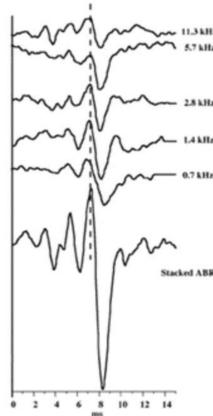


Automated Analysis for Auditory Brainstem Responses (ABR) in Mice

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Background Overview

*In collaboration with the Manor Lab at UCSD



The field of auditory research has seen significant advancements in the understanding and characterization of **Auditory Brainstem Response (ABR)** recordings originating from the cochleae of animals. ABRs provide a measurement of electrical brain activity through the neural pathway **from the auditory nerve to the mesencephalon**, where sound is processed.¹

Figure 1: An example of how ABRs are examined.

ABR wave analysis is used for identifying the **hearing thresholds** of subjects (the minimum decibel level at which a subject can hear an auditory stimulus) at various frequencies.

The curvature of wave peaks and peak amplitudes have been used for threshold identification.² **Wave I** is commonly used for auditory threshold studies because it represents the peripheral auditory nerve, is highly correlated with synapse counts in mice, and can be used as a measure of synaptopathy.³

The hearing threshold can be operationally defined as the lowest level at which a Wave I peak can be visually identified.⁴ Visual examination is relatively easy and fast, but can be inconsistent across examiners, prone to bias, and not strictly quantitative.

Problem Definition

Auditory Brainstem Responses (ABRs) are widely used in hearing studies. However, they present challenges:

- **Standardized Software:** No standard ABR analysis software exists that supports various file types and works across different operating systems.
- **Time-Intensive Workflow:** Features like wave amplitudes, peak/trough detection and hearing threshold detection are often performed manually.

Time-Intensive Workflow

1. Plot ABRs
2. Manually identify wave peaks
3. Manually identify hearing thresholds

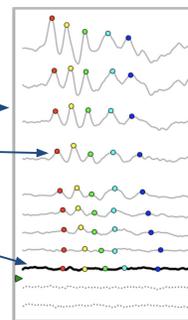


Figure 2: Peak and Threshold Detection software from the Liberman Lab at Harvard University

Methods

Data Collection

Sound stimuli were presented to mice via a speaker, and ABRs were recorded for 10 ms at the onset of each tone. The sound intensity level was decreased from 90 dB SPL to 10 or 20 dB SPL, with 512 responses averaged at each level.

Estimating Hearing Thresholds

A Convolutional Neural Network (CNN) was trained to classify ABRs as indicative of hearing or not. Hearing thresholds were estimated as the lowest dB level classified as hearing for a subject at a particular frequency level

Training Set:

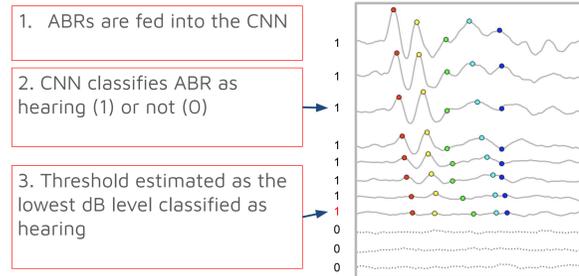
- 21,384 human-labelled ABRs

Input Features:

- Array; complete ABR trajectory
- Float; Tone decibel level
- Float; Frequency

Outcome Variable:

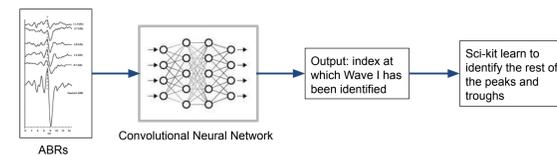
- Binary; whether the ABR is indicative of hearing



Estimating Wave Peak & Trough Location

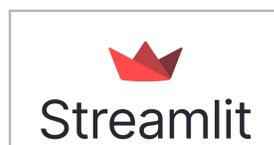
A two-step method is being trained using our labeled data to identify the Wave I-V peaks of ABRs.

- **Step 1:** Use a trained CNN to get predictions for Wave I
 - o Features include the complete ABR trajectories for the 767 ABRs on which we have ground truth Wave I peaks.
- **Step 2:** Use optimization methods built into Sci-Kit Learn to find Waves I-V
 - o Optimized using ground truth Wave IV amplitude data from 211 ABRs



Data Visualization and Analysis

A Graphical User Interface (GUI) was built using Streamlit to integrate our threshold and peak detection algorithms in a user-friendly web application



<https://ucsdabranalysis.streamlit.app/>

Results

Threshold Estimation

The performance of our threshold estimation method was assessed on a test set of 5,384 unseen ABRs.

