Spatial Frequency Tuning of Cortical Responses to positive and negative facial expressions

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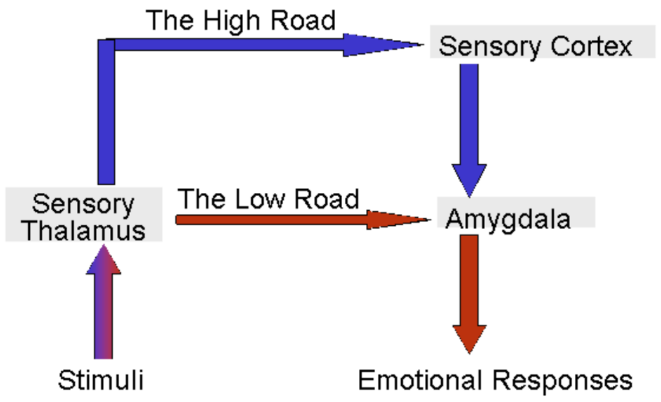
Introduction

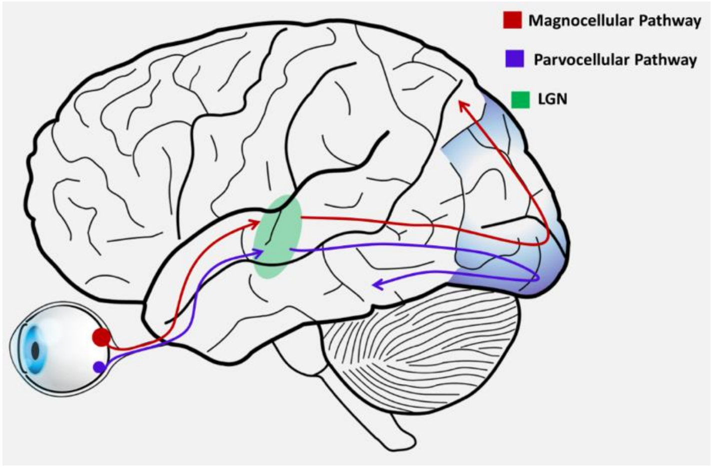
- **Evolutionary models of threat detection** posit a **subcortical "low-road,"** wherein the **amygdala** rapidly processes fearful faces via **coarse, low-spatial-frequency (LSF) cues**.

- There are two neural systems for processing visual information that support the "low road" and "high road" respectively:

  - Magnocellular pathway: Conveys mainly LSF, but rapidly distributes it to fast-responding areas such as the PFC or AMG. It provides only gross info about the shape of an object.
  - Parvocellular pathway: Carries all SFs, necessary for the processing of details such as edges, or small visual elements or contrasts. It exclusively directs towards visual cortex.
  - A key feature that distinguishes the style of processing of these two visual systems is **spatial frequency (SF)**.



LeDoux: Tracing Emotional Pathways (NY Times Nov. 5, 1996)



Literatures: rapid detection of fearful signals in amygdala in human

Vuilleumier, et al. 2003. fMRI study. FFA sensitive to HSF, and AMG sensitive to LSF.

Winston et al. 2003. fMRI. Both FFA and AMG show enhanced responses to fearful expressions driven by LSF. Hybrid faces. Neutral and fearful.

Morris et al. 1998. PET. Subcortical brain regions activated for fear versus happy faces. Morphed happy and fear faces.

Wang et al. 2023; SEEG. AMG sensitive to invisible LSF fear faces, and LSF advantages are absence in cortical regions.

Krolak-salmon et al. 2004. SEEG. Earliest response to fear than other expression in AMG, and later responses are observed in Occipitotemporal, Temporal, Frontal regions.

Meletti et al. 2012. SEEG. Early AMG response to fearful eyes than happy eyes.

Mendez-Bertolo et al. 2016. SEEG. Early 74ms AMG response to fear than happy in LSF images.

Luo et al. 2007. MEG. Short response latency in subcortical brain regions including AMG for fear than other expression or cortical brain regions.

McFadyen et al. 2017. MEG. LSH and HSF fear face. DCM finds a subcortical route not influenced by SF or emotion, but a cortical-amg route for HSF.

Wang et al. 2004. twins study. Genetic factors contribute to LSF processing, and HSF might be learnt.

