The olfactory system may extract sensory information by summating signals from multiple receptors

We interpret the world around us by means of individual sensory nervous systems, vision, hearing, touch, taste, smell, and balance/movement. These systems transduce the physical world into neural information in the brain through multi-step processes. Generally, one type of stimulant initiates the sensory signaling process by evoking cellular responses of differing strengths in different types of receptors. In case of vision, red, green, yellow, and blue comprise the four elemental colors that, in different weighted combinations, allow us to perceive all visible colors. Elemental colors are primarily extracted within the visual pathway, by neurons of the third-order (ganglion cells) or higher, through summation of signals from one or two types of receptors. For example, yellow light induces a relatively strong, and almost equal, response in both the red and green cone cells within the eyes, and a weak response in blue cone cell. This indicates that while detection of the color yellow is a result of three types of receptors, only one type of third-order, or higher, neuron is required.

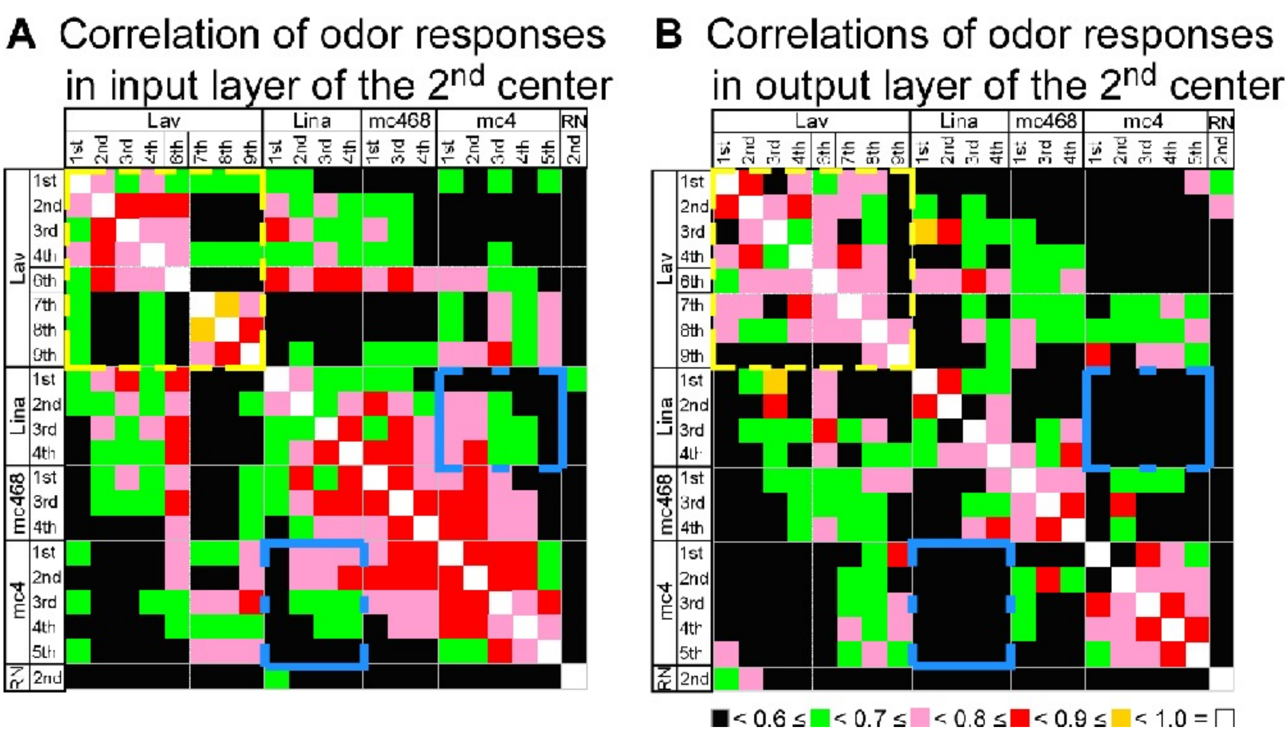

Fig. 1. Correlations of odor responses in wavelet time-frequency power profiles differed between the input (A) and output (B) layers of the secondary olfactory center. The domains of identical odors, especially for Lav (broken yellow square), were mostly occupied with high correlations in the output layer, but not in the input layer. In addition, correlations between the different single component odors Lina and mc4 (broken blue square) decreased to less than 0.6 in the output layer, but some were high in the input layer.

