Real-Time Electrophysiological Detection of Auditory Responses in Fishes

Summary of Project: This project focuses on developing a software tool that detects positive responses during an auditory electrophysiology experiment. The planned approach is novel within the field of non-mammalian EEG recordings[1], as it supports multichannel recordings and implements a statistical method for online response detection. The project aims to improve testing accuracy, reduce total testing time, and identify response characteristics of auditory neural generators (e.g., 8th cranial nerve). The final software will be open source for other researchers.

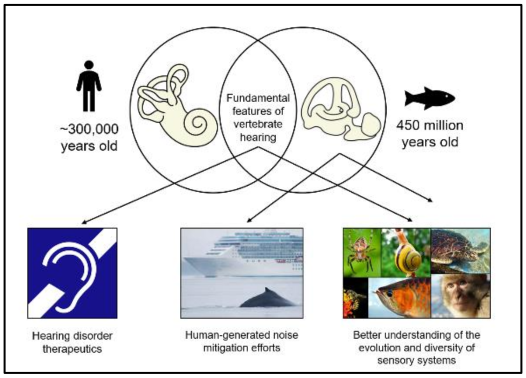

Figure 1: Summary of study significance

Significance: All four-limbed animals (i.e., amphibians, reptiles, birds, and mammals) have auditory systems that are evolved from fish[2]. Because of this shared origin, studies of auditory systems in fish allow foundational understanding of common and evolutionarily conserved mechanisms of vertebrate hearing—with wide-ranging implications (Figure 1). Developing this software will enable more standardized, robust, and time-efficient data collection and analysis in fish, and eventually other species. These efforts may potentially reveal evolutionarily conserved auditory response patterns that are currently inaccessible with existing methods.

Method

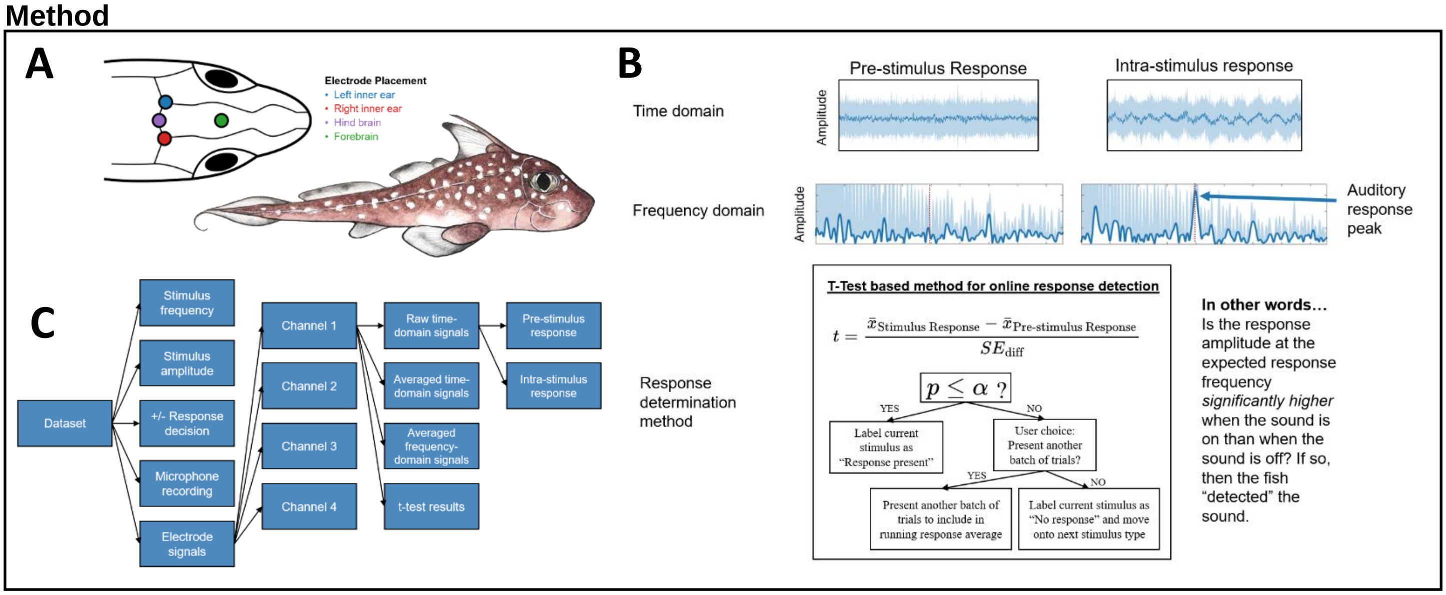

Figure 2: (A) An illustration of the spotted ratfish and a schematic of electrode placement. (B) A summary of the t-test based auditory response detection method. In the top two rows of figures, the thick line traces represent the average auditory response across all 500 trials. The shaded blue areas represent +/- standard deviation of the average. (C) A schematic of experiment output datafile organization

This dataset consists of recordings from ten spotted ratfish (*Hydrolagus colliei;* Figure 2A), a species local to Puget Sound. Sounds of varied frequencies (55 – 1695 Hz) and amplitudes (90-150 dB re: 1 μPa) were presented via an underwater speaker to determine this species audible hearing range. Neural responses were recorded using a four-channel array of extracellular needle electrodes (Figure 2A). Responses were recorded using a custom-built EEG acquisition software, and data were saved as MATLAB files for later analysis in Python. The software conducted t-tests comparing the amplitudes at the expected auditory response frequency before (pre-stimulus) and during (intra-stimulus) sound presentation— defining a positive response as a statistically significant increase during stimulus presentation (Figure 2B). Trial-by-trial raw electrode signals reflect time-series data ("brain waves") sampled online at a rate of 44,100 Hz and saved at 22,050 Hz. Data were also analyzed and visualized online using methods such as signal averaging, Fast Fourier Transform, and t-tests (See Figure 2C for data structure).

