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Electroreceptors

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Synonyms

Ampullae of Lorenzini; Electric organ discharge; Electrogenic; Electroreceptor; Tuberous electroreceptor

Introduction

All living organisms maintain homeostasis, which necessitates that the concentration of ions within the body differs from the outside environment. As a result, a voltage develops across the skin. In an aquatic environment, this voltage has the potential to leak out and create a charge distribution around the body. These charges can be detected by specialized organs known as electroreceptors. Because electroreception relies upon a conductive medium in which to operate, it is restricted to aquatic species, or species that forage in moist environments.

Prevalence

Electroreception is an ancient sensory modality that arose at the base of the vertebrate clade (Albert and Crampton 2005). It remains widespread among extant taxa but has been largely lost among the most speciose groups, the amniotes and actinopterygian (ray-finned) fishes. Among the agnathans, it is found in the Petromyzontiformes (lampreys) but is absent in the Myxiniformes (hagfish). Among the gnathostomes, it is present in the Chondrichthyes and most of the Osteichthyes, with the exception of the Holostei (gars and bowfin) and the Euteleostei. Despite its loss in the Euteleostei, it has re-evolved within the Ostariophysi (catfishes and knifefishes). In addition to its reappearance within some members of the euteleost lineage, electroreception has also independently re-evolved within two amniote lineages: the monotremes (platypus, echidna) and most recently in a single species of cetacean, the Guiana dolphin, *Sotalia guianensis*. Among the amphibians, electroreception is identified in the aquatic larval forms of caecilians and some urodeles (salamanders), but not the anurans (frogs). Although electroreception is taxonomically widespread, the total number of extant species that are electroreceptive is only about 10% of the total number of species within the vertebrate clade (Albert and Crampton 2005).

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Despite the diversity of species that have been documented to be electroreceptive, the majority of research on electroreception is devoted to either the electrogenic mormyrid and gymnotid fishes or the largely non-electrogenic elasmobranch fishes (sharks and rays). Both groups utilize ampullary electroreceptors, which are tuned to low-frequency stimuli, to passively detect the bioelectric fields of prey. Ampullary electrosensory organs were first described in the sixteenth century from sharks and rays, and the elasmobranchs are renowned for their acute electrosense.

Structure

Electroreception in elasmobranchs is mediated by a sensory system known as the ampullae of Lorenzini. The ampullae of Lorenzini consist of hundreds to thousands of glycoprotein-filled tubules which extend from pores on the surface of the head and body of elasmobranchs to blind-ending ampullae within the head that are lined with sensory hair cells. The glycoprotein gel is highly conductive with a conductivity almost equal to that of seawater (Murray and Potts 1961). In contrast, the cells that comprise the walls of the tubules are bound by tight junctions, which serve to insulate the gel in the tubules from the surrounding tissues within the head (Waltman 1966). Compared to the walls of the tubules, shark tissue and the skin offer a relatively low electrical resistance, which means that the basal surface of the electrosensory cells in the head will be at nearly the same voltage as the surrounding seawater immediately adjacent to the head in that region. In the presence of an environmental electric gradient, the apical surface of the electrosensory cells facing the lumen of the ampulla will be at the same potential as the pore opening of the insulated tubule. The difference in electric potential from the pore opening on the surface of the head to the basal surface of the electrosensory cells lining the ampulla is a function of the position of the pore and length of the tubule with respect to the electrical voltage gradient across the head. This likely enables the animal to derive magnitude and direction information from environmental electric fields, which provides it with a richly detailed electric landscape.

Function

The ecological function of the ampullae of Lorenzini remained uncertain for many years because electrophysiological experiments demonstrated that the system responded to a variety of stimuli, including mechanical pressure, temperature changes, salinity changes, and electrical stimuli. Behavioral experiments finally determined that the ampullae of Lorenzini act as electroreceptors, which can detect the presence of prey (Kalmijn 1971). Subsequently, electroreception was demonstrated to be used for mate detection (Tricas et al. 1995) and predator detection (Sisneros et al. 1998). It is also hypothesized that elasmobranchs can utilize their electroreceptors to detect the electric fields induced around their body as they swim through the earth's magnetic field (Kalmijn 1974). An extension of this hypothesis is that sharks might use their electroreceptors to enable them to orient to geomagnetic anomalies on the sea floor (Klimley 1993). Although there is a theoretical basis for support of these magnetic-induction-based hypotheses, definitive empirical data are lacking.

Tuberous Electroreceptors

In addition to passive electroreception mediated through the ampullary electroreceptors, which respond best to low-frequency (<50 Hz) stimuli, electrogenic species, such as the gymnotids and mormyrids, also possess specialized tuberous electroreceptors, which are best tuned to higher-frequency stimuli of 50–2000 Hz (von der Emde 1998). The tuberous electroreceptors work in conjunction with the electric organ discharge (EOD) in these electrogenic species to detect the active EOD of other electrogenic individuals (electrocommunication). Sympatric species produce species-specific EODs, which facilitate identification of conspecifics for mating. The tuberous electroreceptors are also used to detect environmental distortions of their own self-generated electric fields (electrolocation). This enables these species to successfully navigate their environment by sensing and avoiding the presence of conductive and resistive objects. Thus, the tuberous electroreceptors can serve dual purposes, electrocommunication and electrolocation, and, when combined with ampullary electroreceptors for prey detection, can provide the animals with a comprehensive survey of their electrical environment.

Because humans lack an electric sense, we fail to appreciate the wealth of electrical information available in the environment. All living organisms in an aquatic medium generate an electric field around their body, which varies in the range from microvolts to millivolts, and these bioelectric fields provide an important sensory cue that can serve to inform electro-sensitive species. The persistence of electroreception throughout the vertebrate clade, and its reappearance in numerous lineages, illustrates the evolutionarily adaptive value of electroreception.

Cross-References

- ► Caudata Cognition
- ► Caudata Morphology
- ► Caudata Navigation
- ► Caudata Sensory Systems
- ► Chondrichthyes Cognition
- ► Chondrichthyes Morphology
- ► Chondrichthyes Navigation
- ► Chondrichthyes Sensory Systems
- ► Electromagnetic Fields
- ► Electromagnetic Spectrum
- ► Homeostasis
- ► Mechanoreceptors
- ► Sensory Receptors

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