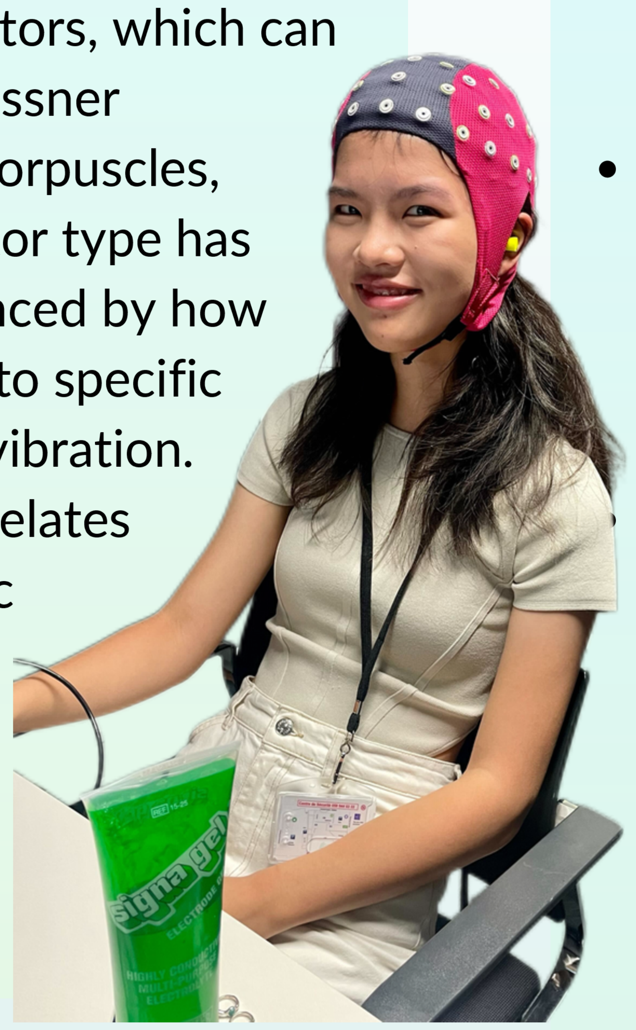
EEG Correlates of Tactile Sensations

By Yi-Chen Pai, Niccolò Venturini Degli Esposti, Leonardo Pollina, Silvestro Micera

Introduction: Brain Activity via EEG

Touch is essential for tasks like object manipulation and recognition, with the somatosensory cortex processing tactile information from the contralateral side of the body. The tactile information from the human hand is delivered through specialized skin receptors known as mechanoreceptors, which can be categorized into four types: Meissner corpuscles, Merkel cells, Pacinian corpuscles, and Ruffini corpuscles. Each receptor type has unique response properties, influenced by how quickly it adapts and its sensitivity to specific tactile stimuli, such as pressure or vibration. To explore the somatosensory correlates captured through encephalographic (EEG) signals during simultaneous tactile stimulation of the fingertips, we designed an experiment using six different combinations of force and vibration levels.

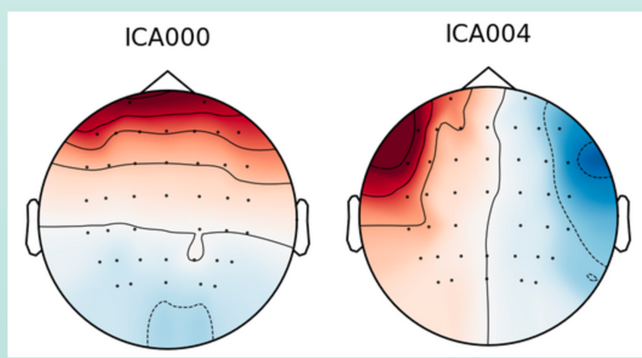


Procedure: EEG Stimuli Experiment

- **Step 1: Equipment Preparation**
  Connect the **ANT Neuro eego™ amplifier** with the 64-channel EEG cap and **TouchDIVER** via **Arduino**. Measure the subject's head for the cap and fingers for adapters. Ensure the cap fits, inject gel, and check impedance is under 25kΩ.
- **Step 2: Collecting Subject Data**
  Subject wears earplugs. Record name, birthdate, and finger data. Introduce six sensations (No/Low/High Frequency, Low/High Voice). Subject must pass with 80% accuracy.
- **Step 3: Experiment Sessions**
  Conduct 6 sessions (90 stimuli each). A cross appears for -1 to 2 seconds, followed by a 3-second break. Random classification checks subject's attention.

