Relating Variability in Scalp EEG to Variability in Cortical Morphology

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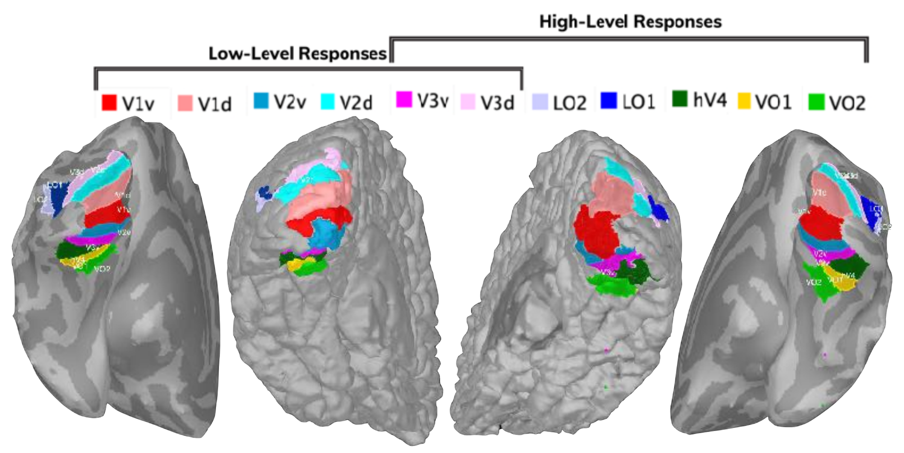
Background

Electroencephalography (EEG) is a widely used noninvasive brain imaging modality. Its utility is limited, though, by uncertainty about the sources of the electrical currents producing a given pattern of cranial voltages. This uncertainty arises because the inverse problem of locating currents given a pattern of voltages does not have a unique solution. However, the forward problem of specifying voltage patterns given currents has a unique solution. Recent research with macaque monkeys has demonstrated that sources of EEG signals can be located with knowledge of cortical morphology (Herrera et al. 2022). The current study uses EEG, sMRI, and fMRI data obtained from 12 participants viewing visual patterns (Kohler et al. 2016) to investigate relationships between variations in cortical morphology and variations in EEG. Steady-State Visual Evoked Potentials were recorded with 128 channels while observers viewed visual symmetry patterns. Previous results demonstrate that V1, V2, and V3 respond to any visual stimulus (detected in even harmonic responses), while V3, V4, VO1, and LOC are selective for symmetry (odd harmonic responses).

