Differential encoding of melodic expectations across brain frequency bands

Juan-Daniel Galeano-Otálvaro[1,4,5], Jordi Martorell[1,2], Lars Meyer[1,3], Lorenzo Titone[1]

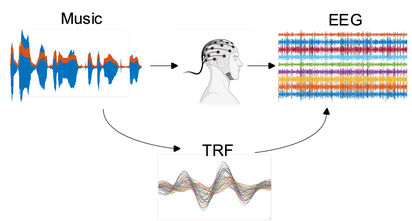
[1]*Max Planck Research Group Language Cycles, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany.*
[2]*Basque Center on Cognition, Brain and Language (BCBL), Donostia-San Sebastián*
[3]*Clinic for Phoniatrics and Pedaudiology, University Hospital Münster, Germany.*
[4]*Techinische Universität München, Munich, Germany.*
[5]*Elitenetzwerk Bayern, Germany.*
daniel.galeano-otalvaro@tum.de

Introduction

Oscillations and prediction

- Neural oscillations synchronize with temporal structure of sensory events, aiding tracking and **prediction** [1,2]
- Predictive mechanisms have been associated with neural activity in specific frequency bands (beta-gamma interplay [3]). In particular, **beta** and **delta** bands have been related to timing predictions [2,4].
- **Prediction** and **prediction error** relate to information-theoretical metrics (**entropy** and **surprisal,** respectively). In music, these values are calculated using computational such as Information Dynamics of Music (**IDyOM**) [5].
- EEG studies on music perception utilized IDyOM metrics and multivariate temporal response functions (**mTRFs**) and revealed that **melodic expectations** are **encoded** differently from acoustic features [6,7].
- **mTRFs (Forward model):** Set of weights obtained from a regularized linear regression of the EEG signal on several stimulus features. [8]

1 Multivariate Temporal Response Function (mTRFs)



- The current project aimed at showing a different neural encoding of temporal and content predictions across EEG frequency bands, during naturalistic music listening. In particular, we focused on the role of **delta-beta** dynamics in timing predictons [4], and **beta-gamma** for content predictions and prediction error [3].
- We expected entropy regressors related to note timing to **increase reconstruction accuracy** in the delta and beta bands and to show **TRF peaks** in pre-stimulus latencies, reflecting their role in timing prediction.
- After the stimulus onset, we expected surprisal regressors linked to prediction errors to be encoded in the beta and gamma bands [2,4,9,10].

Methods

Paradigm and Dataset

Dataset from Di Liberto et al. (2020).
- 20 participants (10 musicians)
- 30 trials (ca. 150 s each) of listening to monophonic pieces by J.S. Bach
- 64 electrodes EEG recording

Stimulus representation

Stimulus features from Di Liberto et al. (2020) extracted using IdyOM [5].
- **Acoustic variables** (A):
  - **Envelope** + 1st order derivative
- **Melodic expectations** (M):
  - **Entropy** (H):
    - Ho: Note onset time entropy
    - Hp: Pitch entropy
  - **Surprisal** (S):
    - So: Note onset time surprisal
    - Sp: Pitch Surprisal

EEG Preprocessing

- Split the EEG in frequency bands: delta (1-4 Hz); theta (4-8 Hz); alpha (8-12 Hz); beta (12-30 Hz); gamma (30-48 Hz).

TRF calculation

- Nested cross validation
- EEG **reconstruction accuracy**
- Pearson's correlation between the real and the reconstructed EEG

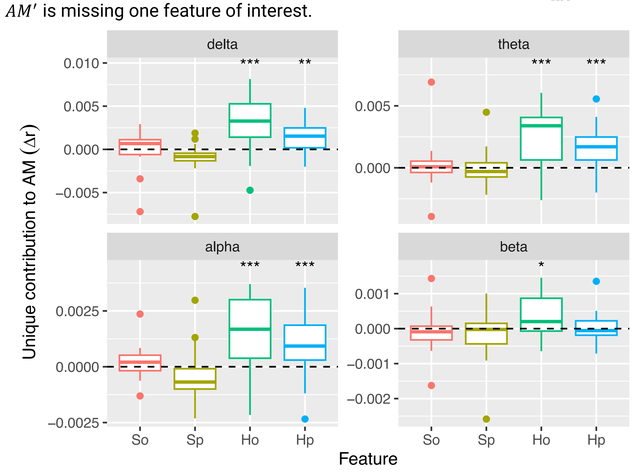
Analysis

- Compute **enhancement** in EEG reconstruction accuracy across different TRF models (after adding / removing one feature) [6,8].
- Get peaks of TRFs weights [11]
- Use **linear mixed effects** models to test the effects of feature type, musical expertise and frequency band on the enhancement.

Results

2 Reconstruction accuracy

Unique contribution of each feature to the full AM model ($r_{AM} - r_{AM'}$) where AM' is missing one feature of interest.

