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Sensory systems

Editorial overview

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Introduction

Our senses provide a means to interact with the physical world. The taste and smell of food and wine, the alarming sensation of fire, the pleasing sounds of music all require dedicated external sensory organs to detect environmental cues and a central nervous system optimized to process, interpret, and act upon such cues. As is traditional with the yearly issue on Sensory Systems, we have sought to assemble a collection of review articles on exciting new developments in areas spanning multiple sensory modalities and levels of approach. This issue balances systems neuroscience with molecular, cellular, and developmental neuroscience to provide a taste of what has been happening in this broad and exciting field in the past few years.

Sensory transducers

The era of molecular biology has been sweeping through sensory systems for several decades, illuminating the underlying cellular mechanisms by which cells detect smells, tastes, and mechanical stimuli. Three chapters in this issue are concerned with the receptor mechanisms that allow cells to detect sensory cues. Montell reviews the surprising and fast-moving field of *Drosophila* gustatory receptors (GRs). Insects appear to be breaking many of the rules established by the mammalian taste field. Rather than using multiple receptor families to detect different taste qualities, insects seem to have diversified within a single gene family of GRs to taste virtually all tastants. In some cases, many receptors are coexpressed within the same taste neuron and the mechanism by which these proteins signal is still an interesting unknown.

Luo, Sun, and Hu provide an update on the molecular mechanisms of oxygen and carbon dioxide perception in vertebrates and invertebrates. It has only recently been appreciated that mammals can be as sensitive to carbon dioxide as invertebrates and this review synthesizes data on neural gas detection studied in diverse species.

Tsunozaki and Bautista describe recent work in the field of mammalian somatosensation, a complex sense subserved by an impressive variety of cell types and organs. While receptors for hot, cold, and noxious stimuli have been proposed, the molecules mediating touch and stretch transduction remain either controversial or unknown.

Two articles discuss links between chemical stimuli and behavior. Spector and Glendinning consider how taste information is represented in the mammalian tongue and how this information might be integrated in central circuits to yield a taste image.

Edison reviews a very new field that of pheromones in the nematode *Caenorhabditis elegans*. The existence of worm-derived molecules that influence developmental fate and behavior has long been inferred, but the discovery of these so-called ascarosides in *C. elegans* occurred fewer than five years ago. This review looks at the chemical diversity of the ascarosides and their role in modulating worm behavior.

Sensory organs

Proper reception of sensory cues begins with a developmental plan to build a sensory organ dedicated to a particular physical or chemical stimulus. Two articles in this issue are concerned with the developmental biology of building a sensory organ and circuit. Fuerts and Burgess discuss the formation and patterning of the mammalian retina. This beautiful structure first requires a plan to differentiate a large variety of morphologically and functionally distinct cell type. Second, these neurons must be organized vertically into the layers and laterally to build a tiled mosaic of cells. The involvement of cell adhesion molecules in achieving such an end is discussed. Turning to the auditory senses, Kelly and Chen review the differentiation and maturation of the mammalian cochlea. Although this organ is intricate and complex, containing a number of specialized cell types and structures, the underlying genetic plan that patterns this sensory epithelium utilizes the planar cell polarity pathway well known in other cellular epithelia. The authors point out that interplay of neuronal and non-neuronal cell types is essential to produce the final form and function of the cochlea.

Gain control mechanisms

A variety of sensory systems are endowed with mechanisms that control neuronal gain, making neurons more or less responsive to sensory input. Two essays in this issue review recent advances on these gain control mechanisms. Robinson and McAlpine describe mechanisms that control gain in the auditory pathway based on the statistics of the input. Saalmann and Kastner describe experiments that have revealed the visual thalamus to be not only a conduit for visual information but also a station where neuronal gain is controlled by cognitive and perceptual factors via top-down cortical signals.

Sensory cortex

The processing of sensory information in cortex remains mostly to be understood, both in terms of circuitry and in terms of computation. Brown and Hestrin review recent advances in the analysis of local circuits in sensory neocortex, which are shown to depend in a remarkably precise way on the exact type of the neurons involved. The precision of these rules of connectivity suggests that earlier statistical approaches to anatomy were inadequate.

Relating form to function has been difficult in all areas of sensory cortex, but particularly so in paleocortex, because of the complex ecology of the world of odors and to the vastness of its space. Gottfried, however, reviews exciting recent work showing that spatial ensemble activity patterns in piriform cortex are closely linked to the perceptual meaning and identity of odor objects.

Three essays in this issue, in turn, focus on the role of coordinated activity in the neocortex. Hromádka and Zador review recent evidence suggesting that activity in auditory cortex consists of sparse and highly synchronized volleys of activity. Kohn, Zandvakili, and Smith review recent studies showing that correlations in activity across neurons are influenced by strong network fluctuations that can extend across cortical areas. These fluctuations depend on cognitive state and stimulus properties, and may thus have great impact on population coding. This potential impact is the topic of the review by Ringach, who argues against the traditional view of spontaneous neural activity as 'noise'. He reviews evidence indicating that spontaneous activity in cortex is highly structured and interacts with sensory stimulation so as to represent a continuous top-down prediction or expectation signal.

Multisensory integration

The brain seamlessly integrates signals from multiple modalities. The mechanisms and computations underlying this integration have only recently begun to be understood. Two essays in this issue describe recent advances on this front. Arenz, Bracey, and Margrie focus on sensory representation in granule cells in the cerebellum, and describe recent discoveries on how these neurons integrate somatosensory, proprioceptive, and vestibular signals. Angelaki, Gu, and DeAngelis discuss the multisensory integration properties of visual-vestibular circuits and the extent to which Bayesian integration provides a means to understand them.

Cover legend

The senses (here depicted by examples of vision, balance, smell, touch, taste, and hearing) provide an interface between the external world and its internal representation in our minds. This issue covers recent exciting advances in sensory neurobiology from diverse approaches ranging from developmental genetics to systems neuroscience.