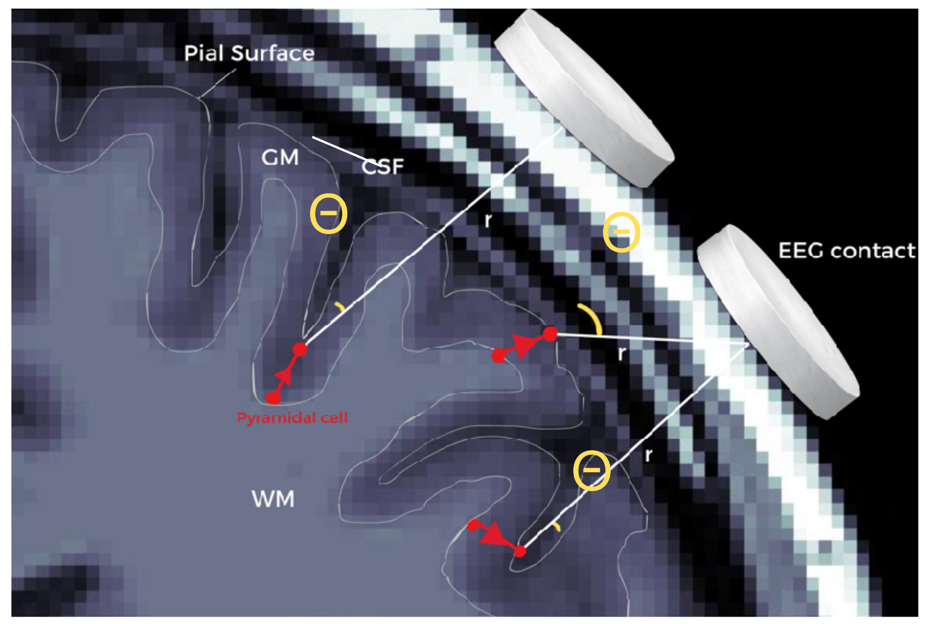


Research Question

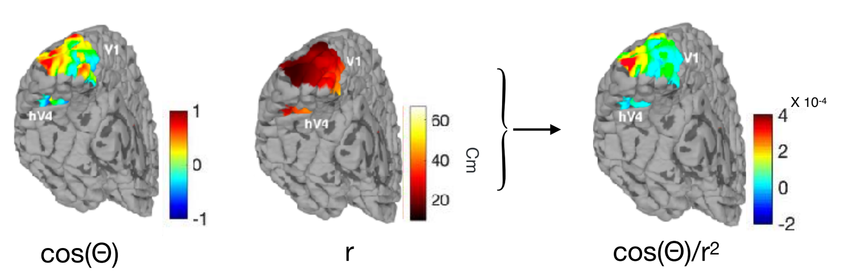
We aim to investigate how variations in cortical morphology relate to the patterns of EEG signals during the perception of visual symmetry patterns in human observers, considering the distinctions in response observed in cortical areas V1, V2, V3, hV4, VO1, and LOC between even and odd harmonic responses.

Methods

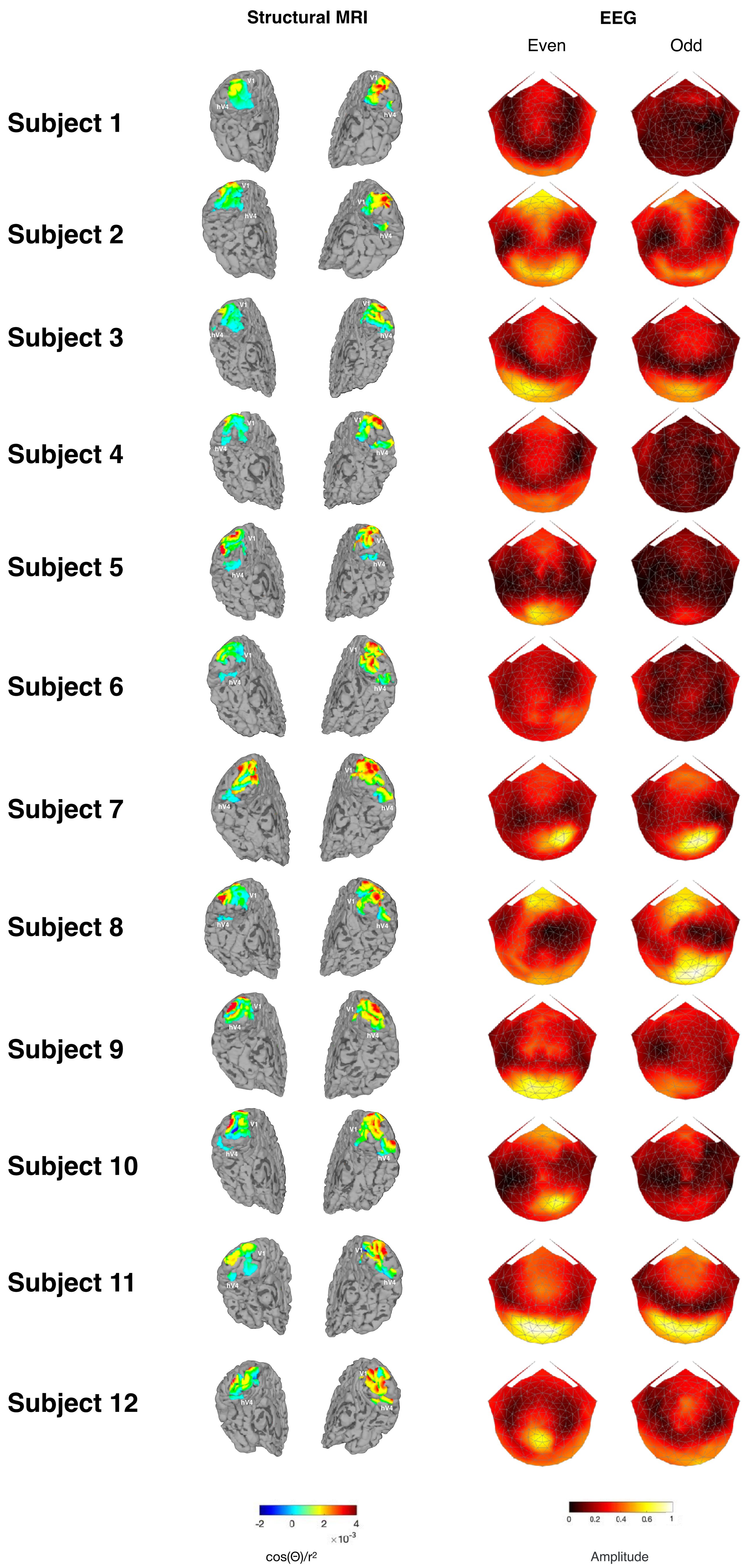
Possible contributions of current dipoles were estimated by the orientation (Θ) and distance (r) of cortical tissue in each area relative to EEG sampling channels (Nunez and Srinivasan, 2006). The contribution was quantified as cos(Θ)/r².



