providing evidence for functional specialization in the fronto-parietal circuit.

References


Schneider GE (1969) Two visual systems: brain mechanisms for localization and discrimination are dissociated by tectal and cortical lesions Science 163, 895–902


