Journal Club

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Parcellating the Medial Frontal Cortex: Evaluative and Cognitive Components of Performance Monitoring

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Review of Taylor et al. (http://www.jneurosci.org/cgi/content/full/26/15/4063)

One of the hallmarks of human behavior is flexibility and a capacity to adapt to new situations. When external circumstances or internal goals change, behavior must be modified in such a way that new requirements are met. Cognitive control plays an instrumental role in overriding previously established and easily retrieved action patterns in favor of task-appropriate, yet novel and unlearned responses. As an example, imagine traveling from the United States or continental Europe to the United Kingdom. When crossing a street, you will now have to inhibit a highly overlearned and prepotent response to look first to the left, then to the right to initiate the appropriate opposite sequence of actions. Note that in this example, unchecked errors may have potentially disastrous consequences, highlighting the importance of cognitive control and error detection mechanisms in the real world.

There is now substantial evidence, mainly from functional magnetic resonance imaging (fMRI) and event-related potentials (ERPs) implicating the medial frontal cortex (MFC) as an important neural substrate of cognitive control mechanisms in the human brain (Ullsperger and von Cramon, 2004). Although activation of MFC is considered to be one of the most reliable neural correlates of cognitive effort, its functional significance is a matter of hot debate. Whereas initial evidence from ERP studies suggested that MFC [especially anterior cingulate cortex (ACC)] might serve as an error detector (Gehring et al., 1993), other experiments using fMRI indicated a broader function of this region in conflict monitoring (Carter et al., 1998). Furthermore, MFC activity might signify an emotional response to errors (Luu et al., 2003). Finally, substantial disagreement exists concerning the specific localization of activity within the region.

A recent study by Taylor et al. (2006) in *The Journal of Neuroscience* goes a long way toward resolving some of the open questions concerning MFC function. Using fMRI and an elegant experimental design, they were able to identify a region in MFC that selectively processes evaluative responses to errors. Furthermore, exhaustive analysis of the collected data based on single-subject results revealed surprising new insights into the localization of error- and conflict-related activations in MFC.

Taylor et al. (2006) presented subjects with strings of letters in which they were asked to identify the odd letter ("target") by either a right or left button press. To manipulate the degree of interference, distracter letters in a string could either be associated with the same ("low" interference) or opposite ("high" interference) button press. Crucially, the emotional valence of each trial was manipulated shortly before stimulus onset. In "gain" trials, subjects could win money if they identified the target within the deadline, whereas "loss" trials signified a financial penalty in case of incorrect response. Finally, during "neutral" trials, no money could be won or lost [Taylor et al. (2006), their Fig. 1 (http://www.jneurosci.org/cgi/content/full/26/15/4063/F1)]. Humans tend to avoid losses more than seek gains ("loss aversion"); thus, the authors reasoned that loss trials would be emotionally more engaging for subjects than gain or neutral trials. Unfortunately, only indirect evidence is provided in support of their logic. The majority of participants reported having tried harder on incentivized compared with neutral trials, and some subjects confirmed that they spent more effort on loss than gain trials. To ensure that loss-related errors did indeed elicit affective responses in subjects, physiological measures such as skin conductance should be reported.

For the purpose of data analysis, Taylor et al. (2006) subdivided the medial frontal cortex into three areas: posterior MFC (corresponding roughly to the pre-supplementary motor area (pre-SMA) and parts of dorsal ACC), mid-MFC (situated in the dorsal ACC) and rostral ACC (rACC) [Taylor et al. (2006), their Fig. 3*a–c* (http://www.jneurosci.org/cgi/content/full/26/15/4063/F3)]. To identify brain regions processing affective reactions to errors, activation attributable to loss errors was contrasted with hemodynamic responses after neutral trials. This strategy revealed a focus in the rACC that was not activated for "failure-to-gain"

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errors [Taylor et al. (2006), their Fig. 3*a*,*b* (http://www.jneurosci.org/cgi/content/full/26/15/4063/F3)].

To exclude a simple effect of motivation in rACC (remember that several subjects reported trying harder when an incentive was given), Taylor et al. (2006) compared correct and erroneous loss trials and confirmed that rACC was activated stronger after errors. Furthermore, they identified an area in mid-MFC that was activated stronger for incentivized correct responses (gain or loss) than for successful target identification on neutral trials [Taylor et al. (2006), their Fig. 3*f* (http://www.jneurosci.org/cgi/content/full/26/15/4063/F3)]. Such an activation pattern would be expected for brain regions associated with enhanced effort exerted during trials in which money could be won or lost. While rACC and mid-MFC seemed to be concerned with the emotional and motivational aspects of the experimental paradigm, posterior parts of the medial frontal cortex showed an altogether different pattern of activation. Although a cluster in the vicinity of pre-SMA also responded to errors, this region was much more active during the high interference condition (when target letters were incongruent to the distracters) compared with low interference trials. Moreover, posterior MFC activation was not contingent on incentive condition [Taylor et al. (2006), their Fig. 4 (http://www.jneurosci.org/cgi/content/full/26/15/4063/F4)]. Both error commission and high interference trials present instances of increased cognitive conflict. It therefore seems reasonable to assume that the pre-SMA cluster corresponds to a conflict monitoring module previously identified in ACC (Carter et al., 1998).

By devising an experimental paradigm that aimed at assessing subjects' affective responses, their motivational state, and the cognitive load of the task, Taylor et al. (2006) established that MFC, far from being a functionally homogenous structure, contains several distinct cortical modules. Their evidence suggests that although dorsal aspects are involved in cognitive components of performance monitoring, more rostral parts play a role in evaluative aspects of behavior.

These results, however, do not explain why several previous studies using cognitive interference tasks have reported activation foci that differ significantly from each other in their location along the dorsal–rostral MFC axis. To approach this issue, Taylor et al. (2006) evaluated activation maps of single subjects, rather than just the averaged group results. Amazingly, they found that individual foci for errors extended over the whole range of medial frontal cortex, clustering somewhat in dorsal and rostral parts [Taylor et al. (2006), their Fig. 5*b* (http://www.jneurosci.org/cgi/content/full/26/15/4063/F5)]. Correspondingly, subject-level analysis for cognitive conflict (high vs low interference) also revealed a substantial variability in cluster location, although more limited to the posterior part of the MFC [Taylor et al. (2006), their Fig. 5*a* (http://www.jneurosci.org/cgi/content/full/26/15/4063/F5)]. These striking results immediately suggest that discrepancies in the localization of error- or conflict-related processes between previous studies may actually be attributable to differential clustering of subjects' activation in the different samples, yielding incompatible group results. Even more importantly, these results call into question the very idea of a consistent cortical localization of higher cognitive functions for different individuals.

To summarize, Taylor et al. (2006) provided conclusive evidence for a functional heterogeneity of MFC. Whereas rACC is more concerned with evaluative components of error commission, posterior parts of this brain region seem to be specialized for monitoring and resolving cognitive conflict. Furthermore, the authors showed a surprising degree of variability in conflict and error processing between different subjects. Understanding the factors influencing this variability will be a major goal for future neuroimaging studies.

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