Exploring Dynamic Field Theory

Using EEG-fMRI Integration for Auditory OddBall Task(AOD)

Introduction

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A **framework** for understanding how the **brain organizes sensory, motor, and cognitive operations** through **dynamic interactions within neuronal populations**.

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Activation Dynamics: Neural fields are characterized by continuous activation levels that change over time in response to inputs and interactions with other fields

Stability and Instability: The theory distinguishes between stable states (sustained activations that can maintain behaviorally relevant information) and instabilities (transitions between states, triggered by inputs that reach a threshold).

What do we wish to understand?

We aim to understand how audio is perceived, recalled and processed at the neuronal level. For this:

Identify Neural Correlates: Determine the specific brain regions and neural pathways that are activated during the Auditory Oddball Task, aiming to better understand the neural basis of auditory perception and attention.

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Identify Neural Correlates: Determine the **specific brain regions and neural pathways** that are activated during the Auditory Oddball Task, aiming to **better understand the neural basis of auditory perception and attention**.

Compare Cognitive Processes: Investigate the differences in brain activation and response patterns between control and patient groups to gain insights into how auditory processing might differ in various populations or under different cognitive conditions.

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Data for the **healthy control group** was extracted from a dataset derived from **simultaneous EEG-fMRI recordings** of both healthy controls and individuals with schizophrenia. All participants in the study were engaged in performing an **Auditory Oddball Task**.

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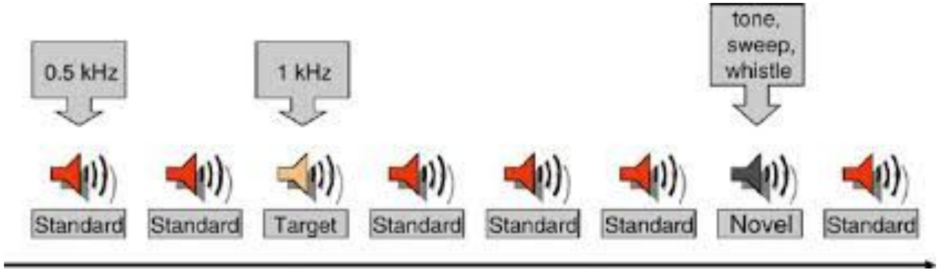
Use Data for the **healthy control group** which was extracted from a larger dataset comprising **simultaneous EEG-fMRI recordings** of both healthy controls and individuals with schizophrenia. All participants in the study were engaged in performing an **Auditory Oddball Task**.

What is **Auditory Oddball Task**?

A series of **repetitive auditory stimuli**, like **tones or beeps**, are presented, with the **occasional unexpected stimulus**, called the **"oddball"**. The oddball stimulus may **differ in pitch, duration, or loudness** from the standard stimuli.

Stimulus Duration : 200 milliseconds(ms)
Interval Duration: 1000 milliseconds(ms)
Participants: 23



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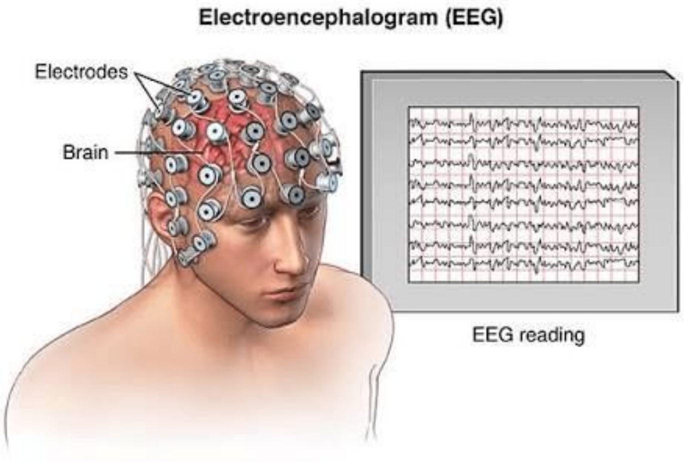
EEG: measures the **electrical activity** of brain by using electrodes places on the scalp. **Records rapid fluctuations in brain** activity over milliseconds, reflecting real-time dynamics of neural circuits.

fMRI: captures **changes in brain blood flow and oxygenation**, which are correlated with neural activity. It **provides high-resolution images of brain structures**, allowing for **precise localization of brain activity** over seconds to minutes.



Why use simultaneous EEG-fMRI ?

