How does the brain keep track of time?

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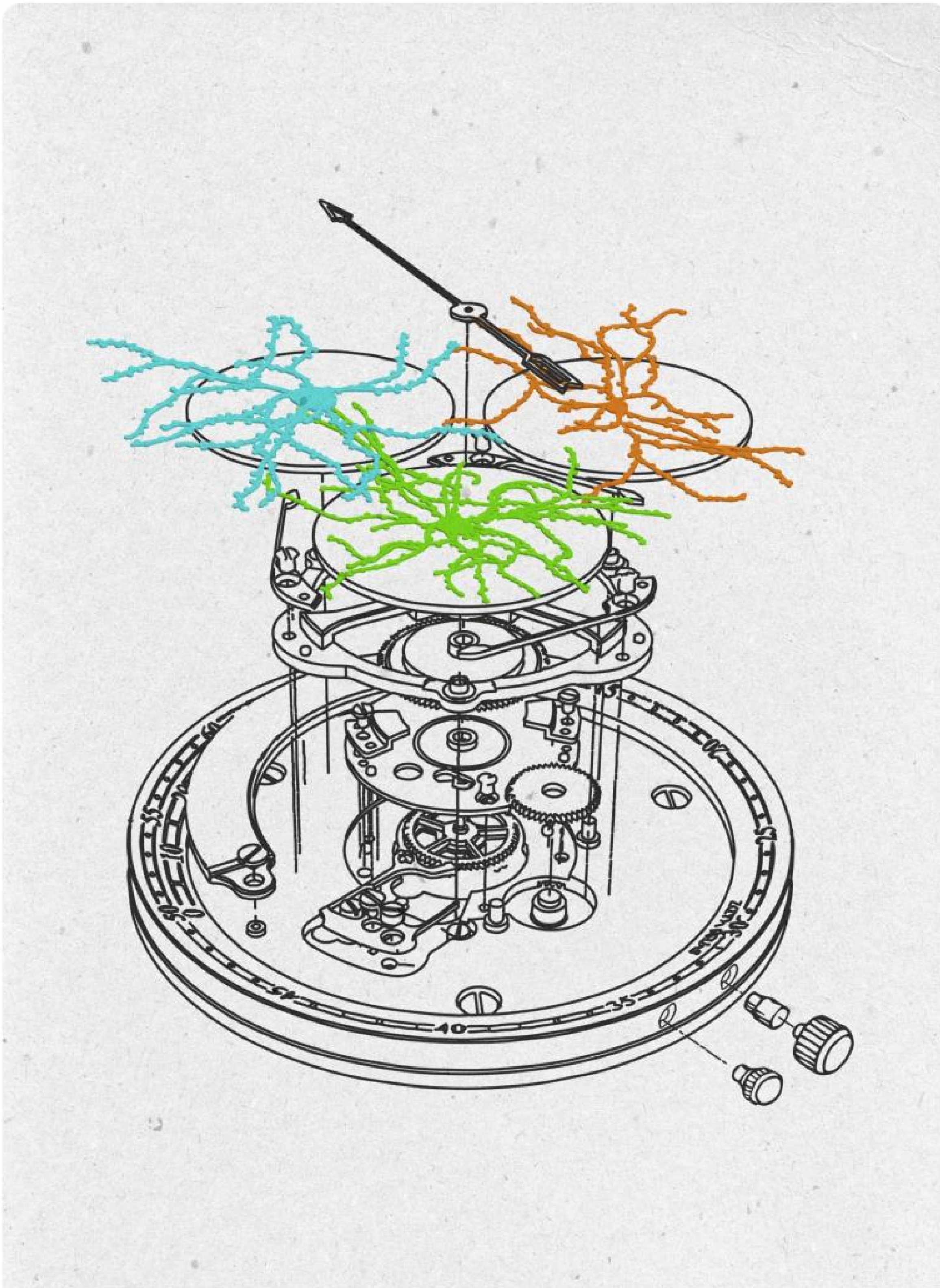

Scalable population code for time in the striatum. Credit: Gil Costa

You are driving to work, late for an important meeting. You are almost there when you have to stop at a red light. When will you begin inching forward? Doing it too early will result in wasting gas and energy, but doing it at the right time will get you to work faster. Estimating the right moment to perform an action critically depends on our innate ability to track time. What is the neural mechanism that underlies this capacity?

"We know that for actions to have successful outcomes, the brain has to keep track of time", says Dr. Joe Paton, head of the Learning Lab at the Champalimaud Neuroscience Programme. "Time is implicit in nature, difficult to tease apart from the on-going behavioural and sensory context, which makes studying it quite challenging."

To pin down this elusive quantity, the researchers focused on a brain region called the Striatum. "Many lines of evidence implicate the striatum as a site of timing information", says Dr. Paton, "as many conditions that affect the striatum, such as Parkinson's and Huntington's disease, result in timing dysfunction."

Gustavo Mello, a graduate student in the lab explains how they tested timing behaviour in rats: "The rats performed a timing task where they had to press a lever to receive a reward, which was available periodically. For example, during a sequence of 15 trials, the reward would only become available after 30 seconds had passed since the last reward. To see whether the rat would be able to estimate different durations, after those 15 trials, the waiting time would change randomly to be either shorter, or longer."

The researchers found that the rats changed their behaviour according to the different waiting times. "Similarly to how we would behave when waiting at a red light, the rats also seemed to prefer not to waste their energy and pressed the lever only when enough time has passed", says Mr. Mello.

To find out what is the neural basis that underlies this behaviour, the researchers recorded the activity of individual neurons in the striatum while the rats were performing the task, finding that the representation of time was coded across the population of neurons. "We found that each time a trial started, the neurons responded in a slow but reliable wave of sequential activity," says Sofia Soares, a graduate student in the lab. "The sequence was conserved across different waiting durations, but changed its timing. In other words, when the waiting time was longer, the sequence was slower and vice versa. Hence, the sequence was shrinking and expanding in a way that corresponded to the current interval between rewards and the behaviour of the animal. You could essentially just look at the location of the wave within the population to read out how much time had passed."

What does the shrinking and expanding of the sequence mean about the way the brain keeps track of time? According to Mr. Mello: "The implication is that time in the brain is relative, not absolute, as it is measured as a position within an interval and not as a unit, such as a second, or an hour."

"This is the first time the full diversity of response dynamics in the striatum was considered during a timing task", concludes Dr. Paton, "allowing us to demonstrate that populations of neurons encode time in a manner that is consistent with timing behavior. In addition, we found that the neurons combined motor and timing information. This composition of time and actions is consistent with motor learning and action selection, functions in which the striatum plays a critical role."

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