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Odor maps in the dorsal and lateral surfaces of the rat olfactory bulb

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Molecular-feature clusters in the odor maps of the olfactory bulb

The surface of the mammalian olfactory bulb (OB) is covered by numerous glomeruli. Since individual glomeruli represent a single odorant receptor (OR) among a repertoire of nearly 1000 ORs, the spatial assembly of the glomeruli forms the maps of ORs. How are the numerous ORs represented spatially in the glomerular maps?

Studies of mapping of odorant-induced glomerular activity using the optical imaging or fMRI methods showed that individual glomeruli responded to a range of odorants and that the range differed widely among different glomeruli. In the present series of experiments, we determined the molecular receptive range (MRR) of individual glomeruli in the rat OB using the method of optical imaging of intrinsic signals and systematic panels of ~70 stimulus odorants. Based on the MRR property, we deduced the characteristic molecular features that were shared by odorants effective in activating individual glomeruli (Takahashi *et al.*, 2004). Examination of the spatial representation of MRRs in a substantial part of the glomerular map would provide the basic knowledge of the spatial representation of the ORs in the glomerular maps.

Detailed analysis of MRRs of individual glomeruli in the dorsal area (mostly zone 1) of the OB indicated that glomeruli having similar and overlapping MRRs gathered in close proximity and formed 'molecular-feature clusters'. Cluster A glomeruli were located at the anteromedial part of the dorsal surface. The characteristic molecular-features of odorants effective in activating the cluster A glomeruli are a carboxyl group {–COOH}, a diketone group {–(CO)(CO)–} or an ester group {–(CO)O–}, functional groups having two oxygen atoms in a neighborhood. In addition, odorants having a single aldehyde group {–CO} or an amino group {–NH_2} at the end of the molecule were effective in activating many glomeruli in cluster A.

Cluster B was located in the most anterior region of the lateral part of the dorsal surface. The characteristic molecular features of cluster B glomeruli were elongated carbon chain structure with a hydroxyl group {–OH}, an alkoxyl group {–O-R} or a carbonyl group {–CO} (in ketones) attached at one side of the molecule.

Cluster C was located at the central region of the lateral part of the dorsal surface. The characteristic molecular features of glomeruli in the cluster C include the combination of the benzene-ring-like hydrocarbon structure and a hydroxyl group, a methoxy group, or an ethoxy group.

Cluster D glomeruli were located at the caudal part of the dorsal OB. Odorants effective in activating the cluster D glomeruli were mainly ketones: cyclic ketones, aliphatic–aromatic ketones, diketones, and a subset of aliphatic ketones with relatively short side chains.

Immunohistochemical staining of OB sections with an anti-OCAM antibody indicated that clusters A–D were located in zone 1 of the lateral map. Although both of the overall molecular shape and the functional group(s) were important determinants in activating individual glomeruli in clusters A–D, the characteristic molecular features common to the glomeruli in each cluster were one or more oxygen- or nitrogen-containing functional groups. This suggests that the presence and the position of functional group(s) in the odorant molecular structure play a key role in activating the glomeruli in clusters A–D.

Hydrocarbon odorants lack a hetero-atom-containing functional group. Except for a few scattered glomeruli, hydrocarbon odorants did not activate glomeruli in clusters A–D in zone 1. In a striking contrast, hydrocarbon odorants activated many glomeruli in clusters F and G, which were located outside of zone 1. Although these glomeruli responded to a relatively wide range of odorants with and without functional group(s), the characteristic molecular features of cluster F glomeruli included the terpene hydrocarbon structure, while those of cluster G were benzene-family hydrocarbons. Hydrocarbon odorants activated glomeruli also in the lateroventral surface of the OB, which were in zones 2–4. Thus the clusters of hydrocarbon-responsive glomeruli were located mostly in zones 2–4.

Mitral and middle tufted cells differ in the manner of decoding the odor maps

Mitral and tufted cells in the mammalian OB are principal neurons that receive a direct synaptic input from olfactory sensory neurons and send their axons to the olfactory cortex. The two types of principal neurons differ in the laminar position of their cell bodies, in the projection pattern of their secondary dendrites and axon collaterals within the OB, and in the axonal projection pattern to the olfactory cortex. The morphological difference suggests that mitral and middle tufted cells are functionally distinct and may process different aspects of olfactory information. To address this question, we recorded single unit responses from mitral cells and middle tufted cells in the cluster A of the dorsal surface of the rat OB. We compared the response pattern to homologous series of fatty acids and aldehydes in mitral and middle tufted cells (Nagayama *et al.*, 2004).

In response to adequate odorants, mitral cells showed spike responses with relatively low firing rates, whereas middle tufted cells showed spike responses with higher firing rates. Most mitral cells exhibited a robust inhibitory MRR, whereas a majority of middle tufted cells showed no or only a weak inhibitory MRR. Responses of mitral cells to an adequate excitatory odorant were greatly inhibited by mixing the odorant with other odorants that activated neighboring glomeruli. In contrast, odorants that activated neighboring glomeruli did not significantly inhibit the responses of middle tufted cells to the adequate excitatory odorant.

These results indicate a clear difference between mitral and middle tufted cells in the manner of decoding the glomerular odor maps. Individual mitral cells may detect the contrast of activity between their own glomerulus and neighboring glomeruli. In contrast, individual middle tufted cells can code the presence of odorants that activate its own glomerulus regardless of the presence of odorants that activate neighboring glomeruli.

References

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