Revealing the neurological basis of time perception

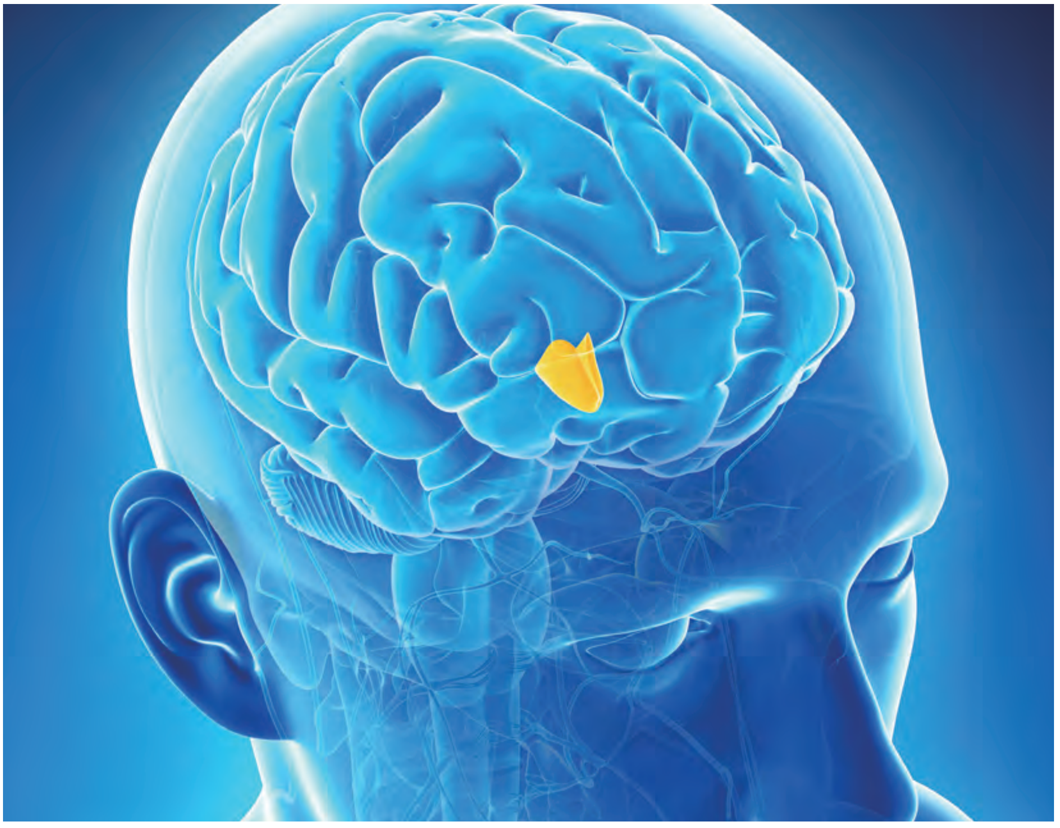
Time that is represented by linearly changing neuronal activity on a logarithmic scale

Single neuron recordings revealed that neurons in rat prefrontal cortex conveyed temporal information based on linearly changing neuronal activity on a logarithmic scale. This finding can explain why the precision of time interval discrimination is lowered in proportion to the elapse of time according to Weber's law.

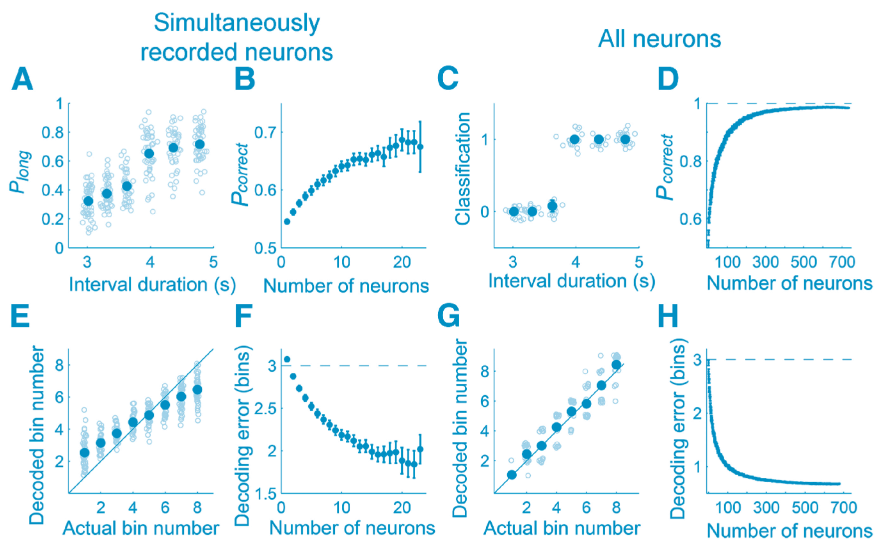
Humans and animals are capable of representing temporal and spatial information and using them for guiding behavior. We now know a great deal about the neural basis of spatial information processing; the brain has sophisticated neural processes for encoding egocentric as well as allocentric spatial information. On the contrary, we know very little about neural processes underlying keeping track of time in the range of seconds to minutes (interval timing). Our ignorance of the neural basis of interval timing is in stark contrast to its importance for understanding the neural basis of diverse cognitive processes. It is increasingly clear that interval timing is an integral part of a broad range of psychological processes such as working memory and decision making.