Coronal brain slice

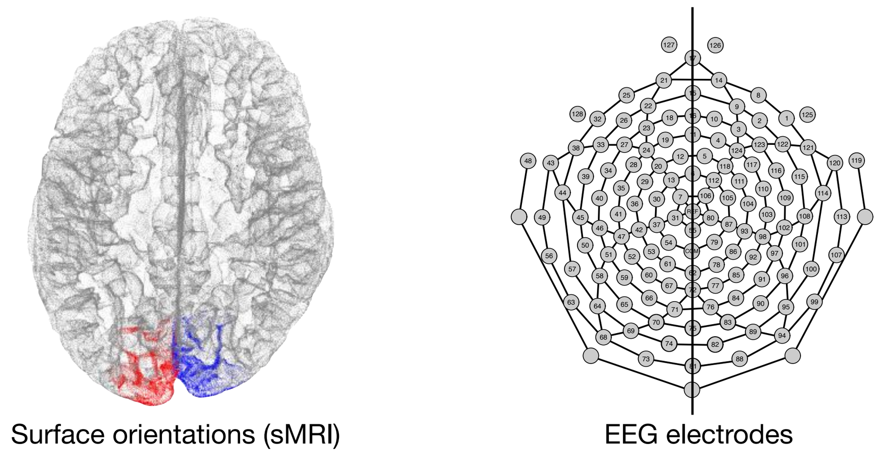


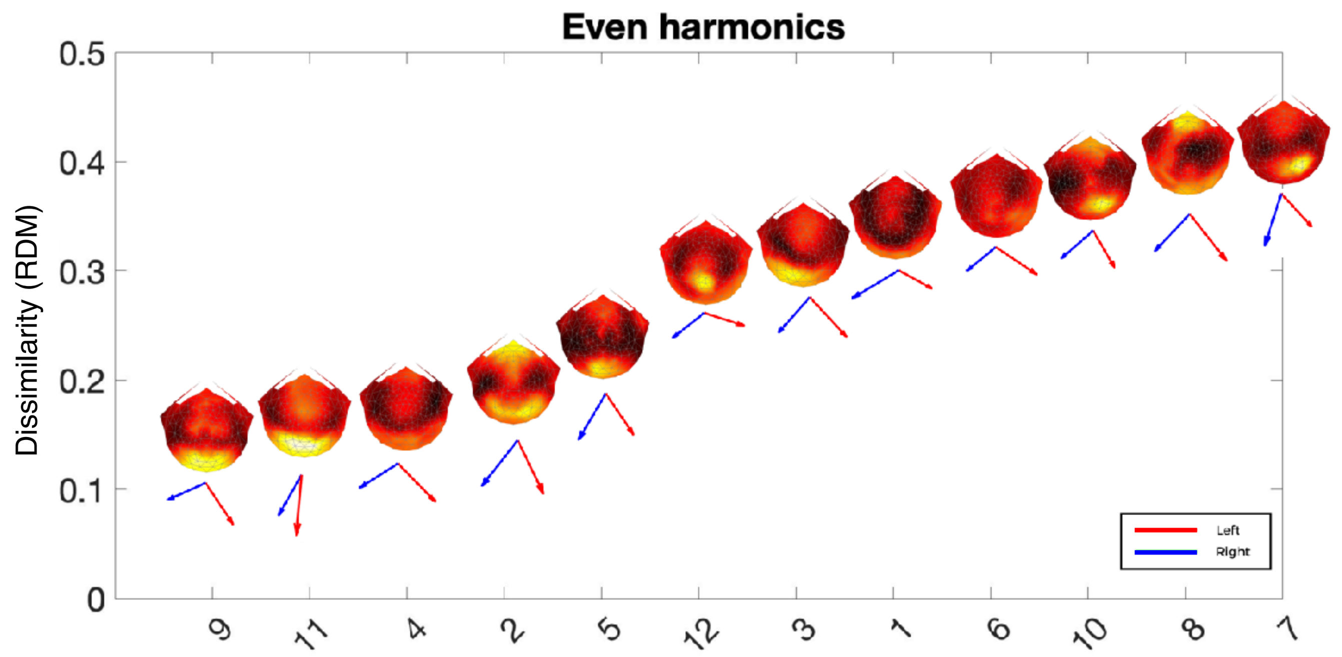
Results:Variation of brain structure and EEG pattern