Carretie et al. 2007. EEG. N135 activated at secondary visual areas for LSF images and with highest amplitudes for negative stimuli. But for intact stimuli, neutral pics were those eliciting the highest amplitudes.

Pourtois et al. 2005. EEG. LSF info from fearful faces produced a right-lateralized enhancement of the lateral occipital P1, relative to unfiltered fearful faces.

Research Gap

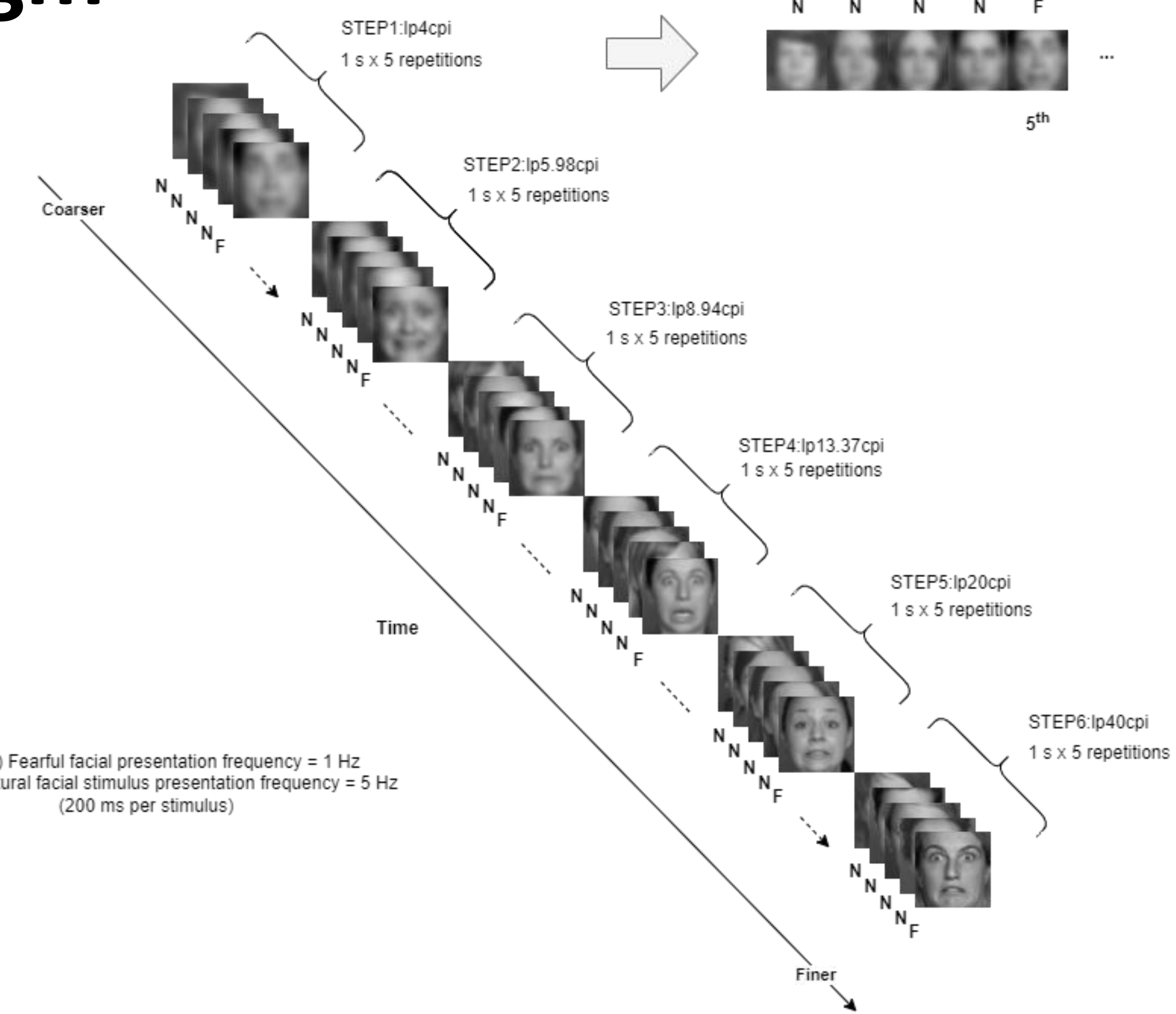
- However, it remains **unclear** whether this **subcortical advantage for fear translates** to a generalized processing priority within **cortical** visual pathways.
- Previous studies have often relied on filtered images (e.g., LSF-only vs. HSF-only), lacking a **systematic manipulation of spatial frequency** to map its continuous influence on expression processing precisely.

