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Time Cognition: Entangled Neuronal Firing

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The neuroscience of time frequently focuses on either measuring short time intervals (sensory timing) or reproducing them (motor timing); during cognition, the two are integrated. New experiments using a combined sensory and motor timing task suggest that neuronal firing during the sensory and motor phases are linked.

Time is ubiquitous in cognition, but the neural basis for time-dependent cognition is poorly understood. Neuroscientific studies have tended to break the problem down into its constituent parts. Hence, experiments usually focus either on sensing time (sensory timing) [1] or on motor tasks that require reproduction of time intervals (motor timing) [2]. Optimal cognitive function, however, requires that sensory and motor timing are integrated. A new study [3] reported in this issue of *Current Biology* provides an insight into how this might occur.

Jazayeri and Shadlen [3] recorded the firing of neurons in the lateral intraparietal area (LIP) of monkeys, while the monkeys performed a combined motor and sensory timing task. In the task, which they call Ready, Set, Go (RSG), the monkey first has to measure a sample time interval. The measured time interval begins and ends with light flashes termed the Ready cue and the Set cue respectively. The monkey then has to reproduce without delay the time interval that it has just measured. Accordingly, the production phase starts with the Set light cue and terminates when the monkey makes a self-initiated saccade (Go) to a visual target area. The sample time interval that has to be measured is varied during trials of the task. The durations of the sample time intervals are coprime, that is, their highest common factor is one. This makes it harder to perform the task like a clock by mentally tapping out a faster rhythm and counting the beats.

Jazayeri and Shadlen [3] found that the firing rate of LIP neurons of their subject monkeys followed a relatively stereotyped sequence during the task. Firing rates decreased after the Ready cue and then slowly increased towards the end of the measurement phase. A difference in firing rates was only evident at the end of the sample interval. This arose because longer sample time intervals allowed more time for the firing rate to increase.

The task was then switched from measurement to production. The firing rates of LIP neurons was seen to dip briefly during the early part of the production interval, reaching a nadir approximately 100 ms after the Set cue, and then to increase rapidly. The increase in firing rate is commonly referred to as ramping [4,5]. The firing rates of LIP neurons converge during the dip and become the same irrespective of the sample time interval. Firing rates diverge after ramping activity is well established. Importantly, the rate of increase in firing rate is slower for longer production intervals. Jazayeri and Shadlen [3] refer to this acceleration of firing during the ramping activity as the build-up rate. The firing rate of LIP neurons continues to build up until a plateau firing rate is reached and a saccade is initiated.

Jazayeri and Shadlen [3] focused their analysis of the firing rate dynamics on time windows when the firing rates are different. Hence, for the measurement phase, they concentrated on the period around the Set cue (±50 ms). For the production phase, the analysis concentrated on the period when the build-up rate differs (500 to 200 ms prior to the saccade). Two key findings emerged. Firstly, the firing rate around the Set cue correlated with the measured time interval. Secondly, the build-up rate was inversely correlated with production interval.

The first sign that firing during the sensory and motor phases of the task might be linked came from the finding that the firing rate around the Set cue — that is, during the measurement phase — was inversely related to the build-up rate during the production phase. This result is not surprising, however, as the measured time interval and production time interval were supposed to be the same during the task. Therefore, Jazayeri and Shadlen [3] took their analysis one step further: rather than look at average firing rates, they analysed firing rates during individual trials. Importantly, error in the measurement phase of the task was associated with a similar error in the production phase. These data provide stronger evidence that neural firing during the sensory and motor components of the task are related on a trial-by-trial basis.

LIP firing has been implicated in several cognitive functions, such as attention [6]. Hence, it is possible that the LIP firing is a consequence of the attentional demands of the task. Jayazeri and Shadlen [3] addressed this issue by training the monkeys to perform a second task, which they refer to as Ready, Go (RG). In this task, the monkey has to make a saccade after a fixed time interval following the Ready light cue. The RG task incorporates the Set light cue. Hence, the monkey is exposed to the same sensory cues and has to make the same saccade in both the RG and RSG task. The difference is that, in the RG task, the monkey does not need the Set cue to perform the task. The prediction would be that, if the LIP firing rate dynamics are driven by the attention to the sensory cues and preparation for the saccade, then the firing rate dynamics should be similar in the RSG and RG tasks. The authors found that they were different and concluded that the attention to the sensorimotor features of the task

did not explain the firing rate dynamics in the RSG task.