EEG: **Records rapid fluctuations in brain** activity over milliseconds, reflecting real-time dynamics of neural circuits.

fMRI: It **provides high-resolution images of brain structures**, allowing for **precise localization of brain activity** over seconds to minutes.

EEG is spatially insufficient to explain the precise neural parts of brains involved, while **fMRI is temporally insufficient** due to hemodynamic response time (time take for the blood to flow)

Hence, combining them would help us capture neural activities with **spatial and temporal precision.**

How do we fuse the two modalities?

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Three categories: EEG-informed fMRI, fMRI-informed EEG, and **symmetric fusion**.

EEG-informed fMRI: identify brain regions where fMRI signals correlate with specific EEG patterns, like NESOI (Nonlinear EEG Synthetization and Optimal Integration).

fMRI-informed EEG: help in pinpointing the electrical correlates of the brain regions highlighted by fMRI, like LMSA (Linear Multivariate Statistical Analysis).

We use **jICA (Joint Independent Component Analysis),** a **symmetric fusion** technique treats both data types equally, identifying components that capture variations shared across EEG and fMRI datasets.

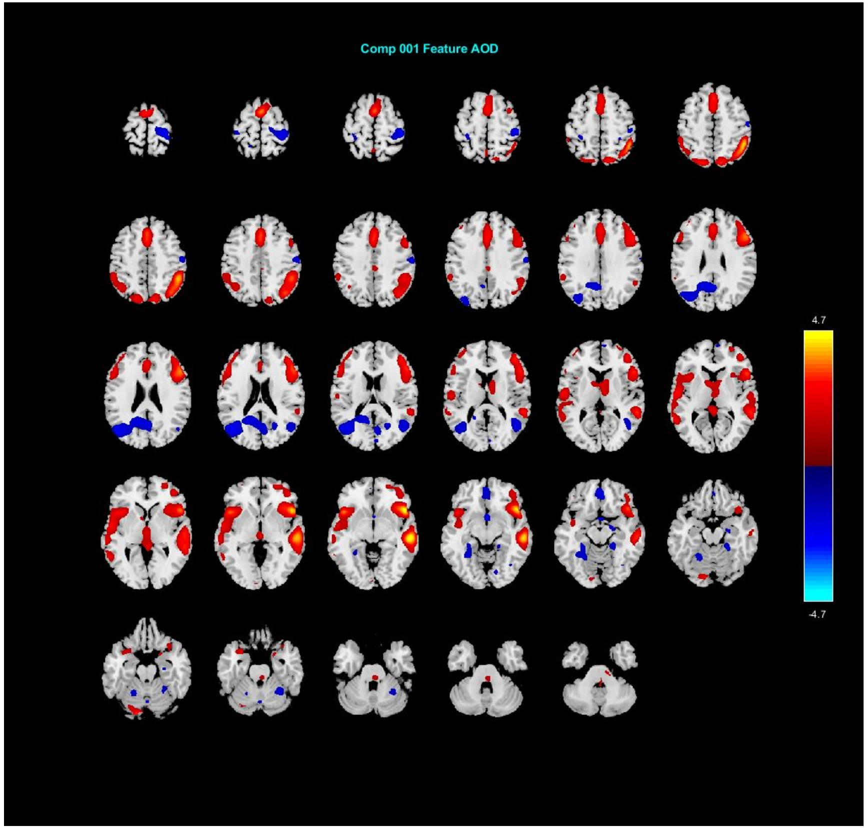
Understanding jICA

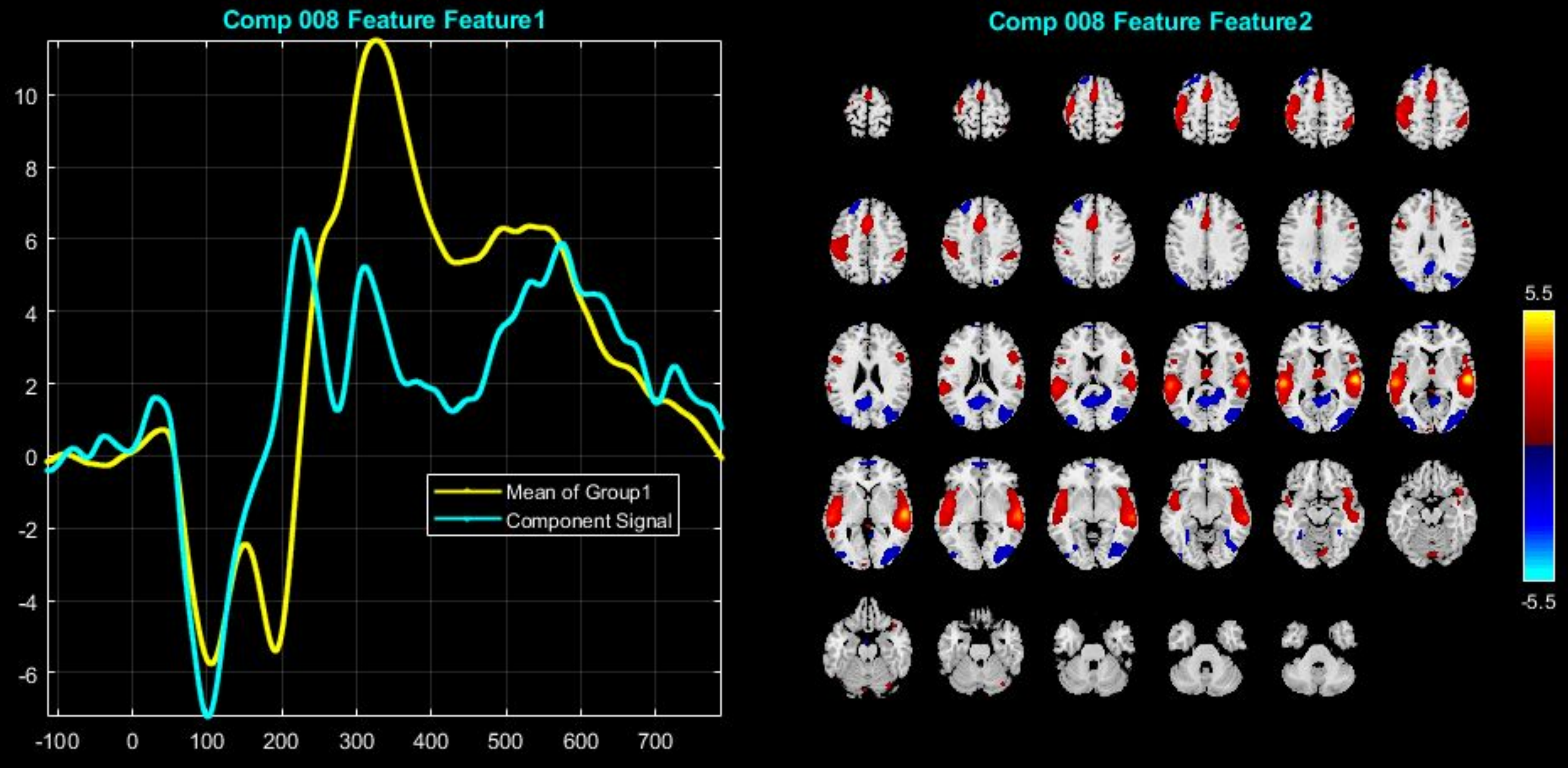
Understanding Independent Components in jICA

Independent components are **statistically independent sources** that contribute to the mixed signals observed in EEG and fMRI data. These components are **extracted from the combined data set and represent underlying brain processes** that manifest across both modalities simultaneously.

jICA identifies components that represent shared information across the modalities, providing a unified view of brain dynamics during cognitive tasks.

We use the **Fusion ICA (FIT)**, a toolbox designed for analysis of preprocessed simultaneous EEG-fMRI Dataset.

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700
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Comp 008 Feature Feature2
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Demo

Interpretation of Dynamic Field Theory (DFT)

Neural Field Stability and Instability:

Peaks in the EEG signal can indicate moments of instability where the **brain shifts its state in response to oddball stimuli**—these are moments when a new auditory input (the oddball) is detected and processed.

The subsequent stabilization (post-peak) might reflect the **brain's return to a baseline state** or preparation for the next stimulus.

Interpretation of Dynamic Field Theory (DFT)

Neural Field Stability and Instability: Peaks in EEG signals indicate neural response instabilities to new auditory stimuli, with stabilization suggesting a return to baseline readiness for subsequent stimuli.

Interaction Between Regions:

Dynamic interactions between activated and deactivated regions suggest how the brain **allocates resources during cognitive tasks**. For instance, deactivation in areas might indicate that resources are being funneled to more critical regions for task performance.