Processing: Preprocessing with MNE

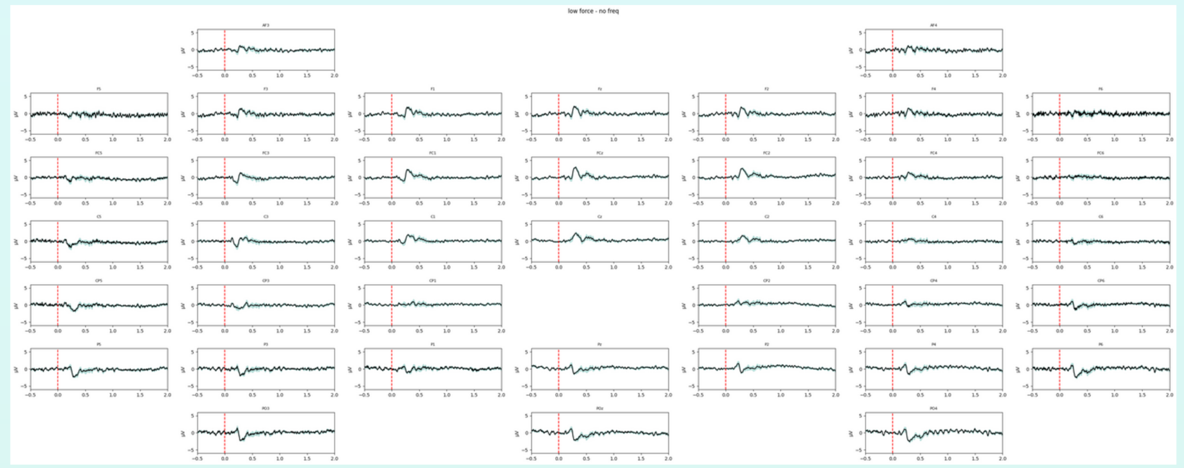
- **Why Preprocessing is Necessary** Preprocessing is crucial to avoid inaccurate EEG analysis. Muscle and eye movement artifacts can distort brain signals. In this experiment with a 64-channel EEG cap, peripheral channels are excluded, and a band-pass filter is used to remove unwanted frequencies.
- **Using Python and MNE** I used Python with the MNE library, an open-source tool for reading, preprocessing, and analyzing EEG data. MNE's versatility makes it ideal for EEG signal processing.
- **Detailed Steps of Preprocessing (12 Steps)**
  - **Load** EEG data using MNE.
  - **Reorder** channels and remove peripheral ones.
  - **Downsample** to 256 Hz and apply a 0.5-60 Hz **filter**.
  - **Relabel** and correct events.
  - **Segment** trials, remove unwanted events.
  - **Mark** bad or noisy channels.
  - **Create epochs** by converting annotations to events.
  - Perform **ICA** for artifact removal.
  - **Re-reference** using common average referencing.
  - **Detect** artifacts and **interpolate** affected channels.
  - Apply **baseline correction** by subtracting the pre-stimulus average.
  - **Save** the processed data for further analysis.