As an effort to reveal neural processes underlying interval timing, we examined neuronal activity in the prefrontal cortex in rats performing a temporal discrimination task. We have shown previously that lesions to the prefrontal cortex profoundly impair animal's ability to discriminate time intervals in the same task. Many recorded neurons conveyed temporal information based on monotonically changing activity profiles over time with negative accelerations, so that their activity profiles were better described by logarithmic than linear functions. Moreover, the precision of time interval discrimination based on neural activity was lowered in proportion to the elapse of time, which is well accounted for by logarithmic, but not by linear functions. Behavioral studies in animals and humans have shown that the precision of time interval discrimination is lowered in proportion to its duration, which is consistent with Weber's law, and there have been intensive debates regarding linear vs. logarithmic time encoding for the past 30 years. Our results show clearly that logarithmic time encoding is at least one way of representing time in the brain, which might be the reason why time perception follows Weber's law.

Because the process of perceiving circadian rhythm and weather rhythm in animals has been fully revealed, we know that the suprachiasmatic nucleus (SCN) in the pituitary gland has an important role in the process. However, the perception of the flow of time itself has been rarely studied.

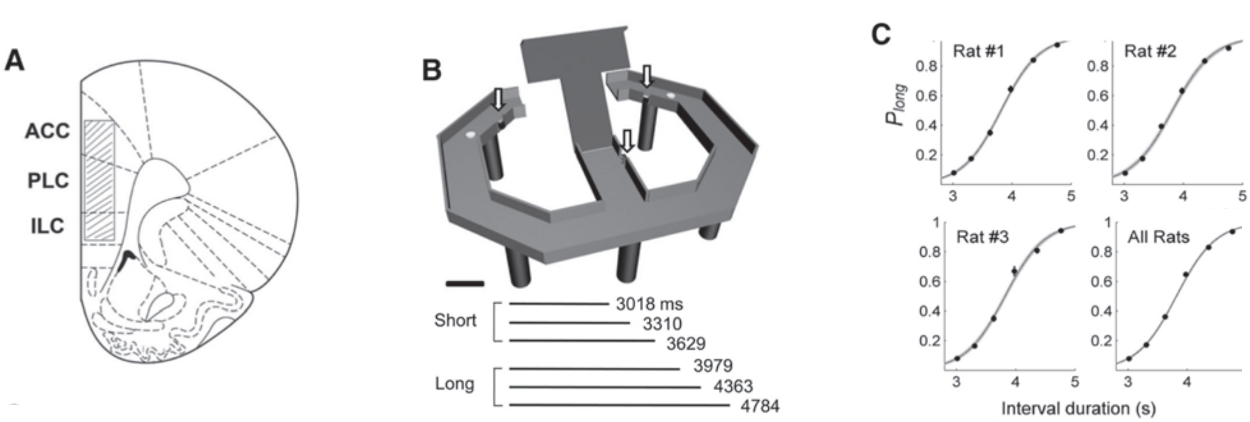


We hope that our findings will be helpful for elucidating neural mechanisms underlying diverse cognitive processes, such as working memory and decision making, and various neuropsychiatric diseases, such as schizophrenia and attention deficit hyperactivity disorder, that are associated with abnormal time perception. Although our results provide clear evidence for logarithmic encoding of time, they by no means indicate that logarithmic encoding is the only way of representing time in the brain. We cannot exclude the possibility that linear time encoding is employed in other brain structures or in the prefrontal cortex during different behavioral tasks. It remains to be determined in future studies whether the brain keeps track of the elapse of time based on exclusively logarithmic time encoding or both linear and logarithmic time encoding.