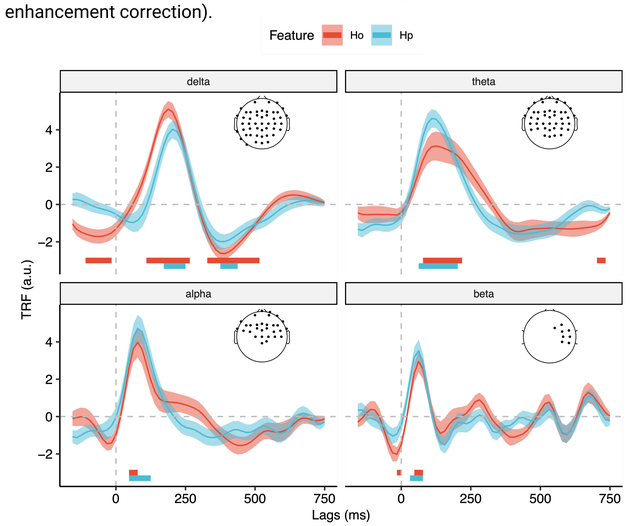


➢ We found a **unique contribution of entropy** (Ho and Hp) in all bands, but none for surprisal (So and Sp).

Results

3 Temporal Response Functions (TRFs)

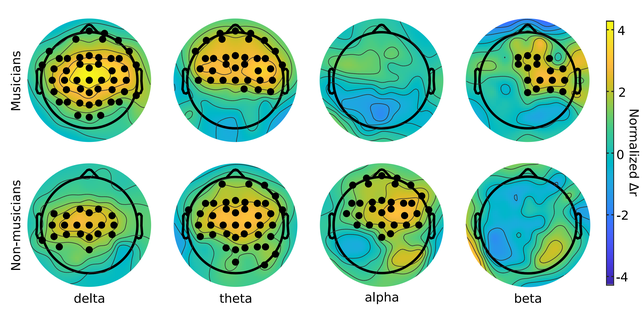
Average TRF weights for AM model across subjects in electrodes with significant reconstruction accuracy enhancement.
Shades → standard error of the mean (SEM).
Bars → peaks significantly different from 0 (p<0.05, threshold-free cluster enhancement correction).



➢ Consistent effects across subjects for delta and beta activity **prior to stimulus onset** for Ho. Significant peaks in delta band around 400ms.

4 Musicians vs Non-Musicians

Difference in reconstruction accuracy ($r_{AM} - r_A$)
Dots → electrodes with sign. enhancement (p<0.05, cluster permutation test)



➢ We found a **double dissociation** in enhancement between musicians and not musicians in beta and alpha bands.

Discussion

Summary

- Full (AM) TRF model showed reconstruction accuracy enhancement in all frequency bands except for gamma. This goes beyond what was previously reported for delta and theta [6].
- Unique contribution of **entropy** regressors in EEG reconstruction accuracy suggests specific encoding of timing and content **prediction** in different frequency bands [2,4,9].
- No frequency band showed unique contributions of the surprisal values. However, our hypothesis expected effects mostly in the gamma band [2,10].
- Pre-stimulus contributions of Ho in delta-beta suggest their possible joint involvement in predictive timing [2,4]
- Significant peaks for both entropy regressors in the delta-band around 400 ms analogous to N400 components [12]
- Significant interaction (lme models) between frequency band and musical expertise (beta in musicians and alpha in non-musicians). This suggests that musical training has an effect in the brain processing of time predictions [13].

Limitations

- Difficulty to study Gamma-frequency in EEG
- Lack of a factorial design in the paradigm
- No source identification
- Phase analysis needed to assess cross-frequency coupling.

Conclusions

- Our findings suggest an important role of brain activity in the delta and beta frequency ranges in timing prediction, consistent with previous literature on the topic [2,4].
- Future research should focus on the interplay between different brain rhythms in scenarios of varying levels of entropy and surprisal.

Acknowledgments: Giovanni M. Di Liberto for data sharing and project discussion

References

[1] Meyer (2018). *The European Journal of Neuroscience,* 48(7).
[2] Arnal and Giraud (2012). *Trends in Cognitive Sciences,* 16(7).
[3] Bastos et al. (2012). *Neuron,* 76(4).
[4] Arnal et al. (2015). *Frontiers in Human Neuroscience,* 6.
[5] Pearce (2018). *Annals of the New York Academy of Sciences*, 1423(1)
[6] Di Liberto et al. (2020). *eLife* 9.
[7] Kern et al. (2022). *eLife* 11.
[8] Crosse et al., (2016). *Frontiers in Human Neuroscience,* 10.
[9] Fujioka et al. (2012). *Journal of Neuroscience*, 32(5).
[10] Wang et al. (2012. *Frontiers in Psychology, 3.*
[11] Gillis et al. (2021). *The Journal of Neuroscience*, 41(50).
[12] Miranda and Ullman (2007). *NeuroImage*, 38(2).
[13] Hansen and Pearce (2014). *Frontiers in Psychology*, 5.