Research question

- At the **cortical** high-level visual areas & with novel methodologies: whether **facial expressions of different valence** can modulate EEG responses as a function of **stimuli spatial frequency**?

Experimental paradigm

- To address this gap, we systematically **manipulated the spatial frequency content of facial images** (across a wide spectrum from 4 to 40 cycles/image in 6 discrete steps) depicting **threatening signals (i.e. fear/anger), and positive signals (i.e. happiness).**
- We tracked the **implicit neural dynamics of expression categorization** under brief presentation conditions (**EXP1: 200 ms at 5 Hz; EXP2: 33 ms at 30 Hz**) using high-density EEG, with a specific focus on **steady-state visual evoked potentials (SSVEPs)** as a robust, objective metric of cortical response strength in **occipito-temporal regions**.
- **Explicit behavioral recognition** was assessed post-EEG.



Stimuli exemplar

anger

fear

happiness

German faces. FACE set.

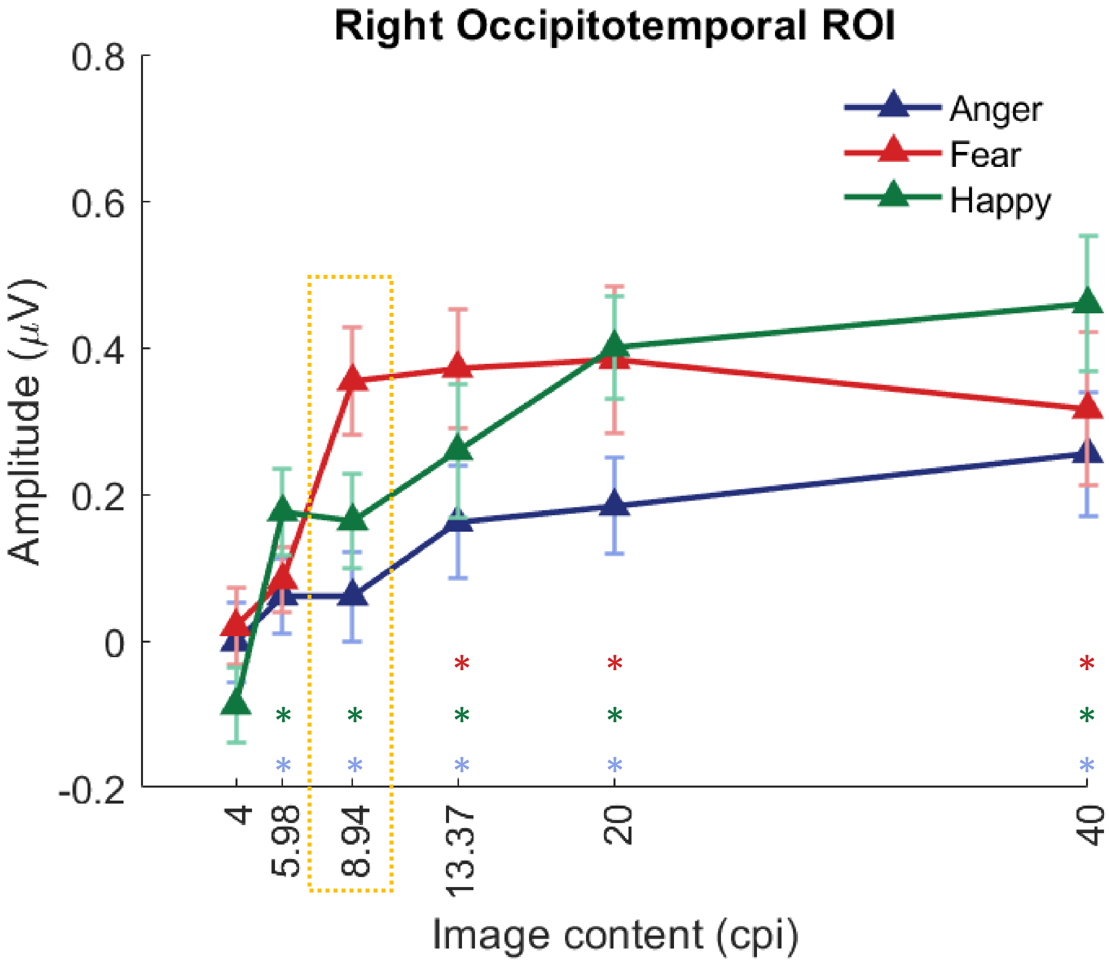
20 images per category

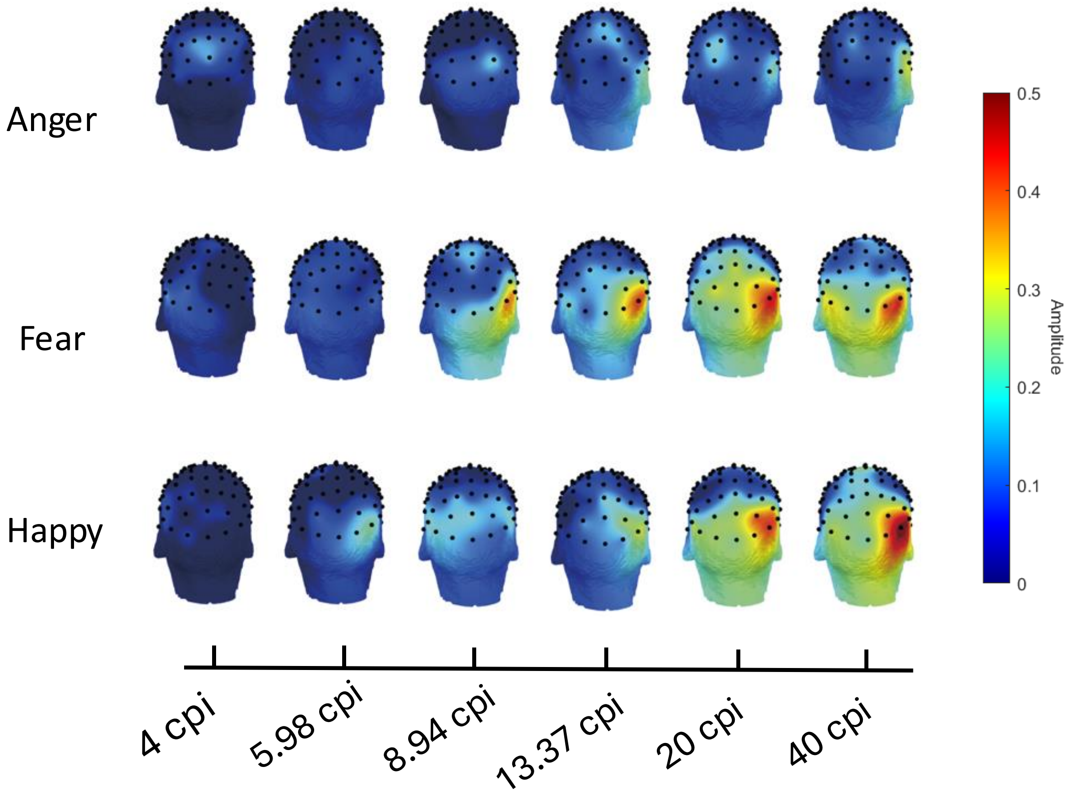
Right OT ROI – **frequency domain** – expression categorization response at 1 Hz and harmonics

Experiment 1: 200 ms at 5 Hz

- Responses show right hemisphere dominance.
- Above chance categorization happens when at 5.98 cpi condition.
- Only at 8.94 cpi, fear is significantly higher than happiness.
- Slow emergence of responses to angry faces.