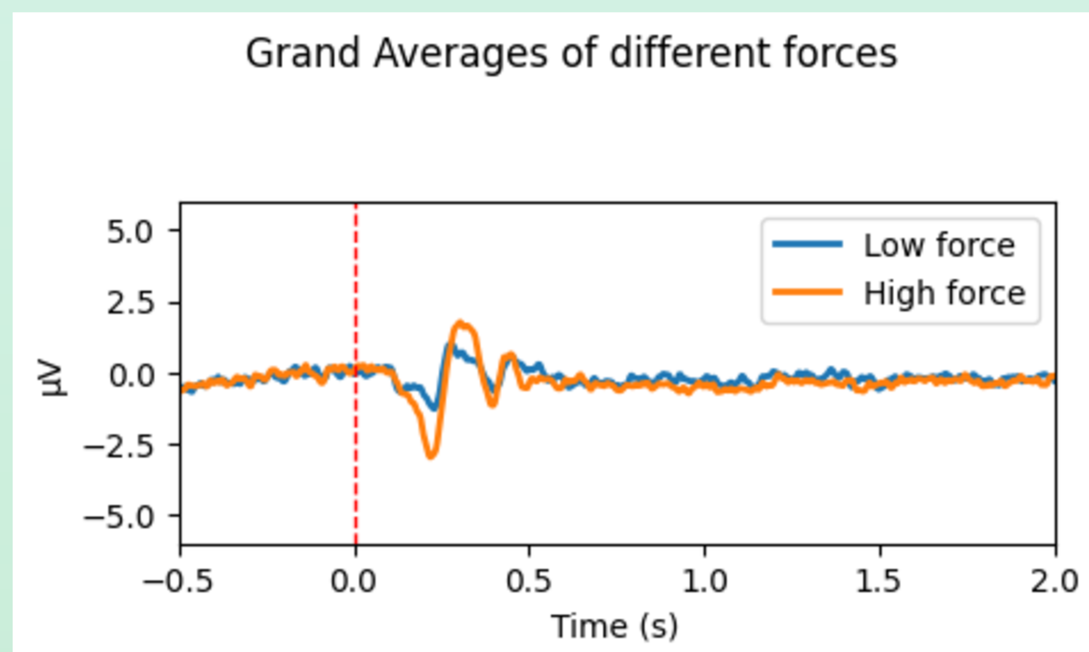
Eye movement artifacts in ICA components typically appear as large voltage shifts in the frontal region. In ICA000, the top-down red-blue gradient indicates vertical eye movements (e.g., blinks). ICA004 shows a left-right red-blue symmetry, characteristic of horizontal eye movements. These patterns suggest strong eye activity influencing the signals in these components.

Preliminary Analysis: Processed EEG

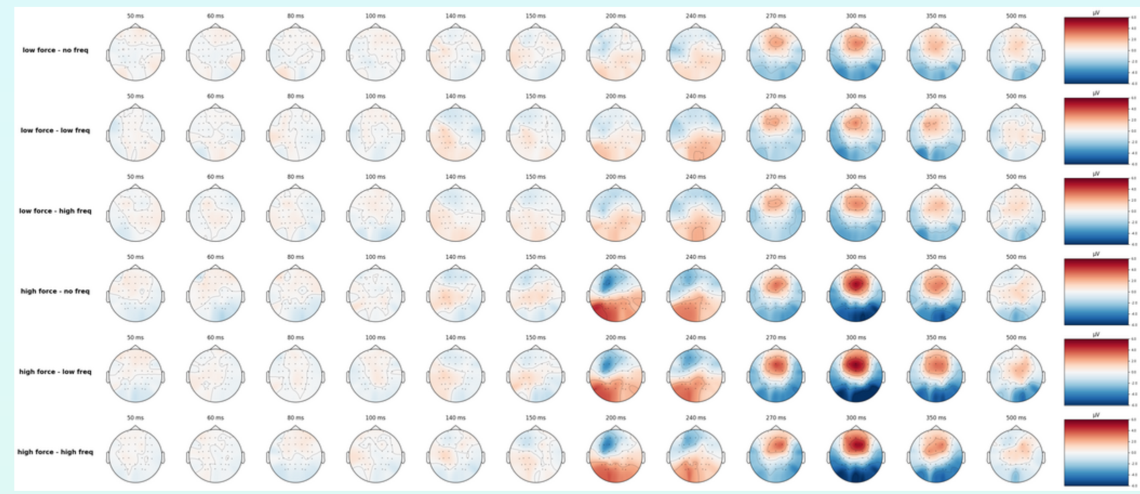
- **Grand Average Evoked Responses by Channel and Condition with SEM (Standard Error of the Mean)**
  - Shows grand average responses for each condition with SEM to highlight variability.
  - Assesses consistency in brain responses across trials and subjects, identifying key brain regions.



