Identification of Temporal Context Cells in Macaque's Precuneus

(猕猴楔前叶中时间背景细胞的存在性验证)

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Introduction

Based on electrophysiological data, this research aims to identify the existence of temporal context cell-a group of neurons that response to time with a specular firing pattern.
这项研究以电生理数据为依据，旨在验证猕猴楔前叶是否存在一类特殊的神经细胞，这类神经细胞以一种特殊的放电模式响应时间，从而参与猕猴情景记忆的编码。

Background

Episodic memory can be decoupled into the information of three dimensions: when , where, and what. It remains controversial so far that how brain encodes the temporal information and fom the representation of time.

情景记忆可以被解耦成时间，地点，事件内容等三个维度的信息。长久以来，学界对于大脑如何编码、表征时间信息并无统一结论。

Time Cell (时间细胞)

The Hippocampal time cell is a specific type of neuron. These cells are widely distributed in the hippocampus, and are each tuned to certain points in a span of time with some firing. In some sense, they bridge time gaps between disparate experiences, and the diverse firing pattern of each time cell reflects the duration from the onset of some stimulation.

海马时间细胞是一种特殊的神经元，这些细胞广泛地分布在海马体中，各自调谐在某个时间点放电。他们填充了相邻经历间的时间空隙，并且通过不同的放电模式反应刺激发生的时间。

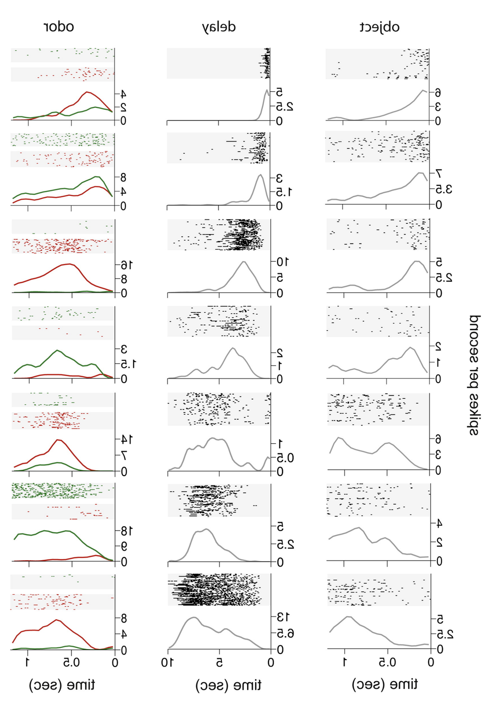

Figure1. Hippocamal time cells

Mathematical Models of Timing Mechanism by Howard and Shankar (计时机制的数学模型)

A theoretical model to explain how the brain might in theory encode time indirectly has been put forward by Howard and Shankar. This model predicts that there exists a group of time receptive neurons, which will be activated (inhibited) immediately once some event happens, and then decay (rise) to the baseline with different rates. In this process, the brain maps temporal information of that event to some intermediate representation by Laplace transform. Afterwards, the brain can map the intermediate representation back into the time cells by inverse Laplace transform.

霍华德和尚卡尔提出了一种大脑间接编码时间的理论模型。这一模型预测，存在一种时间感受细胞，他们会在事件发生时被立即激活，并以不同的速率衰减。在这一过程中，时间信息以拉普拉斯变换的方式被映射到一层中间表征上。之后，时间细胞由此可以将这个中间表征映射回来，以形成时间体验。

The existence of time cells has been widely verified. It is until recently, however, that scientists have experimentally verified the existence of time percetive neurons, and named them temporal context cell.

