fundamentally disrupts long-term potentiation is likely to have a profound effect.

Together, these papers provide the first experimental evidence that gene duplication and divergence have influenced the evolution of cognition. Of course, many genes generally affect any given cognitive trait, and some genes affect many traits. Given the complexity of behavior, some genes likely interact in non-additive ways, and considerably more work needs to be done to understand the complex neural intermediates between biochemical activity and behavior. Nonetheless, these two studies provide a powerful rubric for investigations into how genomic duplication events affected synaptic function and led to an expansion in cognitive complexity.

COMPETING FINANCIAL INTERESTS

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Parietal and prefrontal neurons driven to distraction

Behrad Noudoost & Tirin Moore

The ability to filter out distracting sensory information is crucial to adaptive behavior. A primate study finds that prefrontal cortex is more important than parietal cortex in that function.

Our behavior requires that we consistently and successfully discriminate between information that is relevant and information that would otherwise distract us from a particular goal. Whether that goal is shopping for the right tie while ignoring a sale on shirts, minding the road ahead while driving in a heavy storm or locating a friend in a crowd, our behavior depends heavily on filtering out distractors from a constant barrage of sensory stimuli. That we need to attend to some things and ignore others is clear. What is not clear is how the nervous system accomplishes this. We do know that a portion of the human population finds it much more difficult to filter out distractors. People with attention-deficit hyperactivity disorder, for example, are overly susceptible to perceptual interference from extraneous sensory stimuli[1], which may account in part for their increased risk of poorer educational achievement and underemployment[2]. But what underlies this impairment, at the level of neural circuitry, remains largely unknown. In this issue of *Nature Neuroscience*, Suzuki and Gottlieb[3] examine the relative contribution of neurons in parietal and prefrontal cortex to the suppression of distracting visual information.

The authors studied the activity of neurons in the lateral intraparietal area (LIP) of posterior parietal cortex and in prefrontal cortex (**Fig. 1**) of monkeys performing a task in which they were required to make eye movements to the location of a briefly presented visual target stimulus, following a delay period. Thus, the monkey had to remember the location of the transient target to correctly indicate, with its eye movement, where that target had been. Neurons in both parietal and prefrontal cortex are known to encode the remembered locations of targets in this task, and they tend to exhibit sustained spiking during the delay period[4]. To make the task more demanding, Suzuki and Gottlieb[3] presented a distractor (a stimulus identical to the target) during the delay period. The distractor could appear at a location near to the target or far from it, and could be presented soon after target presentation or long after it. As the authors expected, the distractor interfered with the ability of monkeys to correctly indicate the location of the target. Moreover, the interference was greatest when the distractor appeared nearer to the target location and closer in time to its appearance.

Next, the authors measured the visual responses of parietal and prefrontal neurons when either the target or the distractor stimulus appeared in the receptive field of a given neuron. In both cortical areas, the neuronal responses to targets were stronger than to distractors. This observation is consistent with many previous neurophysiological studies of these areas and is consistent with the response preference for attended stimuli observed among neurons throughout posterior visual cortex[5]. However, the authors also found that neuronal responses to distractors were considerably weaker in prefrontal cortex. Furthermore, in contrast with parietal responses, prefrontal neuronal responses were positively correlated with the rate of errors committed by monkeys in the task. Thus, the degree to which distracting stimuli drove the activity of neurons in this area predicted the degree to which monkeys were actually distracted by those stimuli. In addition, the authors observed that the response transient caused by distractors was not only much smaller in prefrontal cortex, but was largely independent of both distance and onset time relative to the target. In contrast, parietal responses to distractors were both spatially and temporally dependent. In short, the activity of prefrontal neurons more closely paralleled the behavior carried out by the monkey; these neurons encoded the identity and location of the target while conveying little information about irrelevant distractors.

Suzuki and Gottlieb[3] then went one step further and directly tested the causal contribution of parietal and prefrontal cortex to the filtering of distractors. In the same regions in which the recordings had been made, they infused small volumes of the $GABA_A$ agonist muscimol, thereby inactivating neuronal activity. As was consistent with the correlative neurophysiological evidence, they found that monkeys were much more distractible after inactivation of prefrontal cortex, whereas parietal inactivation only produced mild effects.

Evidence from human neuroimaging and monkey neurophysiological studies has implicated a parietal-frontal network of areas in the control of attention. One general shortcoming of this evidence is that it has not adequately addressed the relative contributions of parietal