Interpretation of Dynamic Field Theory (DFT)

Neural Field Stability and Instability: Peaks in EEG signals indicate neural response instabilities to new auditory stimuli, with stabilization suggesting a return to baseline readiness for subsequent stimuli.

Interaction Between Regions: Deactivated areas likely reflect resource reallocation to activated regions critical for task-specific processing.

Temporal and Spatial Coupling:

The coupling between the temporal dynamics and spatial activations provides insights into how quickly and where exactly the brain responds to changes in auditory stimuli. This is crucial for understanding the neural basis of perception and attention within the framework of DFT, which posits that cognitive processes are supported by dynamic interactions across neural populations.

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Neural Field Stability and Instability: Peaks in EEG signals indicate neural response instabilities to new auditory stimuli, with stabilization suggesting a return to baseline readiness for subsequent stimuli.

Interaction Between Regions: Deactivated areas likely reflect resource reallocation to activated regions critical for task-specific processing.

Temporal and Spatial Coupling: The linkage between EEG-derived temporal patterns and fMRI-derived spatial activations elucidates the rapid and localized brain responses to auditory changes.

Future Scope

Advancing Neuroscience: Provides a deeper understanding of cognitive processes, aiding in the development of treatments for auditory and cognitive disorders.

Enhancing AI Models: The study's insights can inform AI, improving algorithms for sensory processing and anomaly detection, and inspiring more brain-like neural network architectures.

Interesting Insights

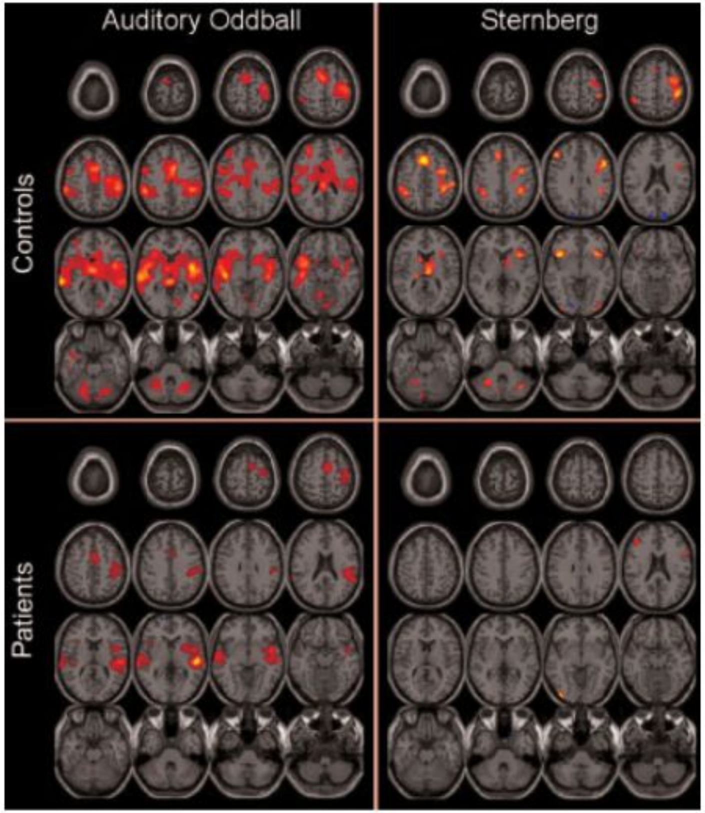


Figure 5.
Auditory oddball (AOD)/Sternberg (SB) group analyses. AOD target statistical parametric mapping (SPM) maps (left) and SB recognition SPM maps (right) for controls (top) and patients (bottom). Controls and patients both activated expected regions for both tasks, with patient activation being qualitatively less than controls.

Questions?

