The music of silence reveals neural auditory prediction

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Introduction

- Music listening and enjoyment is know to be closely related to musical expectation and prediction following events.
- Therefore, according to predictive coding, music listening is thought to involve a comparison of **bottom-up sensory** responses and **top-down prediction** signals
- However the neural machinery associated with bottom-up and top-down processes remains unclear as **it is challenging to disentangle the two**
- Here we aim to test whether predictive processing explains this duality by **measuring endogenous processes in absence of sensory inputs** with EEG

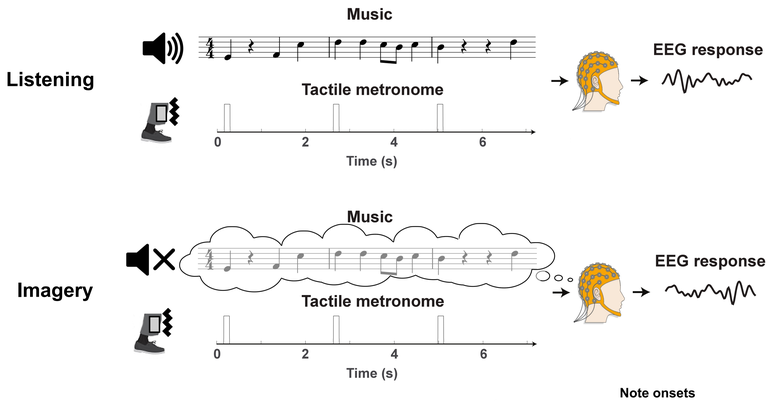
Part I: Imagined Music

Rationale and hypothesis

- Rationale: The EEG signals during auditory imagery reflect endogenous processes in isolation from sensory responses
- Hp1: Auditory imagery of melodies elicits robust neural responses that are synchronised to the imagined music sounds [3]
- Hp2: Imagery responses are modulated by melodic expectations

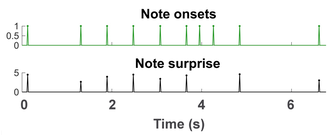
The experiment

- Melody listening and imagery experiment
- N = 21 subjects median age: 25 years (6 female)
- 64-channel EEG
- Four monophonic piano pieces (~35 seconds)
- 88 trials. One piece per trial.
- 50% of listening trials, 50% of imagery trials in random order
- Tactile metronome at marking the start of 100bpm bars (2.4s)



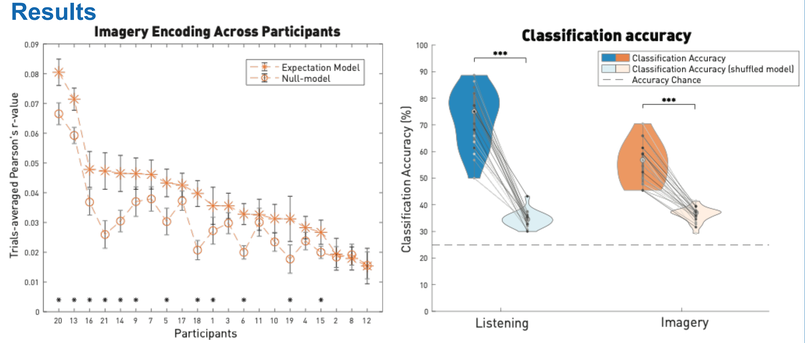
Analysis Procedure

- Stimulus features were extracted describing:
  a) Note onsets
  b) Note surprise according to IDyOM model [2]
- Temporal response functions (TRFs) describing the linear forward mapping *music* → *EEG* were evaluated for each feature vector (mTRF toolbox) [3]
- EEG predictions were obtained for each model. We expected reduced EEG prediction correlations when the surprise values were shuffled.