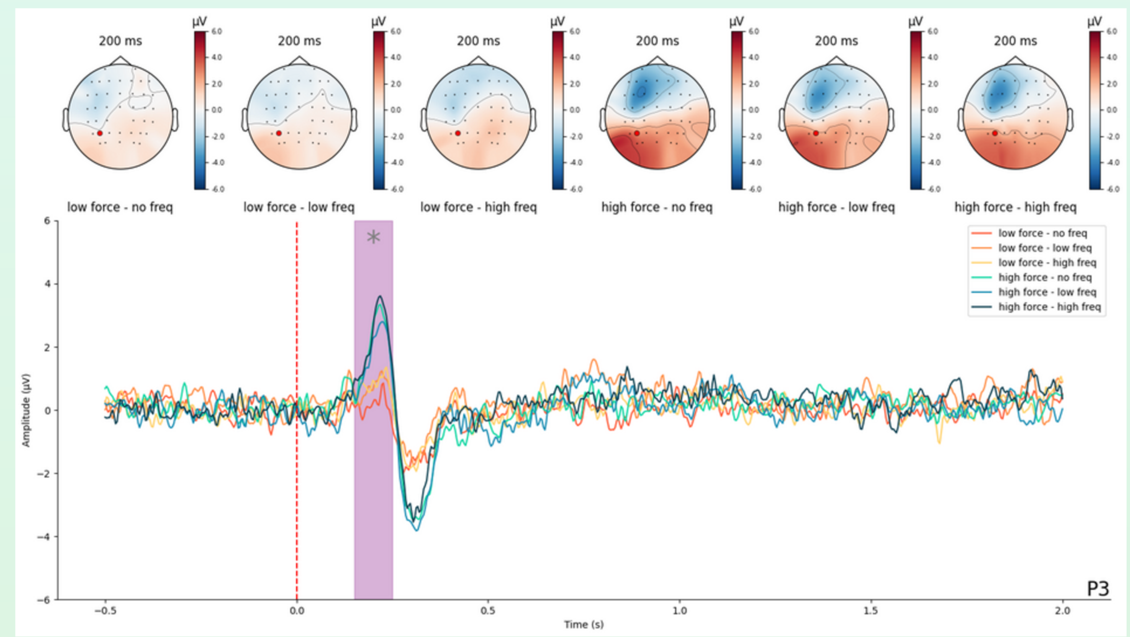
- **Overlay of Channel-Specific Responses for Each Condition**
  - Displays individual EEG channel responses for a single condition.
  - Highlights regional variability and timing differences in brain activity.
- **Condition-Wise Averaged Responses Across All Channels**
  - Averages evoked responses across all channels for each condition, overlaid in one plot.
  - Simplifies comparison of overall brain activity between conditions.
- **Grand Averages of Different Forces**
  - Compares low-force and high-force conditions.
  - Reveals how varying force levels affect brain responses.



- **Topographies at Interested Time Points**
  - Visualizes brain activity at specific time points for each condition.
  - Provides a spatial view of how neural responses evolve across the scalp.



- **Spatio-temporal Characteristics of ERP Waveforms and Topomaps Across Conditions**
  - Highlights differences in brain activity across conditions by combining ERP waveforms with topographic maps at specific time windows.
  - Clarifies how varying stimuli (force and frequency) impact spatio-temporal activation patterns in the brain.



Conclusion

This study revealed distinct EEG responses to tactile stimuli. In the early window (50-150 ms), both high and low force stimuli showed central-parietal activity. By the mid-time window (200-300 ms), the P200 component was stronger in the parietal region for high force stimuli, reflecting enhanced sensory processing. Later, in the 300-500 ms window, the P300 component shifted to the central region, more pronounced in high force conditions, indicating increased cognitive processing. This highlights a shift from sensory to cognitive engagement, especially for stronger stimuli.