Molecular Physiology

Unveiling the Neurobiological Basis of Short-Term Gustatory Memory

Yuxin Zhang

Abstract:
The sensory system plays a crucial role in the survival of organisms, with taste and taste-related memories closely tied to our experiences in the wilderness. Short-term gustatory memory is particularly linked to rapid food selection for life sustenance. Zhang et al. conducted behavioral experiments, optogenetics, and other methods to reveal the gustatory cortex as the neural substrate for short-term gustatory memory, showing its correlation with both the decay and enhancement of such memory.

The taste system primarily responds to five basic taste qualities: sweet, umami, bitter, sour, and salty[1]. Previous research by the authors' team demonstrated that taste receptor cells (TRCs) are responsible for conveying this information[1],[2]. TRCs then transfer the information to corresponding taste neurons, eventually reaching the central nervous system and connecting with the appropriate brainstem neurons. The gustatory cortex, in turn, communicates with other brain regions to drive behavior triggered by taste. Animals utilize short-term gustatory memory to distinguish and make choices about food, and existing studies suggest that the storage of short-term memory and stimulus response may occur in the same region[3],[4],[5]. The authors, through a comprehensive approach encompassing behavior, physiology, brain neuron activity recording, and manipulation, directly elucidated the mechanisms of the gustatory cortex and short-term gustatory memory.

The authors initiated behavioral experiments to establish short-term gustatory memory using a simplified 3-arm model. Thirsty mice were trained to make correct choices based on different liquid samples (sweet and bitter) and odors (sweet and bitter), forming short-term gustatory memory.

Following the successful model establishment, brain responses to different taste stimuli were tested using fiber-optic recording. Fiber optics were implanted in the GCbt brain area, previously associated with bitter taste perception[6]. To eliminate interference from mouth licking behavior, animals were allowed to establish a baseline for water licking and dry licking. Subsequent tests with sweet and bitter samples revealed robust activity in taste cortex neurons corresponding to bitter and sweet responses, confirming the involvement of the gustatory cortex in taste perception.

Controlled modulation of taste response time revealed sustained activity signals. To demonstrate that this sustained activity was not residual from the samples, the authors used optogenetics to activate bitter taste signal-sensing neurons, replicating the sustained activity observed in the mouse model. By targeting bitter taste neurons in the brainstem

with GtACR1 inhibitory opsin, the authors disrupted taste signals from the tongue to the cortex. Behavioral comparisons between animals with and without inhibition showed no difference, indicating that taste-induced sustained activity could be reproduced through transient (optogenetic) stimulation.

The results collectively point to the involvement of GCbt and short-term gustatory perception and memory storage. The authors hypothesized that the time course of memory trace decay should correlate with animal performance in short-term memory. Secondly, during variable delay periods, transient silencing of the gustatory cortex should eliminate memory traces. Finally, prolonging decay should aid in preserving short-term memory for an extended period, consequently improving animal performance in short-term memory tasks. To validate these hypotheses, they extended the decay time, observed correct behavior rates as indicators of animal short-term memory performance, and found a corresponding improvement. Further experiments involving optogenetic stimulation of inhibitory interneurons in GCbt during the delay period resulted in the termination of sustained activity in bitter-activated neurons, leading to mice being unable to maintain memory of bitterness. Additionally, enhancing GCbt activity by using VIP to relieve inhibition on pyramidal cells showed an improvement in memory performance.

In conclusion, the comprehensive experimental results underscore the profound impact of GCbt's sustained activity on the ability of animals to maintain gustatory stimulus memory, confirming the gustatory cortex's role as the substrate for short-term gustatory memory[8].

References

[1] Yarmolinsky DA, Zuker CS, Ryba NJ. Common sense about taste: from mammals to insects. Cell. 2009 Oct 16;139(2):234-44. doi: 10.1016/j.cell.2009.10.001. PMID: 19837029; PMCID: PMC3936514.

[2] Lindemann B. Taste reception. Physiol Rev. 1996 Jul;76(3):719-66. doi: 10.1152/physrev.1996.76.3.719. PMID: 8757787.

[3] Yu L, Hu J, Shi C, Zhou L, Tian M, Zhang J, Xu J. The causal role of auditory cortex in auditory working memory. Elife. 2021 Apr 29;10:e64457. doi: 10.7554/eLife.64457. PMID: 33913809; PMCID: PMC8169109.

[4] Huang Y, Matysiak A, Heil P, König R, Brosch M. Persistent neural activity in auditory cortex is related to auditory working memory in humans and nonhuman primates. Elife. 2016 Jul 20;5:e15441. doi: 10.7554/eLife.15441. PMID: 27438411; PMCID: PMC4974052.

[5] Serences JT. Neural mechanisms of information storage in visual short-term memory. Vision Res. 2016 Nov;128:53-67. doi: 10.1016/j.visres.2016.09.010. Epub 2016 Oct 4. PMID: 27668990; PMCID: PMC5079778.

[6] Chen X, Gabitto M, Peng Y, Ryba NJ, Zuker CS. A gustotopic map of taste qualities in the mammalian brain. Science. 2011 Sep 2;333(6047):1262-6. doi: 10.1126/science.1204076. PMID: 21885776; PMCID: PMC3523322.

[7] Peng Y, Gillis-Smith S, Jin H, Tränkner D, Ryba NJ, Zuker CS. Sweet and bitter taste in the brain of awake behaving animals. Nature. 2015 Nov 26;527(7579):512-5. doi: 10.1038/nature15763. Epub 2015 Nov 18. PMID: 26580015; PMCID: PMC4712381.

[8] Juen Z, Villavicencio M, Zuker CS. A neural substrate for short-term taste memories. Neuron. 2024 Jan 17;112(2):277-287.e4. doi: 10.1016/j.neuron.2023.10.009. Epub 2023 Nov 8. PMID: 37944522.