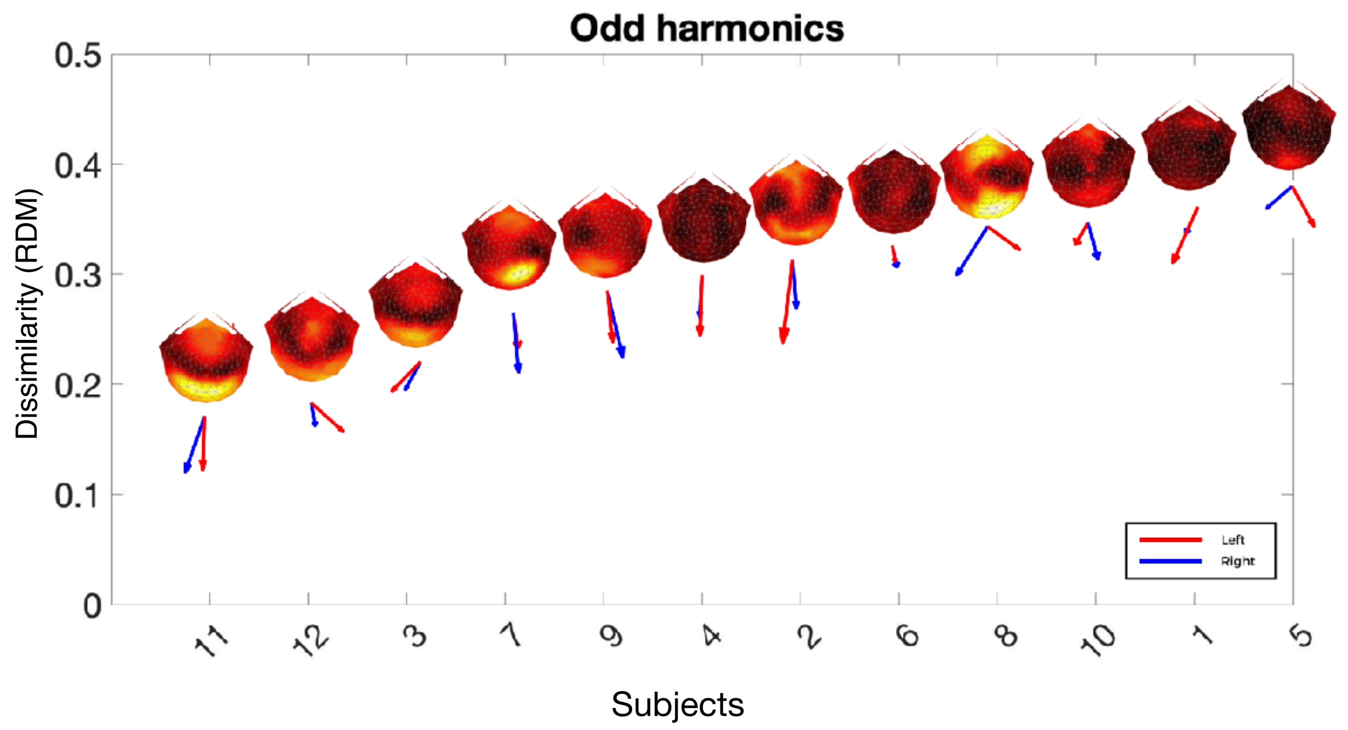


Results: Variation of Hemispheres in each participant

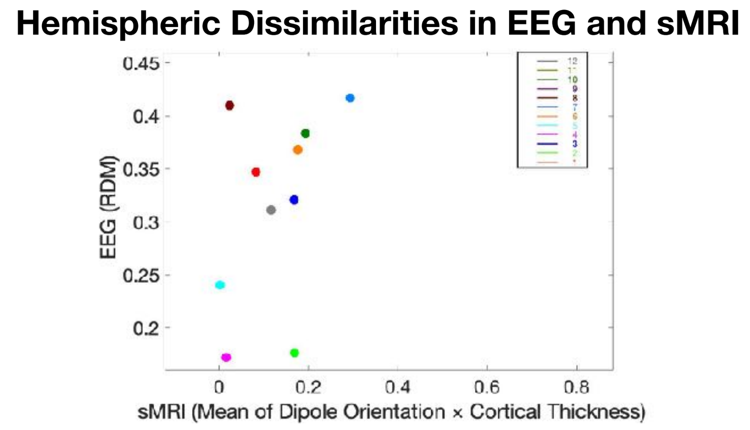
Utilizing two EEG sessions per individual, we computed the coherent average, followed by mean calculations for the first 5 odd and even harmonics. For inter-hemispheric amplitude comparison, we identified corresponding electrodes and determined the dissimilarity using the RDM method. Additionally, we assessed hemispheric dissimilarity in sMRI data by calculating the vector average of orientation multiplied by cortical thickness for all dipoles within V1, V2 and V3, subsequently computing the overall average.