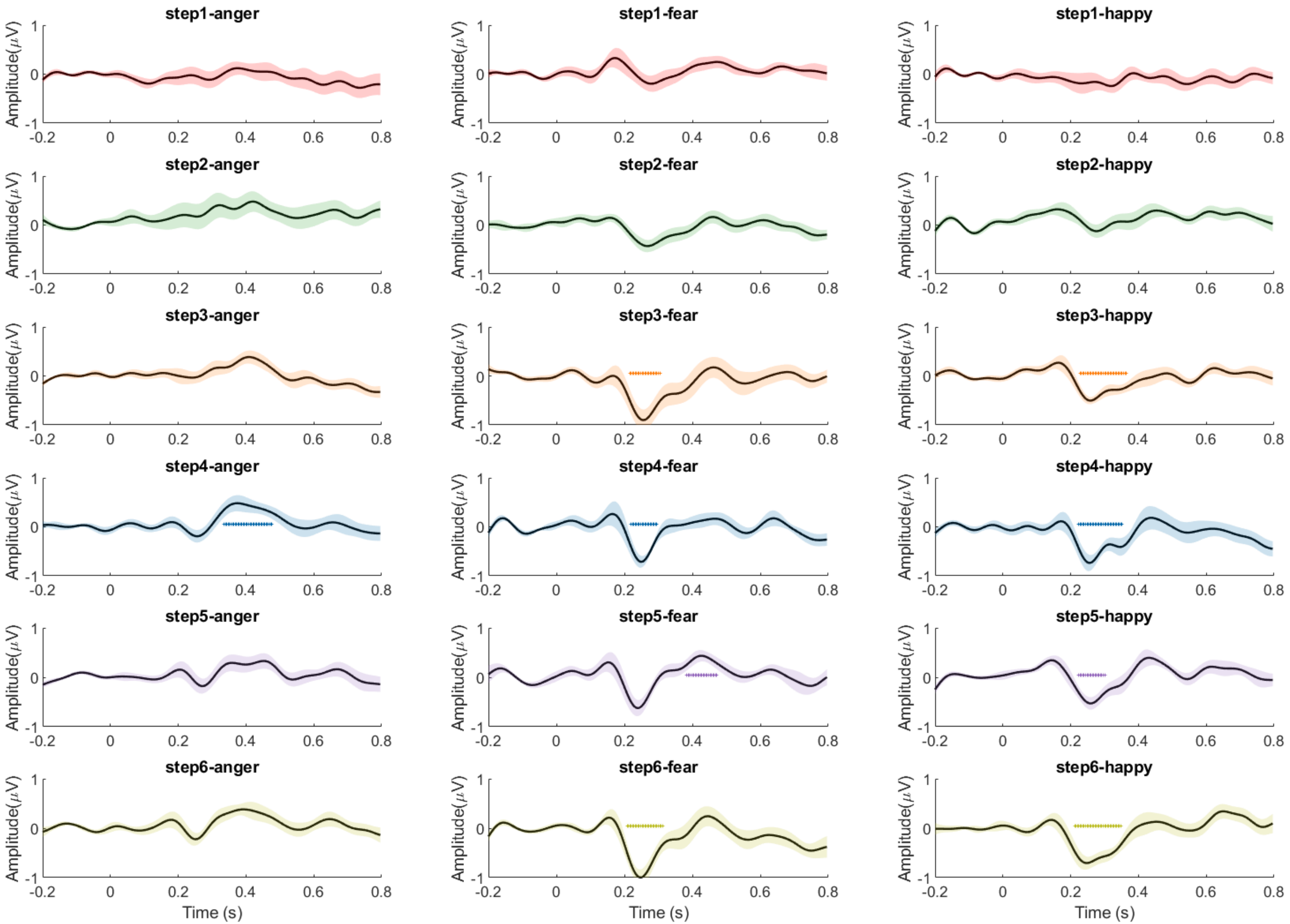
N = 16





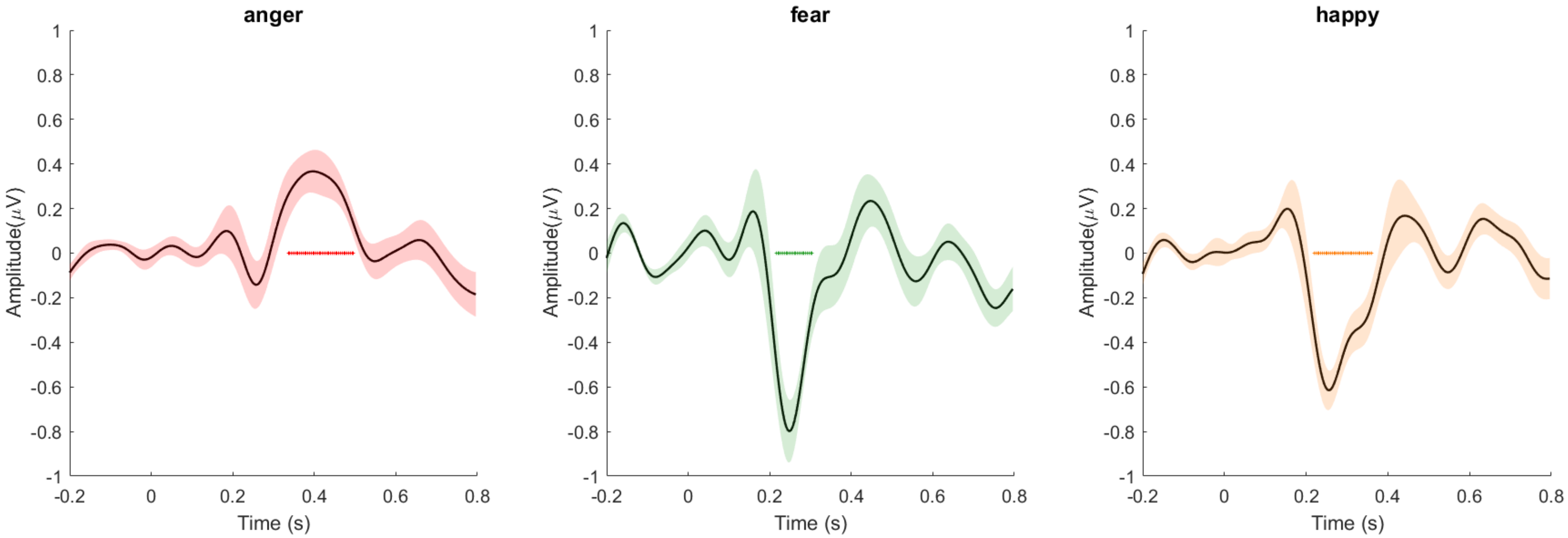
significant responses indicated with *

