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Introduction to signal processing in peripheral sensory organs

Stephen D. Roper*

Department of Physiology & Biophysics, Miller School of Medicine, University of Miami 1600 NW 10th Ave., Miami, FL 33136, United States

It is all too easy to think of our peripheral sensory organs as passive responders to environmental stimuli. We too readily believe that these sensory structures merely send signals to the central nervous system where the information is modulated, smoothed, amplified, or otherwise shaped for eventual interpretation by higher brain centers. Rarely are sensory end organs considered as microcircuits where stimuli are transduced and signals are processed prior to being exported to the spinal cord and brain. The collection of papers in this issue directly addresses this issue: signal processing in peripheral sensory organs and sensory endings. The conclusion is inescapable that peripheral signals are indeed shaped by local interactions between cells. Indeed, a common thread running through the chapters is that cell–cell interactions are involved and potent neuroactive compounds, including serotonin, adenosine, dopamine, GABA, glutamate, acetylcholine, and ATP, act as paracrine or autocrine modulators during sensory signaling.

I have selected 7 leading laboratories that study peripheral sensory signaling to join me in presenting an up-to-date view of how signals are shaped by local influences. A variety of end organs are described, including interoceptors and exteroceptors. The sensory cells discussed on the following pages include chemoreceptors, mechanoreceptors, and nociceptors. A pictorial overview of the scope of these sensory organs and the chapters where they are discussed is presented in Fig. 1.

That there is signal processing in peripheral sensory organs has several implications. For instance, the cellular interactions underlying signal processing may present potential targets for new therapeutic agents. That is, if sensory signals are to a degree shaped in the periphery, there may be readily accessible sites for drug interventions that can enhance, prolong, or diminish sensations. Pharmacological manipulation of receptors for paracrine and autocrine sensory neuromodulators is one such possibility.

Another implication of peripheral signal processing pertains to sensory coding by the nervous system. A view held by some, particularly in the chemical senses, is that sensory signals are coded by labeled lines. In its simplest and most reduced form, labeled line coding means that a given stimulus activates a specific sensory receptor cell that connects directly to a set of equally specific sensory axons. These axons transmit unmodulated, unmixed, and invariant signals to relay centers in the central nervous system where they are passed on in a series of linear connections to higher brain centers. At each stage, the signals remain invariant, simple, and “true” to the one quality and modality of the original peripheral sensory stimulus. Thus, if one were to record the neuronal activity at any level along such a “labeled line”, from periphery to CNS, the activity would reliably map one-to-one with the initial stimulus and would be a faithful representation (“label”) of that unique stimulus. Perhaps the origin of such a labeled line coding might be attributed to Rene Descartes.

Descartes wrote that the heat of a fire pulls on a filament (labeled line), and opens a tiny pore or conduit in the brain: “*ainsi que tirant l’un des bouts d’une corde, on fait sonner en mesme temps la cloche qui pend à l’autre bout. (just as, pulling one end of a cord, one simultaneously rings a bell which hangs at the opposite end)*”, illustrated in his classical drawing from *Traite de l’homme* (*Treatise of Man*) [1] (Fig. 2).

Yet, our current understanding of how signals are processed and shaped by cellular interactions and neuromodulators in peripheral sensory organs now weighs counter to labeled line coding. The data suggest that there is not a direct and simple one-to-one encoding of receptor activation. It is more likely that sensory signals are transmitted by some form of combinatorial or temporal coding wherein any one neuron in the “line” can be activated or influenced by two or more different sensory qualities (“labels”). Only when the activity of the activated neurons is taken *in toto* can a representation of the original stimulus be reconstructed. It is well-established that many sensory modalities in mammals, such as olfaction, encode odor qualities by combinatorial coding [2]. In contrast, in *drosophila* certain olfactory stimuli are encoded via a labeled line [3]. How information is transmitted—whether via labeled line or combinatorial/temporal code—in the sensory modalities described in this issue may be controversial. However, the predominance of the evidence favors some form of computational coding, not a labeled line.

References

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Fig. 1.

Distribution of sensory organs discussed in this issue. Figure adapted from: Andreas Vesalius, 1543, *De humani corporis fabrica libri septem*; Giovanni Maria Lancisi, 1722, *Tabulae Anatomicae Bartholomaei Eustachii*; Henry Gray, 1918, *Anatomy of the Human Body*; Akisik MF, Sandrasegaran K, Aisen AA, Maglinte DD, Sherman S, and Lehman GA. (2006). Dynamic secretin-enhanced MR cholangiopancreatography (**olfactory epithelium:** Lucero, *Peripheral modulation of smell: Factor fiction?*, **taste buds:** Roper, *Taste buds as peripheral chemosensory processors*, **Islets of Langerhans:** Caicedo, *Paracrine and autocrine interactions in the human islet: More than meets the eye*, **nociceptors:** Loyd et al, *Serotonergic neuromodulation of peripheral nociceptors*, **cochlea:** Mammano, *ATP-dependent intercellular Ca^{2+} signaling in the developing cochlea: Facts, fantasies and perspectives*, **carotid body:** Nurse & Piskuric, *Signal processing at mammalian carotid body chemoreceptors*, **pulmonary neuroepithelial bodies:** Cutz et al, *Recent advances and controversies on the role of pulmonary neuroepithelial bodies as airway sensors*, **nephron:** Praetorius & Leipziger, *Primary cilium-dependent sensing of urinary flow and paracrine purinergic signaling*). *Radiographics* 26:665-77 (with permission); with help from Dr. T. Champney (Miller Sch Med, U Miami).

Fig. 2.

Sensory coding as described by René Descartes, possibly the first description of a labeled line. “Thus, if fire *A* is near foot *B*, the particles of this fire (which move very quickly, as you know) have force enough to displace the area of skin that they touch; and thus pulling the little thread *cc*, which you see to be attached there, they simultaneously open the entrance to the pore [or conduit] *de* where this thread terminates [in the brain]”. From Hall, T.S. (1972) René Descartes, *Treatise of Man*, French text (1680 edition) with translation and commentary. Harvard University Press, Cambridge, pp 34.