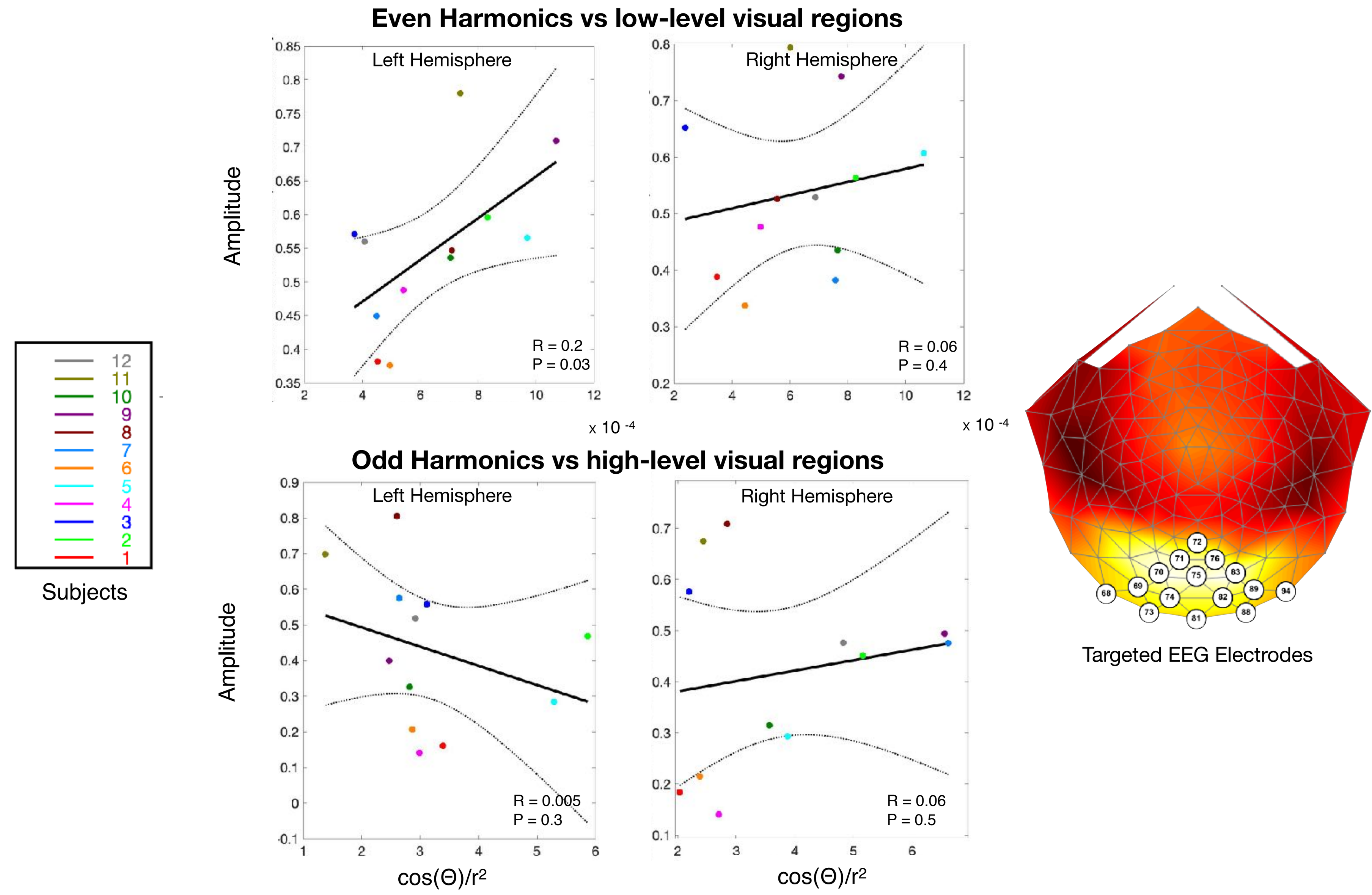


As the dissimilarity between the brain's left and right hemispheres increases in sMRI (V1, V2, and V3), so does the dissimilarity in the even harmonics of EEG signals in the majority of participants.



Results: Correlation between sMRI and EEG

The study compared EEG signals' even harmonics' average amplitudes in both brain hemispheres and calculated cos(Θ)/r2 averages for specific brain regions (V1, V2, V3) using sMRI data. Figures depicted correlations between EEG signal amplitudes at particular electrodes (75, 83, 81, 82,89,88,76,94,72) and cos(Θ)/r2 averages for corresponding regions in the left hemisphere, and electrodes (70, 75, 74, 81,69,73,71,68,72) in the right hemisphere. Additionally, the analysis extended to odd harmonics, showing correlations for both left and right hemispheres and areas V3, V4, LO, and VO. Variability among participants was evident in higher-level responses, particularly in V4, suggesting its importance in these responses. Thus, the expected correlation between odd harmonics and visual cortical area was not observed.

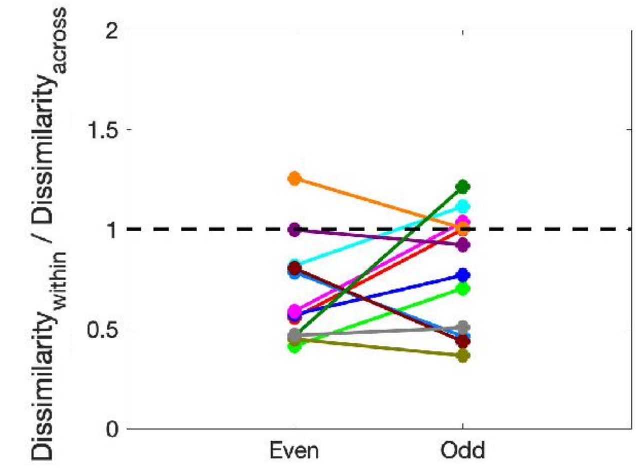


Results: Comparing EEG Sessions

Differences in EEG spatial patterns were quantified with a Relative Difference Measure (RDM) (Meijs et al. 1989). RDM values closer to 0 indicate higher similarity.