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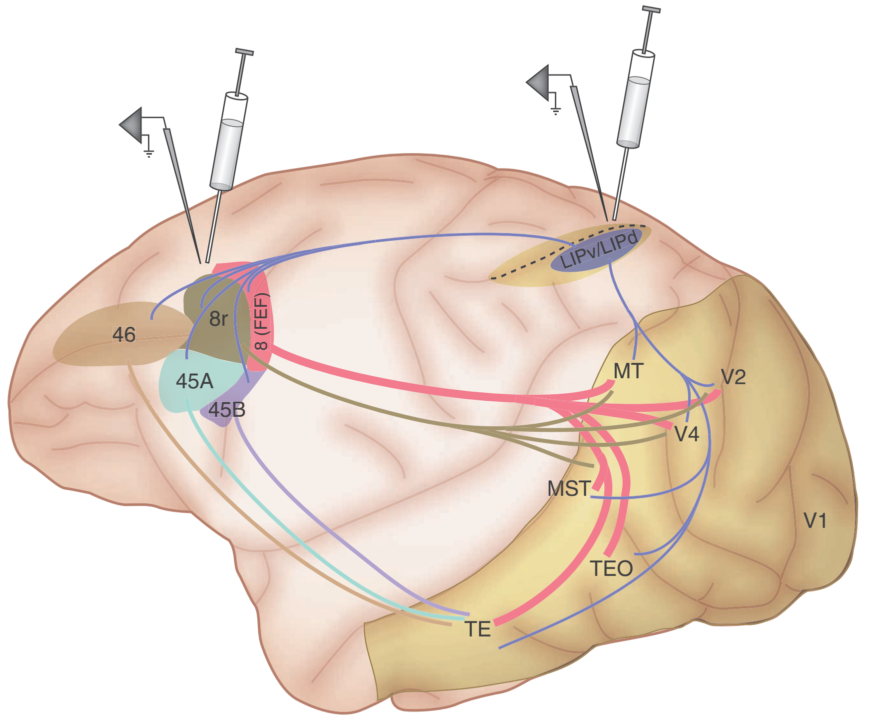

Figure 1 Electrophysiology and local inactivation of parietal and prefrontal cortex. The dorsal and ventral lateral intraparietal areas (LIPd and LIPv) in parietal cortex and areas of prefrontal cortex are shown on a lateral view of the macaque cerebral cortex. Major connections between LIP and prefrontal cortex, as well as parietal and prefrontal connections to major areas in posterior visual cortex are shown. Visual cortical areas beyond V1, including V2, V4, MT, MST, TEO and TE are indicated as examples. Suzuki and Gottlieb[3] studied the influence of visual distractors on the responses of LIP and prefrontal neurons and compared the effects of local inactivation of these areas on behavior. Prefrontal areas 46, 45A, 45B, 8r and 8 (FEF) are based on ref. 7.

and frontal areas to attentional control. Suzuki and Gottlieb's results[3] demonstrate a leading role of prefrontal cortex in the filtering of distractors and suggest that parietal cortex is less crucial for this specific aspect of attentional control. The results are particularly compelling given that both the neurophysiological and the inactivation effects were compared in the same experimental animals performing a single behavioral task. The parietal area studied by Suzuki and Gottlieb[3], LIP, is composed of two subdivisions, one dorsal (LIPd) and one ventral (LIPv), and recent evidence suggests that LIPv is the division most associated with attentional control[6]. Assuming that the parietal inactivations carried out by Suzuki and Gottlieb[3] included LIPv, the less pronounced deficits observed, compared to those found after prefrontal inactivation, provide the best evidence yet of a greater contribution of prefrontal cortex to attentional filtering.

The more prominent role of prefrontal cortex in distractor suppression evident in Suzuki and Gottlieb's study[3] is consistent with other recent studies that have begun to address how prefrontal areas directly influence sensory representations to select behaviorally relevant stimuli and filter out distracting ones. Prefrontal cortex includes a set of distinct areas with differing cytoarchitecture and patterns of connections with areas in posterior visual cortex[7]. Among these areas is the frontal eye field (FEF), which lies caudal to the region studied by the authors and is the prefrontal area most involved in the control of saccadic eye movements. The FEF is extensively and reciprocally connected with retinotopic areas in posterior visual cortex. As the authors note, the attentional influences of prefrontal cortex documented in past studies are mediated largely by the FEF, which is known to be necessary for attentional deployment[8] and appears to serve as the interface between prefrontal cortex and areas in extrastriate visual cortex[9] (**Fig. 1**). Indeed, FEF neurons also exhibit suppressed responses to distractors appearing both near and far from a remembered location[10]. More importantly, it has been shown that changes in FEF neuronal activity are sufficient to modulate visual responses in posterior visual cortex[11] and that this modulation includes both enhancement and suppression[12]. Thus, the region of the prefrontal cortex studied by Suzuki and Gottlieb[3] seems to operate in conjunction with, or perhaps via, the FEF to modulate posterior visual representations so as to select targets and filter distractors. One important goal of future work should be to begin parsing the relative contributions of prefrontal areas to selective attention.

Lastly, the observations of Suzuki and Gottlieb[3] also highlight an important, although poorly understood, fact about the control of attention: its conspicuous interdependence with mechanisms of working memory. In both parietal and prefrontal cortex, neurons encode the location of a visual stimulus even well after that stimulus is extinguished, provided that that stimulus is to be remembered. This persistent signal has classically been interpreted as a signature of visual working memory[13]. As in the present study, previous work has shown that neurons with working memory–related properties tend to be the same ones that best discriminate between targets and distractors[10]. Moreover, a recent study found that, in addition to their apparent function in working memory[14], dopamine D1 receptors also mediate the modulation of visual cortical activity by prefrontal neurons[11], and thus they appear to function in the prefrontal control of visual attention. Much remains to be determined, however, about how neural circuits that maintain sensory information in the absence of input may also be instrumental in reducing interference from distractors.

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