Objective 1: Improve accuracy of positive auditory response detection

Hypothesis	Solution	Data Scientist Role
Detection of a positive auditory response by comparing the amplitudes at the expected response frequency during pre-stimulus and intra-stimulus periods may be **too simplistic.** This approach may omit other potentially relevant response features such as expected absolute voltage values and amplitudes at other response frequencies.	Conduct **cluster analyses** to identify patterns amongst response characteristics— including the mean auditory response amplitude across all trials and standard deviation of the averaged response. These patterns will inform how the software defines positive responses. Further, utilize **more sophisticated denoising** methods to increase signal to noise ratio of electrode signals. This will allow better detection of true auditory responses that may be hidden in the noise floor.	1. Provide guidance on which types of cluster analyses to conduct and help employ these techniques in a data analysis pipeline. 2. Help employ de-noising methods to increase signal to noise ratio of electrode signals (e.g., ICA, wavelet denoising). 3. Provide critique on current statistical response detection method and propose alternative approaches.

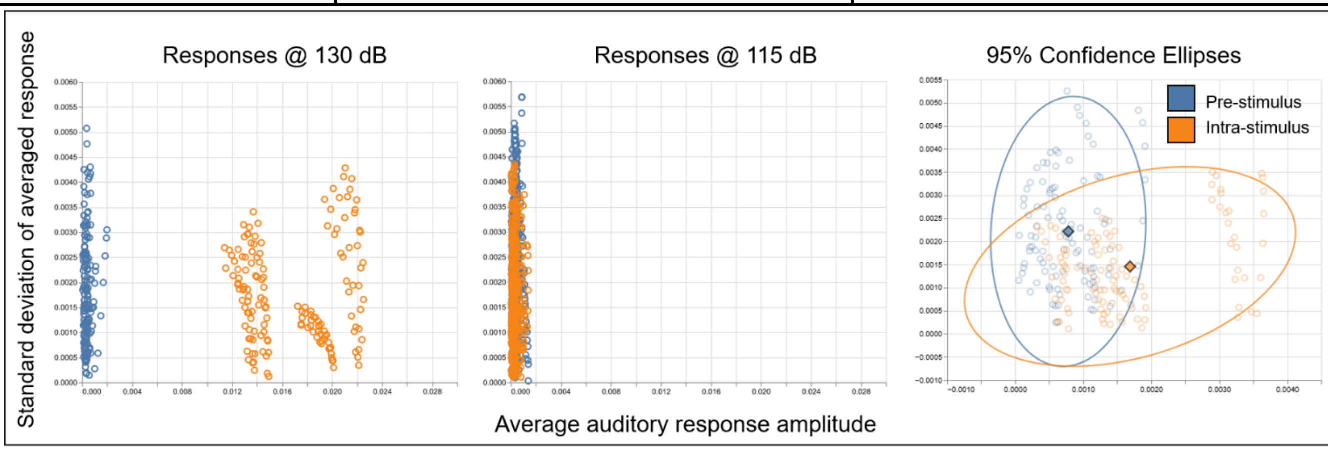

Figure 3: (A) Through initial exploration of my dataset, clusters of responses and differences in cluster shapes can be seen. Response amplitudes during pre-stimulus and intra-stimulus periods are differentiated by color. Each plot represents data at a single response frequency (B) An example of my initial attempt at cluster analysis

Objective 2: Identify unique neural generators from 4-electrode montage

Hypothesis	Solution	Data Scientist Role
Activity from the 8th cranial nerve, hindbrain, and forebrain, contributes to the composite auditory response signal recorded by the needle electrodes. Each neural generator has **distinct response characteristics**. For example, the 8th cranial nerve afferents respond at twice the stimulus frequency, whereas more central structures do not.	Apply Independent Component Analysis (ICA) and other blind source separation techniques on the four-channel dataset to distinguish unique neural generators.	1.Share resources that provide background knowledge needed to understand how ML techniques like ICA work. 2.Identify and help implement ML techniques to this dataset.

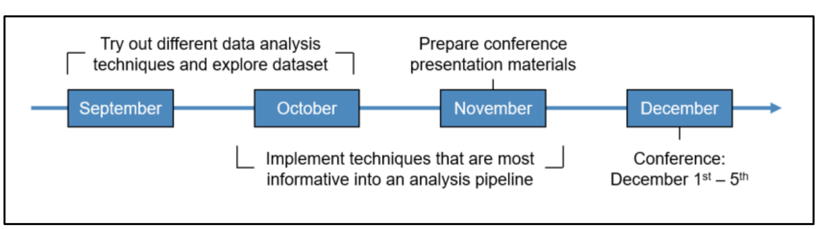

Figure 4: Proposed Fall 2025 timeline for this project

Timeline: Minimum, achieve *Objective 1* by late November in time to prepare presentation for early December conference (Acoustical Society of America, ASA). If needed, efforts for *Objective 2* can be pushed off till Winter 2026.

References

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