Part I: Imagined Music

Results

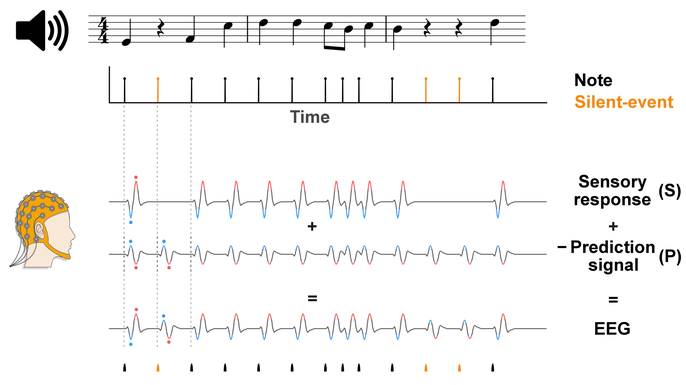


- Significant coupling between EEG and note onset vector in both listening and imagery ($p < 10^{-30}$).
- Expectation vector allow for significantly better coupling than shuffled expectations.
- Classification based on note onset and expectations coupling is significantly larger than chance for both listening and imagery.
- **EEG signals encode imagined notes and their melodic expectation.**

Part II: Music Silence

Hypothesis

- According to PP, auditory neural responses correspond to the subtraction between sensory responses and prediction signals (S-P).
- Because of the absence of S, the neural correlates to musical imagery is -P
- Similarly, music silence should correspond to –P, leading to a robust (prediction) neural signal when a note is plausible (silent-events)

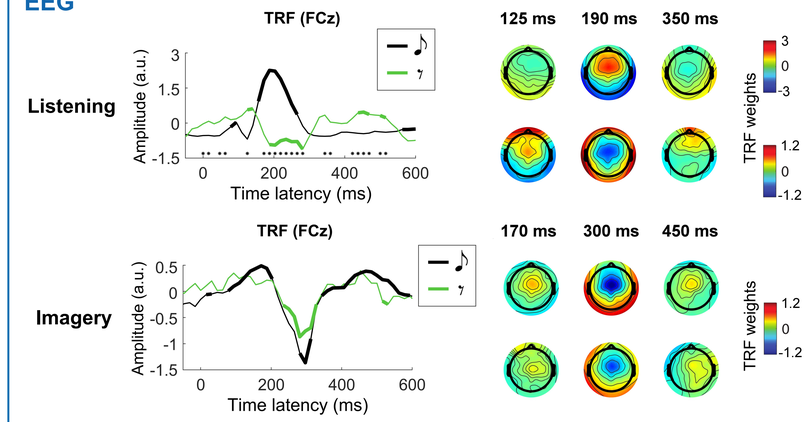


Analysis Procedure

- Silent-events were derived based on IDyOM (the next most likely note onset)
- Forward TRFs were derived for notes and silent-events in listening and imagery conditions separately

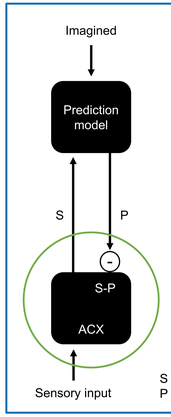
Part II: Music Silence

EEG



- TRF weights showed significant responses to notes and silence in both conditions
- Inverted polarities emerged between the TRF for notes in the listening condition (where S > 0) and all others (where S = 0)

Discussion



S = Auditory cortex responses
P = Predictive responses

- Imagery elicits robust neural signals. In line with previous work (e.g. fMRI)
- The imagery activation shows responses that are delayed and with inverse polarity compared to the responses to notes
- Similar patterns to imagined notes emerged for silent-events in both listening and imagery
- PP explains these results as the S-P duality
- These results suggest that neural signals require a combination of S and P to be sufficiently explained
- Previous (exogenous-only) evoked-models should be revised to include P

References

[1] Di Liberto GM, Pelofi C et al., *eLife*, 2020. 10.7554/eLife.51784
[2] Pearce MT, *PhD thesis, City University London,* 2005
[3] Crosse et al., *Front in Hum Neurosci*, 2017
[4] Di Liberto GM, O'Sullivan JA, Lalor EC, *Current Biology*, 2015. 25: 2457-65.

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