Thank you

Related Studies

Dynamic thinking: A primer on dynamic field theory (Book)
This book is a comprehensive primer on DFT, providing theoretical backgrounds and applications in cognitive science

Neural Dynamics of Attending and Ignoring in Human Visual Cortex
This paper integrates DFT with empirical data to explain attention mechanisms in the visual cortex

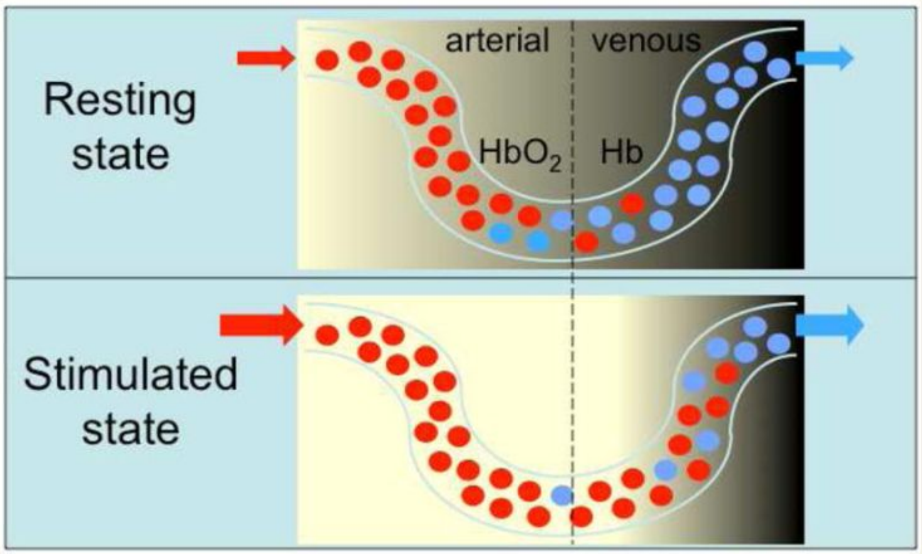
The Dynamic Brain: From Neural Spikes to Behaviors
This collection explores the dynamics of neural activity from various methods including EEG and fMRI, providing insights applicable to DFT

Integrating Eye Tracking with Neuroimaging: Methodologies and Applications Across Disorders
Discusses the benefits and methodologies of integrating eye-tracking with EEG and fMRI for comprehensive neural analyses

Differences Between Parallel ICA and Joint ICA:

- **Mixing Matrices**: In Parallel ICA, each modality has its own mixing matrix, which suggests that the same brain processes might be mixed in a similar but not identical manner in different modalities. In contrast, Joint ICA uses a single shared mixing matrix for all modalities, assuming a more uniform representation of brain processes across the modalities.
- **Component Linkage**: Parallel ICA focuses on identifying specific components that are more similarly expressed across modalities than others. This approach allows for the study of inter-subject variations and how certain brain processes are similarly or differently manifested across different modalities. Joint ICA, meanwhile, tends to look at the interconnections and the combined effects of components across all included modalities as a whole.

Figure 1.



