The Auditory Pathway from Brainstem to Cortex in one Simultaneously Recorded EEG-MEG Dataset

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Significance:

Understanding *where* (spatial) and *when* (temporal) neural activity occurs in response to auditory stimulus is important in the fields of neuroscience and hearing research. The existing non-invasive brain measurement techniques have their strengths and weaknesses, and none can receive both a high spatial (subcortical and cortical) and high temporal resolution. In this study we evaluate a set of sparse linear filters, called neuro-current response function (NCRF), on brain activity data measured by both electroencephalography (EEG) and magnetoencephalography (MEG) simultaneously. We utilize the strengths of each technique, where EEG can estimate subcortical high-frequency responses to speech, while the cleaner, low-frequency, MEG measurements are superior at cortical tracking of the low-frequency speech envelope. Our goal in this ongoing study is to sparsely map the auditory pathway (from the cochlear nucleus, through the subcortical structures to the auditory cortex) both spatially and temporally. This could provide insights into the connection between the two regions and their combined role in speech perception, which might be overlooked when analyzing different datasets separately.

Extended abstract:

The mystery of the human brain has fascinated and puzzled people for thousands of years. Ethical guidelines have restricted harmful methods, leading to the development of safer, non-invasive techniques such as electroencephalography (EEG) and magnetoencephalography (MEG), which avoid injections, surgery, and ionizing radiation. These methods have provided valuable insights into the brain's role in hearing and hearing loss over the past decades.

The auditory pathway describes the route and transformation of a sound wave entering the ear to the high-level processing of electrical signals in the auditory cortex. It is a complex journey, where the role of each stage has major impact on the final sound perception. In the first stages (outer ear, middle ear, inner ear), air vibrations are converted to neural signals, which thereafter travel through the auditory nerve to the brainstem and its surrounding regions for early signal processing. These subcortical structures are located deep into the brain and are responsible for localization of where the sound is coming from by detecting the time differences and sound intensity between the ears. Subcortical responses are characterized by weak and rapid (within 10ms) waves for each processing stage and are only detectable with high sampling frequency [1].

Afterwards, the electrical signals travel to the auditory cortex for higher-level processing. Cortical regions refer to the outer layer of the brain and is associated with higher-level thinking, language and speech processing. Auditory cortical responses are typically slower than subcortical responses, which means they can be accurately captured using a lower sampling frequency. In conclusion, the functions and characteristics of subcortical and cortical responses are very different form each other, and have therefore often been recorded, modelled and analysed separately. Hence, the selected measurement technique can enhance certain analyses more effectively than others.

EEG is known for its high temporal resolution, meaning that it can detect changes in brain activity on a very short time scale (millisecond-by-millisecond). Our brain consists of billions of neurons, and if large groups of well-synchronized neurons fire simultaneously, their combined electrical signal becomes large enough to be picked up by EEG-sensors placed on the scalp if the sampling rate is high enough. Although measurable, typical neural responses measure in the microvolts, resulting in a low SNR when measuring at the EEG sensors. Another issue is the non-trivial signal propagation from source to sensor, as the varying conductivity of brain tissue, skull and scalp significantly distorts the signal and harms the spatial resolution. Naturally, brain activity closest to the sensors, on the brain surface, travels shorter distance before being detected by the scalp sensors and is less distorted compared to activity from deeper (subcortical) regions. In summary, EEG measurements are characterized by high temporal and poor spatial resolution, where subcortical regions are detectable but inherently noisier compared to cortical regions.

Despite its reputation for high temporal and good cortical spatial resolution, one major drawback with magnetoencephalography (MEG) is its inability to measure from subcortical regions. The technique employs sensitive magnetometers placed in a dome around the scalp to detect the tangential (currents flowing in parallel to the skull) magnetic field generated by electrical signals. Most subcortical regions produce radial currents (perpendicular to the skull), which in combination with their greater distance to the sensors makes MEG almost insensitive to subcortical activity. On the other side, tangential magnetic fields from cortical regions can pass through brain tissue, skull and scalp without much distortion and are typically less noisy compared to EEG. This advantage has led to successful research in cortical source localization using MEG.

Source localization algorithms address an inverse problem, utilizing data from tens to hundreds of sensors to map measurement to thousands of brain sources. Typically, these methods involve two steps: (1) fitting a linear model for each sensor, and (2) solving the inverse problem to estimate the source activity. If these two steps are done independently and in sequence, the risk of leakage between the two steps increases which often results in blurry source localization. NCRF, a sparse source localization method, was developed where the two steps are executed simultaneously in an iterative procedure [2]. The method was developed for cortical analysis with MEG data and has recently been shown to have potential for cortical EEG analysis [3].

Our goal in this ongoing study is to sparsely map the auditory pathway (from the cochlear nucleus, through the subcortical regions to the auditory cortex) both spatially and temporally. We are utilizing the NCRF-method with a simultaneous recorded EEG-MEG dataset, where our test participants were tasked to pay attention to one of two overlapping speakers. Subcortical analysis is based on high-frequency EEG data, while we switch to low-frequency MEG data for our cortical analysis. As this study is new and ongoing, only preliminary results will be presented.

References:

[1] Middlebrooks, John C. & Simon, Jonathan Z. & Popper, Arthur N. & Fay, Richard E. *The Auditory System at the Cocktail Party.* Edited by John C. (John Charles) Middlebrooks et al., 1st edition., ASA Press, 2017.

[2] Das, Proloy & Brodbeck, Christian & Babadi, Behtash. (2020). *Neuro-Current Response Functions: A Unified Approach to MEG Source Analysis under the Continuous Stimuli Paradigm*. NeuroImage. 211.

[3] Wilroth, Johanna & Kulasingham, Joshua P. & Skoglund, Martin A. & Alickovic, Emina. (2023). *Direct Estimation of Linear Filters for EEG Source-Localization in a Competing-Talker Scenario.* IFAC. Volume 56, issue 2.