时间细胞的存在已经被广泛地证实，然而，科学家最近才实验性地验证了时间感受细胞的存在，并把他们命名为时间背景细胞(temporal context cell)。

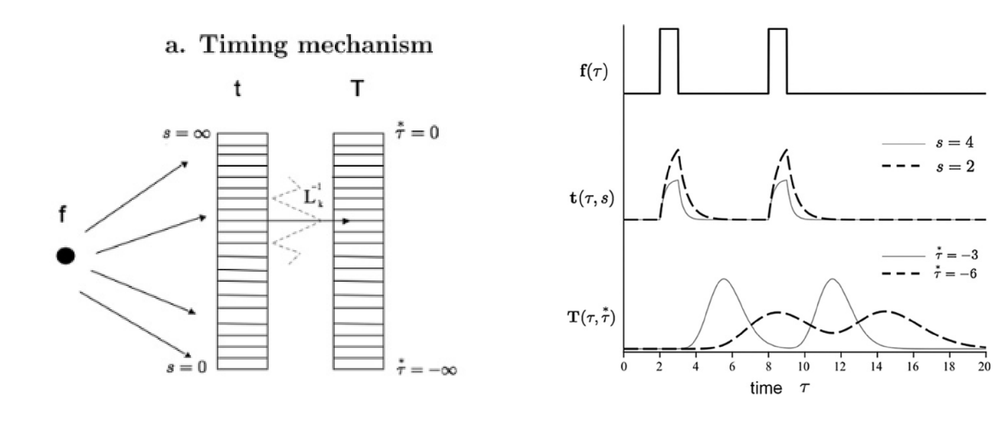

Figure2. A. Illustrations of timming mechanism B. firing patterns of temporal context cells and time cells.

Temporal Context Cell （时序背景细胞）

Temporal context cells was firstly identified in lateral entorhinal cortex, but predictably, temporal context cells might be widely distributed in the brain due to its close connection with time cells. Our main work is to identify the existence of temporal context cell in the precuneus of macaque's brain.

尽管时间背景细胞最初在猕猴的外侧内嗅皮层中被发现，可以预见的是，由于与时间细胞的密切联系，时间背景细胞可能更广泛地存在于大脑中。我们的主要工作就是通过分析电生理数据来验证时间背景细胞在猕猴楔前叶的存在。

Methods

Head-fixed monkeys performed naturalistic free viewing of video clips of 8 seconds, and finished the TOJ task. The neuron activity of macaque's precuneus was recorded at the single neuron level in this process.

头部固定的猕猴观看时长为8s的视频片段，之后完成TOJ任务。同时在单神经元水平上记录猕猴楔前叶部分神经元的活动。

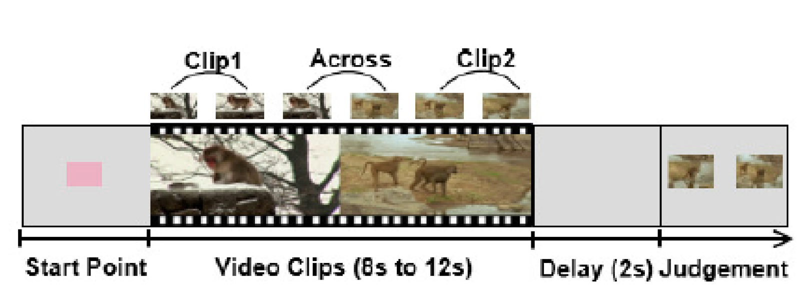

Figure3. Experimental Procedure

Data Analysis

Data Acquisition (数据获取)

We analyze electrophysiological data extracted from two monkeys when watching video clips. We obtained the spike data of overall 676 neurons (401 from Jupiter and 275 from Mercury)

Nested Model Fitting (嵌套模型拟合)

We calculated model fits of nested models for each neuron across all trials via a maximum Likelihood estimation

- constant model: $F_{const}(t; a_0) = a_0$
- Gaussian model: $M_{gauss}(t; a_0, a_1, \sigma, \mu) = a_0 + a_1 e^{-\frac{(t-\mu)^2}{2\sigma^2}}$
- Ex-Gaussian model: $M_{ex-gauss}(t; a_0, a_1, \sigma, \mu, \tau) = a_0 + a_1 \int_{-\infty}^{\infty} e^{-\frac{(t-\mu)^2}{2\sigma^2}} e^{-\frac{t}{\tau}} dt$

We selected neurons that 1) were better fitted by the ex-Gaussian model at the 0.05 level via a likelihood ratio test, 2)changed their firing rate by at least 2 Hz, 3)reached a firing rate of at least 4 Hz. They were identified as visually responsive (they might be time cells or temporal context cells)

Results

Displays of Fiiting Results (模型拟合)