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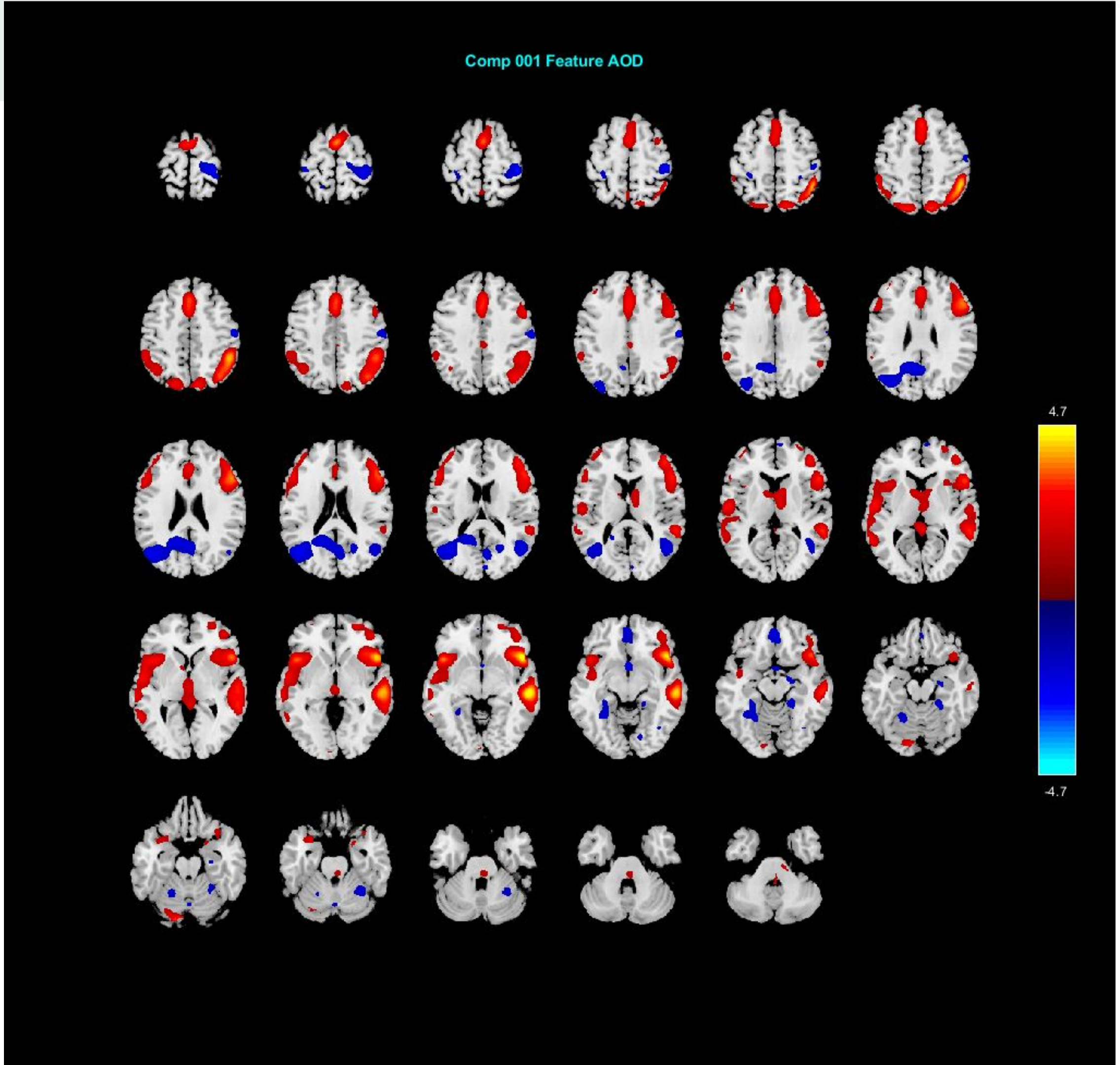
Sketch of brain tissue containing a capillary during rest (top) and activation (bottom). Red and blue circles represent red blood cells that are fully oxygenated (HbO2) and fully deoxygenated (Hb), respectively. The MRI signal is depressed in the venous side of the capillary due to the paramagnetic susceptibility of the HB acting as an endogenous contrast agent (shown darker). In the stimulated condition, increased blood flow causes the Hb to be swept out and replaced by HbO2, causing a BOLD signal increase.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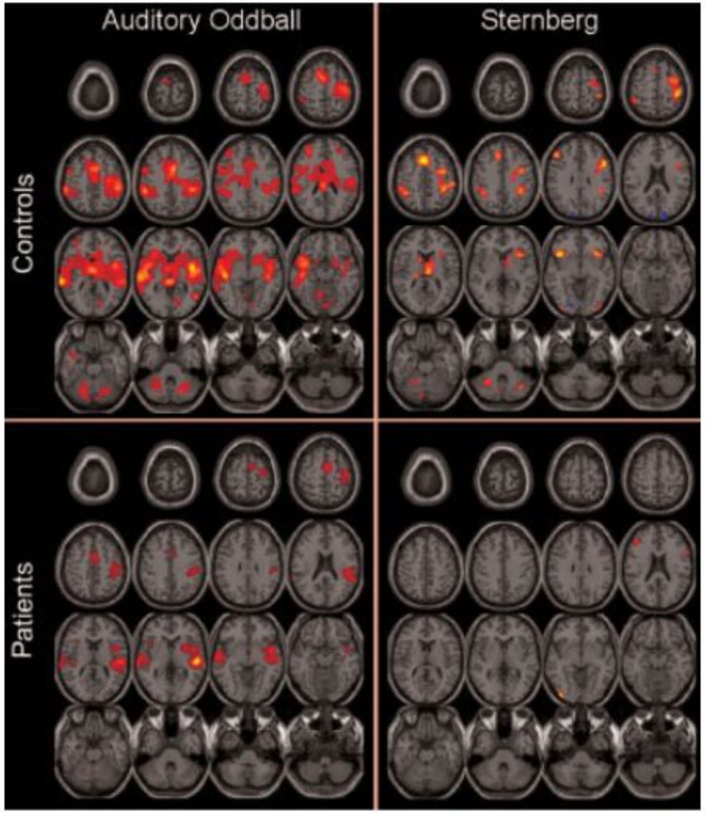

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