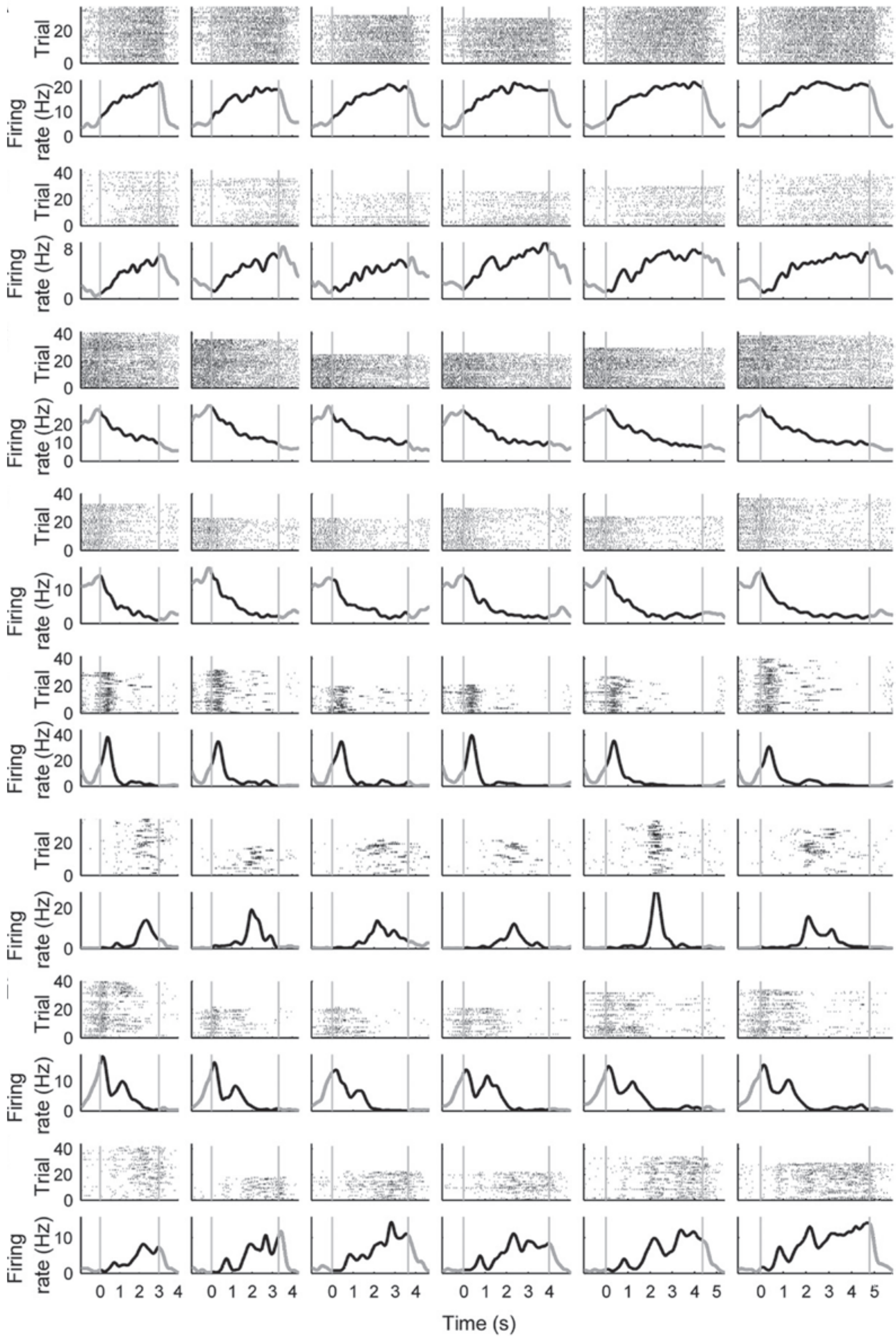


The main data of experiments performed by the IBS Center for Synaptic Brain Dysfunctions to identify the mechanism of the perception of time. This represents the relationship between the signal in the prefrontal cortex and the flow of time.

An overview of the experiment. In rats performing a temporal discrimination task (B), the neural signals coming from each region of the rat's brain (A) were recorded. By combining the resulting data with the data on the rat's behavior (C), the relationship between the activation of neural signals and the perception of time has been identified. The measurement of neural signals was performed at 3 regions, which are the anterior cingulate cortex (ACC), prelimbic cortex (PLC) and infralimbic cortex (ILC).



Data from the rat's prefrontal cortex. This shows the gradually reduced neural signals over time.



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