Time domain: Right OT



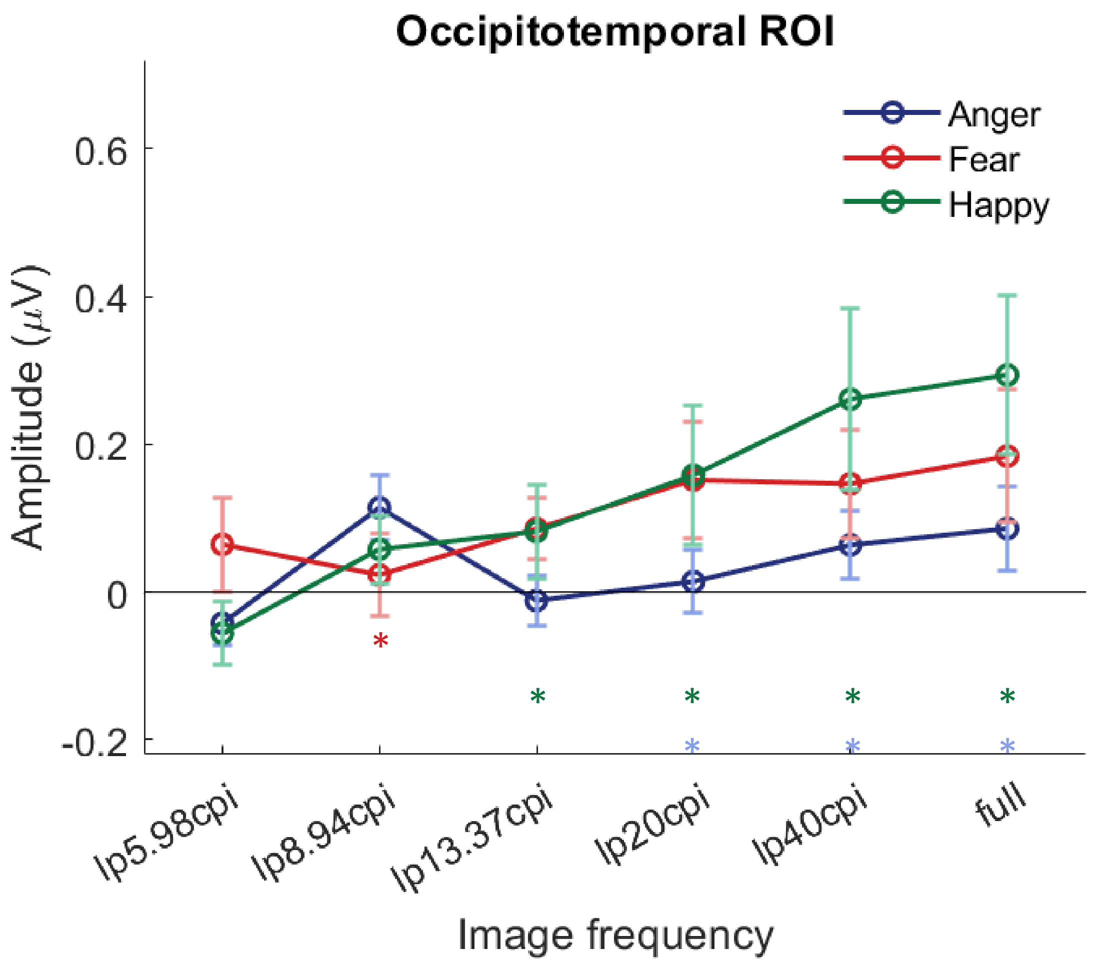
Average step4-step6

- Fear and happiness responses reach significance earlier than anger.
