Multi-tasking of Attention and Working Memory Signals in Prefrontal Cortex

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We recorded the activity of 957 single neurons in the dorsolateral prefrontal cortex (PFdl) of two rhesus monkeys, as they performed an eye-movement task. On each trial of the task, a visual cue consisting of a white circle appeared initially either up, down, left or to the right from a central fixation point. The cue then revolved smoothly along a circular trajectory to another of these four positions and stopped. During the delay period that followed, the monkeys had to attend to the cue covertly in order to detect a subtle luminance change. Until that event, the monkeys had to maintain central fixation. Brightening of the cue instructed a saccade to its initial, remembered location; dimming instructed a saccade to the cue’s final, attended location. Thus the task required the monkey to remember one location while attending to another. The present analysis focused on understanding how these two locations are represented in PFdl.

A two-way ANOVA showed that firing rates during the delay period exhibited significant main effects of the remembered location, the attended location or both for 555 neurons (p ≤ 0.05). In agreement with our previous report [1], most of these neurons (70%, 390/555) exhibited a single main effect. Attention tuning occurred three times more frequently than memory tuning for this cell population, with greater depth of tuning as well. Attention-tuned cells were significantly more prevalent in lateral parts of PFdl, whereas memory tuned cells were concentrated more medially (p < 0.0001, χ² test) [1]. Thus, the cognitive operations of memory and attention for these cells tend to be relegated to separate neurons and to spatially segregated parts of PFdl.

In contrast to this overall tendency, 30% of the tuned neurons (165/555) exhibited main effects of both attention and memory. For these neurons, we calculated one preferred direction (PD) for memory and another one for attention by vector averaging the firing rates over the four remembered and attended locations, respectively. Surprisingly, most of the neurons with both main effects were not tuned to a single direction, but instead had large differences in their PD for memory versus attention. The PDs for memory and attention differed by more than 30° for 140 of the 165 neurons (85%) that showed both main effects. Close agreement, defined as less than a 30° difference, occurred no more frequently than expected for a uniform distribution of angular differences between two PDs. Most common were neurons with a memory PD that was nearly diametrically opposite their attention PD (differences of 150°–180°). This large difference was found in 57 of the 165 neurons exhibiting both main effects (35%), more than twice as many as expected for a uniform distribution. Thus, during the delay period, some PFdl neurons discharged when the cue had initially appeared near its memory PD or stopped near its attention PD — and these directions were often opposite one another.

These results indicate that, although most PFdl neurons process attentional or mnemonic signals almost exclusively, other neurons contribute to both of these cognitive operations. Such cognitive multitasking represents an efficient way of encoding and distinguishing between different executive processes within a neural network of fixed resources.