The active electric sense of weakly electric fish: from electric organ discharge to sensory processing and behaviour

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Outline

• An electric fish primer
• Sensory processing with multiple topographic maps
• Quantification of the properties of natural sensory stimuli: from the lab to the field and back
The electric organ discharge (EOD)

1. Primer: weakly electric fish

Apteronotus leptorhynchus (brown ghost knifefish)

~ 30 mV

5 ms
Electroreceptor organs are distributed over the surface of weakly electric fish

MacIver, after Carr et al. (1982) J Comp Neurol 211:139-153
Passive electroreception present in early vertebrates; re-emerged multiple times since then.
Two groups of teleosts independently evolved electrosensation and some of those evolved active electrosensation.

1. Primer: weakly electric fish

1. Primer: weakly electric fish

Electric organ discharge types and frequency

**Pulse-type EOD/fish**
- *Gymnotus sp.* 20 ms
- Novelty response 200 ms

**Wave-type EOD/fish**
- *Eigenmannia sp.* 4 ms
- *Sternopygus sp.* 10 ms
- *Sternarchorhynchus sp.* 2 ms
How is the EOD generated?

Gymnotiformes

1. Primer: weakly electric fish

Pacemaker nucleus

Spinal motor neurons

Voltages sum in series

Electric organ

Single electrocyte


Caputi et al. (2005) In: Electroreception (Bullock, T. H. et al., eds), pp 410-451 New York: Springer
Current flow and the shape of the waveform of the EOD

“Active sensing” enables electric fish to forage and communicate at night and in turbid water.

1. Primer: weakly electric fish
Local stimuli contain only low AM frequencies; Global stimuli can be of high or low frequency.
The electrosensory pathway

1. Primer: weakly electric fish

Electrosensory Lobe (ELL)
spinal cord

primary afferents

ampullary (passive) and tuberous electroreceptor afferents

electroreceptors in the skin

Telencephalon
Cerebellum
midbrain
VIII
medulla
Three topographic maps of the body surface receive identical afferent input (+ one ampullary map), all via 8th nerve.
# Parallel processing of electrosensory stimuli

## 2. Multiple topographic maps

<table>
<thead>
<tr>
<th>Types of pyramidal cells</th>
<th>CMS</th>
<th>CLS</th>
<th>LS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
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<tr>
<td>Intermediate</td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
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<tr>
<td>Deep</td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
<td><img src="image9" alt="Graph" /></td>
</tr>
</tbody>
</table>

**Size of RFs**

![Fish Image](image10)

Current Opinion in Neurobiology

Receptive field properties, feedback circuitry, ion channels, and neuromodulators

2. Multiple topographic maps

Plus cell-intrinsic properties (ion channels) and neuromodulation

Trying to understand sensory processing?
→ Natural sensory scenes

http://www.gigantofraktulus.de/newyork/sonstiges.html
3. Quantification of natural electrosensory stimuli

Measurement of natural electrosensory scenes

Start with recordings of the transdermal potential from an immobilized fish
3. Quantification of natural electrosensory stimuli

Estimating the amplitude of electrosensory stimuli in immobilized fish

prey stimulus: up to ~3%

tail bending: up to ~5%

non-conducting boundary: up to ~40%

Chen et al. (2005) J Comp Physiol A 191:331–345
The dynamics of natural stimuli is determined by environmental movement **AND** self-movement.

Telemetric recording of the transdermal potential from freely swimming fish.

Haleh Fotowat

Fotowat et al. (2013) J Neurosci 33:13758-13772
Self-movement produces relatively small and slow amplitude modulations.

- modulation depth < 20%
- body bending, boundaries

Graph showing EOD with AMs and log(normalized power) versus AM frequency (Hz).

Fotowat et al. (2013) J Neurosci 33:13758-13772
3. Quantification of natural electrosensory stimuli

Movement and communication

Fotowat et al. (2013) J Neurosci 33:13758-13772
The natural electrosensory world?
3. Quantification of natural electrosensory stimuli

“The Grid”:
Long-term “electric observation” in the natural habitat

Jan Benda

Jörg Henninger
3. Quantification of natural electrosensory stimuli

Peña Vijagual, Darien, Panama
Chirps are brief modulations of EOD frequency
Summary

• Weakly electric fish actively generate electric fields and sense their perturbations (caused by self-movement, objects in the environment, communication).
• Electroreceptor organs are distributed over the skin.
• The electrosensory body surface is mapped multiple times in parallel in the hindbrain (and multiple times at higher levels).
• Parallel processing streams filter sensory input in different ways depending on receptive field structure, feedback circuitry, cell-intrinsic properties, and the activation of neuromodulators.
• (Higher levels of processing become increasingly selective for specific stimulus patterns).
• Weakly electric fish are an excellent system in which to quantify the properties of natural sensory stimuli (i.e., constraints on sensory processing) and to use that knowledge for probing mechanisms of sensory processing.
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Literature


