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COGNITIVE NEUROSCIENCE

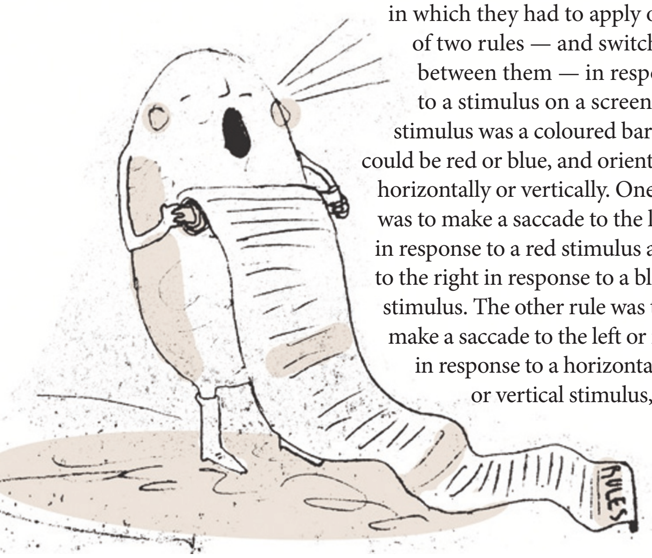
Rules of neural engagement

> “beta-synchronization of LFPs between pairs of electrodes changed in a rule-specific way”

Our behaviour is guided by rules, at least most of the time. Of course, different rules apply at different times, and the prefrontal cortex (PFC) has a major role in selecting the relevant rule at any particular moment and directing behaviour accordingly. Miller and colleagues now show that, in monkeys, neuronal synchronization in the dorsolateral PFC may support this function.

Single-neuron recordings in monkeys have indicated that multiple PFC neurons can encode the same rule and that individual PFC neurons can encode multiple rules. This suggests that neuronal ensembles reflecting different rules may dynamically form and dissolve according to which rule applies. As synchronization of local neuronal oscillations has been proposed to promote communication between neuronal ensembles, Miller and colleagues investigated whether they play a part in rule selection.

Monkeys were trained in a task in which they had to apply one of two rules — and switch between them — in response to a stimulus on a screen. The stimulus was a coloured bar that could be red or blue, and orientated horizontally or vertically. One rule was to make a saccade to the left in response to a red stimulus and to the right in response to a blue stimulus. The other rule was to make a saccade to the left or right in response to a horizontal or vertical stimulus, respectively. The colour around the border of the screen indicated whether the ‘colour rule’ or the ‘orientation rule’ applied in the upcoming trial.



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Monkeys performed the task with high accuracy. Their reaction times increased after a switch from the orientation rule to the colour rule but not the other way around, suggesting that the orientation rule was dominant. Neuronal recordings from the dorsolateral PFC revealed that most neurons preferentially fired in response to a particular rule and/or a particular stimulus.

Recordings of local field potentials (LFPs) in monkeys performing the task showed that beta-synchronization of LFPs between pairs of electrodes changed in a rule-specific way. Some pairs of electrodes showed stronger beta-synchronization during colour rule trials, but more pairs increased beta-synchrony during orientation rule trials. This suggests, like the behavioural data, that the orientation rule was dominant.

The LFP measurements revealed two neuronal assemblies that showed increased beta-coherence during the colour rule (the ‘colour rule assembly’) and during the orientation rule (the ‘orientation rule assembly’), respectively. Importantly, these assemblies partially overlapped: an electrode that increased LFP beta-coherence with a set of electrodes during the colour rule could increase coherence with another set of electrodes during the orientation rule.

In addition, the authors showed rule-dependent coherence between spiking in individual cells and the LFP during the task. For example, during orientation rule trials involving a blue stimulus, neurons with a preference for that colour beta-synchronized their activity with the orientation rule assembly, whereas in colour rule trials the same neuron would be synchronized with the colour rule assembly.

The authors also found rule-dependent alpha-coherence changes: electrode pairs that increased alpha-coherence mostly did so in colour rule trials. Interestingly, this alpha-synchrony was observed only in the orientation rule assembly. Alpha-synchronization has been proposed to reflect inhibition of irrelevant processes; in this study, increased alpha-synchrony within the orientation rule assembly during colour rule trials may reflect de-selection of this assembly, allowing the neurons relevant to the colour rule to dominate. Indeed, alpha power correlated with activity of colour-preferring neurons, but not orientation-preferring neurons, during colour rule trials.

Last, the authors showed that rule-selective alpha- and beta-coherence inversely correlated with reaction time (that is, the time from stimulus presentation to saccade), suggesting that they may have functional relevance in rule-based tasks.

It has been proposed that neuronal synchronization supports the flexible linking of task-relevant neurons during sensory processing and attention. The new study suggests that this may also be the case in high-level cognitive processes such as rule selection.

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ORIGINAL RESEARCH PAPER Buschman, T. J. *et al.* Synchronous oscillatory neural ensembles for rules in the prefrontal cortex. *Neuron* **76**, 838–846 (2012)