摘 要

快速检测环境中的动态变化信息、捕捉视野中的新颖元素，是生物体高效适应外部环境，从而顺利生存繁衍的必要条件。过往神经生物学研究提示：视觉系统根据近期输入，动态调整其反应特性的能力（“神经可塑性”）以及快速检测视觉新颖信息的能力（“视觉显著性检测”），可提升神经元对感觉输入的反应差异性，进而有助于实现生物体对视觉输入信息的高效编码。

自然界的动态视觉输入中，视觉特征（例如：方位、空间频率等）往往具有随时间动态变化的概率分布模式。然而，目前学界仍不清楚：视觉系统如何有效检测上述动态视觉输入的新颖性信息。为探究该问题，我们采用一种较为新颖的视觉适应范式（倾向性方位适应：方向覆盖 0~360°、顺序随机分布，但呈现概率不相等的正弦光栅刺激），在猫的丘脑-腹侧视觉通路（外侧膝状体、皮层 17 区、21a 区）进行在体电生理单细胞记录，并结合计算机建模拟真，系统研究了视觉系统对具有“时间统计学分布模式”的动态视觉流刺激在单个神经元层面的适应后效和神经机制，探究了其在视觉高效编码方面的意义。

本课题研究表明：

（1）倾向性方位适应中，呈现概率稍高（0.1~0.2）的刺激方位，可在皮层 17 区单个神经元层面诱发分钟级别的、明显的反应增强效应，而当呈现概率更高（> 0.3）时，则转变为明显的反应抑制效应（“增强–抑制”双向可塑性）；

（2）上述呈现概率依赖的反应增强效应只可在最优刺激参数附近被诱导，但在一定参数范围内，上述增强效应可发生跨“刺激参数”和跨“输入眼”的传递，提示其皮层 17 区起源；

（3）“反应潜伏期分析”与“感受野结构实验”结果共同提示：上述增强效应可能产生于皮层 17 区内部，并且是感受野中央区-大周边区相互作用的结果。据此我们提出“感受野中央-周边适应竞争”模型以解释双向可塑性的形成机制，并得到计算模拟实验的验证；

（4）上述双向可塑性在外侧膝状体（LGN）和皮层 21a 区均存在，并体现出等级递进的功能模式变化。“皮层 17 区损毁实验”使 LGN 的增强效应消失，

进一步证实双向可塑性的皮层起源；

（5）计算模拟实验结果显示：上述皮层 17 区的双向可塑性，可以实现对动态视觉输入的“显著性检测”，从而有助于视觉系统的高效编码。

上述结果表明，视觉系统在对动态视觉输入的神经编码过程中，存在着一种快速的、呈现概率依赖的可塑性机制。该机制有助于视觉系统对动态视觉信息的快速显著性检测与高效编码，从而实现生物体对外界环境的快速响应与适应。

关键词：方位适应，初级视皮层，外膝体，21a 区，倾向性适应，显著性检测

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Abstract

Rapid detection of novel elements within the dynamically changing environment is crucial for the survival of animals. Previous studies suggested that in visual system, neurons could dynamically alter their responsiveness according to recent history of inputs ("neural plasticity"), and could perform rapid detection of novel visual targets ("visual saliency-detection"), which contributes to visual efficient-coding by increasing the difference of neural responses to sensory inputs.

The statistical-distribution pattern of basic visual attributes (orientation, spatial frequency, *etc*.) of dynamic natural visual inputs varies over time, while the details of the novelty-detection function of visual system during dynamic visual stream still remains unclear. Therefore, we adopted a newly reported visual adaptation protocol (biased orientation adaptation: randomly presented but unevenly distributed stimuli with directions covering 0~360 deg), systematically investigated the neural plasticity during temporal-statistically distributed visual adaptation in the visual thalamo-ventral pathway (LGN, Area 17, Area 21a) of cats, by electrophysiological single-unit recordings and computing simulations.

This thesis presents our findings that:

(1) During biased orientation adaptation, stimuli with slightly higher occurrence-probability (0.1~0.2) could induce minute-level, single-neuronal significant response potentiation in Area 17, while stimuli with much higher occurrence-probability (> 0.3) could induce significant response suppression.

(2) Above occurrence-dependent potentiation effect could only be induced near the optimal stimulation parameters, while within certain parameter-space, above potentiation effect could be transferable across parameters and eyes, suggesting its Area 17 origin.

(3) Results of "latency-analysis" and "receptive field structural test" both indicated that, above potentiation effect might be originated from the interaction between receptive field center and surround components of Area 17 neuron. We thus purposed

"receptive field center-surround adaptation competition" model to account for the formation of bidirectional-plasticity, and performed computing simulations.

(4) Above bidirectional-plasticity also exists in LGN and Area 21a, with hierarchical progressive pattern-change. Area 17 lesion could eliminate the potentiation effect of LGN neurons, supporting the cortical-origin hypothesis of bidirectional-plasticity.

(5) Computing simulation results indicated that, above bidirectional-plasticity of Area 17 neurons could contribute to the saliency-detection of dynamic visual inputs.

Taken together, our findings demonstrate a rapid probability-dependant plasticity on the neural coding of visual stream, and suggest its functional role in the efficient-coding and saliency-detection of dynamic environment.

Key Words: orientation adaptation, primary visual cortex, LGN, Area 21a, biased adaptation, saliency detection

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