How can the data be explained? Jazayeri and Shadlen [3] modelled a number of possibilities to find out which system best accounts for observed firing rate dynamics of LIP neurons. The alternatives included anticipation of events that could drive LIP firing, for example, anticipation of the Set cue, anticipation of reward for completing the task accurately, or anticipation of the expected time of reward. Another possibility was that LIP firing reflected a Bayesian estimate of the sample time interval. The model that best explained the data, however, was one based on their analysis of the firing rate dynamics and referred to as 'preplanning'. In this model, the firing rate around the Set cue is tied to the build-up rate during the production interval.

This led to the proposal that the firing rate of LIP neurons during the measurement phase encodes information that is used to reproduce the time interval. Essentially, this means that information is not only encoded about the sample time interval during the measurement phase. Information is encoded too about a motor reproduction of the sample interval to be performed in the near future. Hence, Jazayeri and Shadlen [3] propose that there is a direct link between sensory and motor timing that is set up during the sensory phase of the RSG task.

How might this work? A simple explanation would be that both the sensory and motor information remained stored in the firing of the LIP neurons. Jazayeri and Shadlen [3] found, however, that the firing rate of LIP neurons equalizes soon after the beginning of the reproduction phase. So, it is not clear how firing rates could continue to store information needed to complete the reproduced time interval. It remains possible that the information is stored in LIP neurons in another form. Alternatively, information about reproducing the time interval may not be stored in LIP neurons and, hence, may need to be imported when needed. Further experiments will be needed to elucidate these issues.

Jazayeri and Shadlen's [3] study shines some light on the neural basis for how perception of time is integrated with our actions. Their work propels us on the way to an understanding of the neural basis perception of time and how time can contribute to dynamic adjustment of activities, which benefit from rhythm, such as dancing and speech.

REFERENCES

1. Leon, M.I., and Shadlen, M.N. (2003). Representation of time by neurons in the posterior parietal cortex of the macaque. Neuron *38*, 317–327.
2. Medina, J.F., Carey, M.R., and Lisberger, S.G. (2005). The representation of time for motor learning. Neuron *45*, 157–167.
3. Jazayeri, M., and Shadlen, M.N. (2015). A neural mechanism for sensing and reproducing a time interval. Curr. Biol. *25*, 2599–2609.
4. Maimon, G., and Assad, J.A. (2006). A cognitive signal for the proactive timing of action in macaque LIP. Nat. Neurosci. *9*, 948–955.
5. Merchant, H., Harrington, D.L., and Meck, W.H. (2013). Neural basis of the perception and estimation of time. Annu. Rev. Neurosci. *36*, 313–336.
6. Bisley, J.W., and Goldberg, M.E. (2010). Attention, intention, and priority in the parietal lobe. Annu. Rev. Neurosci. *33*, 1–21.

Insect Olfaction: Telling Food from Foe

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The same sensory signal can be interpreted differently according to context. A new study in *Drosophila* uses cell-type-specific tools to identify neural circuits that integrate context during olfactory processing and surprisingly implicates memory-recall neurons.

For an olfactory driven creature like a fruit fly, living in a cluttered and smelly world, the ability to classify odors into meaningful percepts is crucial. Objects may have overlapping odor profiles despite possessing vastly different values for the insect. For the fruit fly, CO_2 can signal either food or danger, as it is both a by-product of yeast respiration and an avoidance signal produced by stressed adults [1]. In order to choose the appropriate behavioral response, whether to feed or flee, the fly brain must thus somehow take into account the context and modify CO_2 processing accordingly. But how does such contextual modulation of behavior work on a circuit level? The impressive neurogenetic arsenal of *Drosophila melanogaster* makes it possible to answer this question and crack the circuits involved. In a recent *Current Biology* paper, using a combination of precise neuronal manipulations, *in vivo* imaging and behavioral experiments, Lewis *et al.* [2] build on previous work to map out the neural substrates of how the fly distinguishes food from foe.

The fly olfactory system is one of the best-characterized sensory model systems and ideal to study context-dependent sensory processing. Olfactory