- 95.08% accuracy in classifying ABRs as indicative of hearing.
- True Positive Rate (TPR) = 95.36%
- False Positive Rate (FPR) = 5.49%.

In terms of threshold estimation,

- 94.42% of the estimates were within 15dB of the ground truth,
- 91.15% were within 10dB
- 81.31% were within 5dB.

These results demonstrate the effectiveness of our method in estimating the threshold with high accuracy.

Peak and Trough Location Estimation

- The performance of our peak detection method based on Wave I latency has a Mean Absolute Error (MAE) of **0.0986 ms** on 154 testing ground truth labeled ABRs.
- For reference, the Lauer Lab at Johns Hopkins University has their own open-source tool for analyzing ABRs⁵, and on those same 154 ground truth labeled ABRs, the Lauer Lab software has a MAE of **0.3730 ms**.

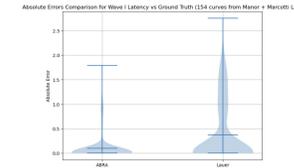


Figure 3: Violin Plot Comparing ABRA's Absolute Errors with the Lauer Lab Software's Absolute Errors

Interactive Web Application

A web application is created using Streamlit which allows users to batch-upload and analyze ABR data

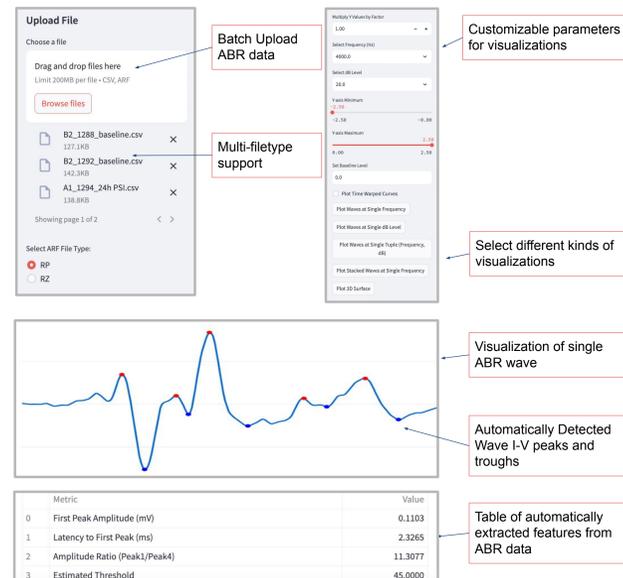


Figure 4: An Example of Interactive Web Application
The GitHub repository for this dashboard is publicly available at <https://github.com/abhierra2/ucsdpracticum>

Discussion

Pros of the Automated ABR Analysis (ABRA) Tool

- Reduces workload: no human intervention is required
- Easy to use: low computational cost
- Flexible: only a few restrictions on data input rules

Comparison with Other Available Tools

The Lauer Lab at Johns Hopkins University has created an open-source tool of their own for analyzing ABR waves. Here are some observations we've made about their tool compared to ours:

	ABRA	Lauer Lab Software	EPL ABR Peak Analysis App (Liberman Lab)
Stability	When errors arise, app can recover easily	Prone to crashing (one error and the app crashes and you must close the app and start over)	When errors arise, app can recover easily.
File Type Support	Only a couple rules related to the file structure. Multiple data types welcome.	Each file must follow the same restrictive file structure	Only supports EPL file type
Operating Systems	Operational on Windows, Mac and Linux	Only operational on Windows	Operational on windows and mac
Web Support	Web-based application that can also be run locally	Run on local machines only	Run on local machines only
Data Extraction	Generate metrics table with a single click.	Must click through all waveforms to generate a metrics table (tedious task)	Metrics are not accessible
Metric Exports	Metric table only has three metrics per wave + the estimated threshold.	Metric table much more comprehensive	No metrics table
Threshold Detection	Does automated thresholding	Does not do automated thresholding	Does automated thresholding
Accessibility	Free and open source	Free and open source	Free and open source
Visualization Exports	Can download plots as .png	No functionality	No functionality

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