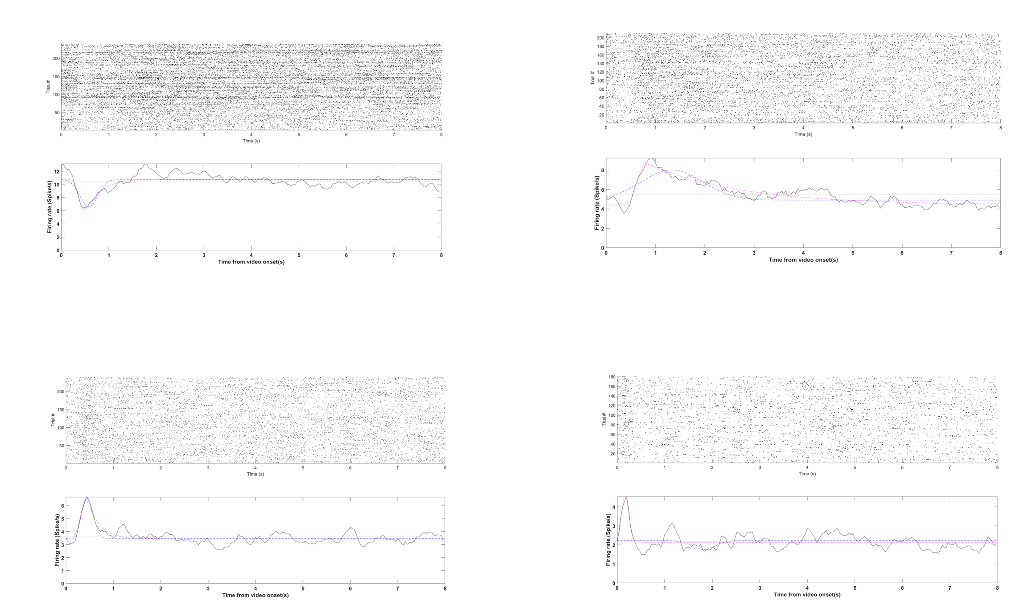

Figure4. Jupiter (right) and Mercury (left)

Population Analysis on Neurons Identified as Visually Responsive (视觉响应神经元的群体分析)

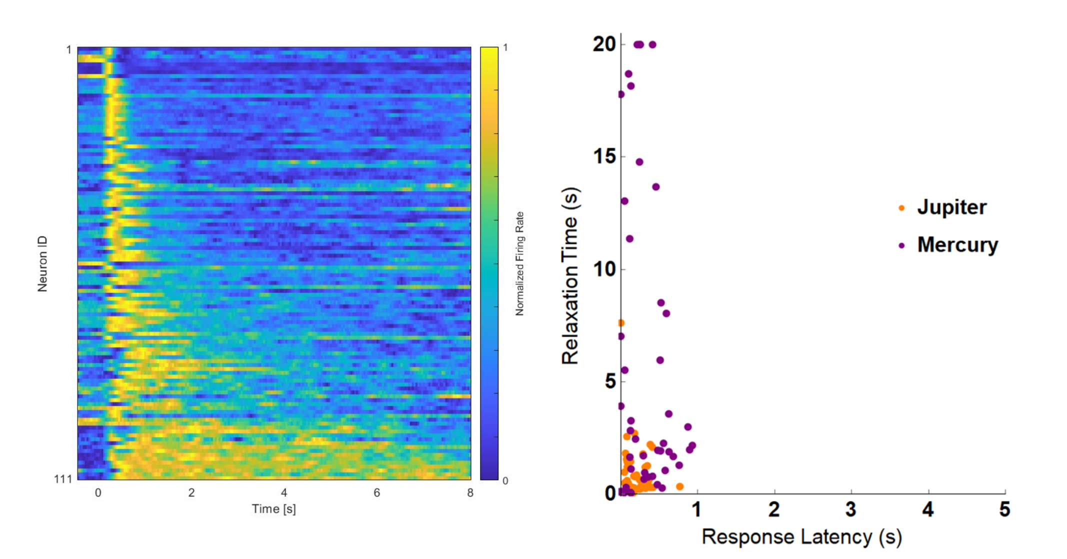

Figure5. **Heatmap of the normalized firing rate of all 111 neurons identified as visually responsive (66 from Jupiter and 45 from Mercury) (left) and A scatterplot of the joint distribution of each neuron's Response Latency (the time at which a cell begins to respond) and Relaxation Time (right)**

For visually responsive neurons, 1) Response latencies did not span the entire 8s, 2) Relaxation time spanned the entire 20s (the boundary for fitting), 3) a neuron' s response latency and relaxation time were not correlated.

视觉响应神经元在群体上很好地反应出符合时间背景细胞的性质：它们的反应延迟集中地分布在1s以内；衰减速率则广泛地分布在0~20s 之间；神经细胞的衰减速率与反应延迟没有明显的相关性。

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