$$RDM = \left\| \frac{y}{\|y\|} - \frac{\hat{y}}{\|\hat{y}\|} \right\| = \sqrt{\sum_e \left(\frac{y(e)}{\sqrt{\sum_e y(e)^2}} - \frac{\hat{y}(e)}{\sqrt{\sum_e \hat{y}(e)^2}} \right)^2}$$

We performed an analysis comparing EEG patterns across sessions and participants. By computing the ratio of the RDM across participants to the average RDM within sessions for each individual, our study unveiled a noteworthy finding: The similarities found between sessions were stronger than those noticed among participants.



Conclusion

- Our analysis revealed that different sessions within the same participant produced more similar data than data across different participants, indicating that there is consistent individual variability in EEG scalp topographies.
- Remarkably, our analysis unveils a correlation between the orientation and distance of brain dipoles in V1, V2, and V3 of left hemisphere to the even harmonics of EEG signals. These findings are demonstrating a distinct correlation between sMRI measurements and EEG signals within the right hemisphere, as well. Notably, our observations indicate behavioural divergence in two individuals compared to the broader group, potentially attributed to left-handedness or other unidentified factors.
- The next step involves identifying a model capable of establishing the relationship between possible other relevant measures such as cortical thickness, the size of the Region of Interest (ROI) together.

References

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