Thus, in the case of color vision, summating signals from different receptors emphasizes sensory information that is received from multiple receptors and reduces extraction of non-overlapping sensory signaling. As a result, we hypothesized that the olfactory system might behave similarly, in that elemental odors may be extracted by third-order neurons in the olfactory pathway. If our hypothesis is correct, we should observe that responses of the third-order neurons to identical odors are more similar than those of the corresponding input. These odor responses are transient and oscillatory, and there currently exist no published methods for quantifying the similarity of these types of responses. To this end, we developed a novel wavelet-correlation analysis for quantifying similarity between transient oscillatory responses, and tested our method on the odor responses. The wavelet transform is like a running, windowed Fourier transform in that over time it slides a window of a specific size along an axis and computes the fast Fourier transform at each time point, using only the data within the window.

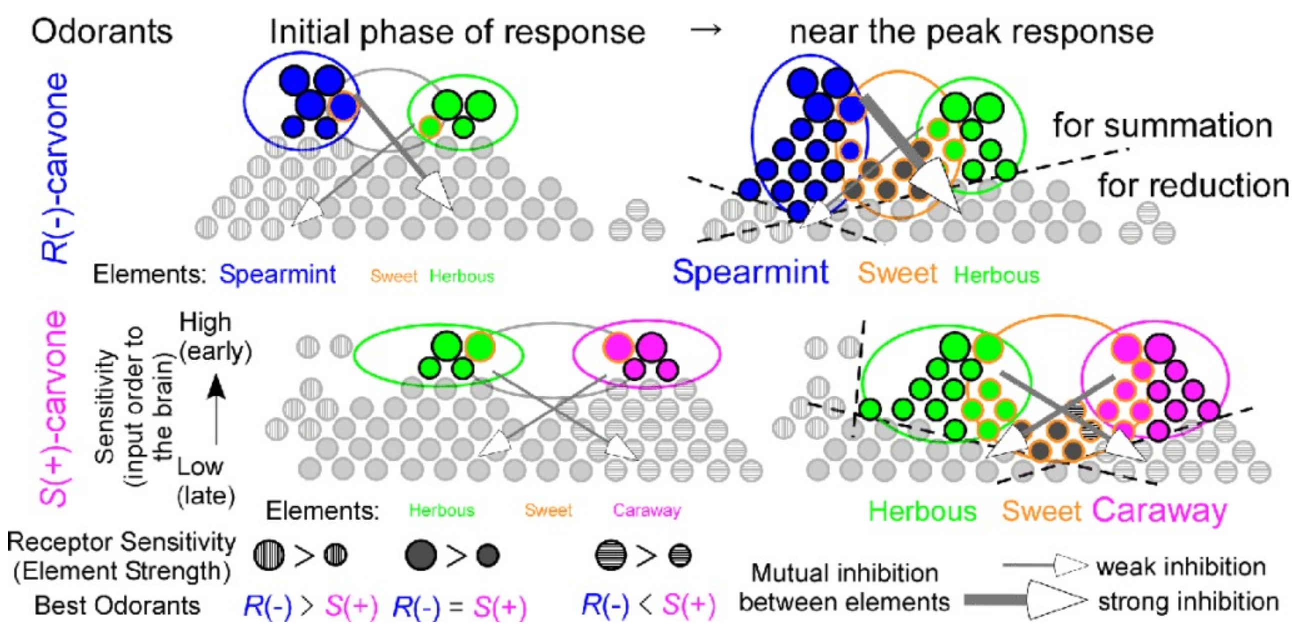

Fig. 2. The olfactory system may extract and enhance characteristic elements by summating signals from multiple cognate receptors via inhibitory signals.

The wavelet transform enabled us to visualize rapid changes in oscillatory responses in time, frequency, and oscillatory power. Each wavelet time-frequency power spectrum was rescaled across odor responses of a given brain preparation in logarithmic ratio arrays of cross-/auto-correlations, which were subjected to response similarity analysis. By using a wavelet-correlation analysis, we revealed a stimulus-dependent correlation between odor responses of the third-order neurons (in the output layer of the secondary olfactory center) (Fig. 1B.), and experience-dependent correlations between those of the second-order neurons (in the input layer) to some of the included identical, or different odors (Fig. 1A.). The former result is in agreement with our hierarchical model of the coding of elemental odors (Fig. 2.), and indicates that signals from multiple cognate receptors may be summated in third-order neurons in the olfactory pathway, thereby streamlining the flow of sensory information. However, because the repertoire of human olfactory receptors is ca. 100-fold larger than that of visual receptors, definitively proving this model will require further research and considerable experimental data. This study provides insight into how the brain extracts and integrates sensory information, and includes unexpected observations. Furthermore, our novel wavelet-correlation analysis is a promising tool for quantifying the similarities between transient, oscillatory neural responses.

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