- Anger reached significant in later window only.



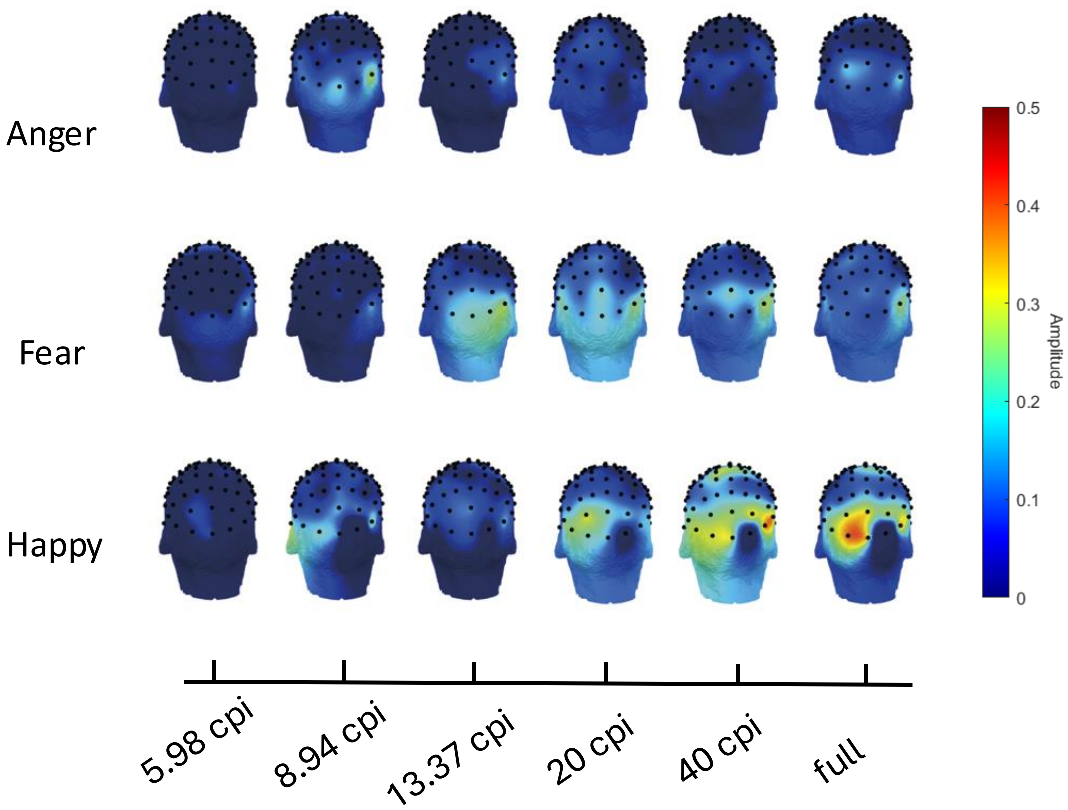
Experiment 2:
33 ms at 30 Hz

N = 16

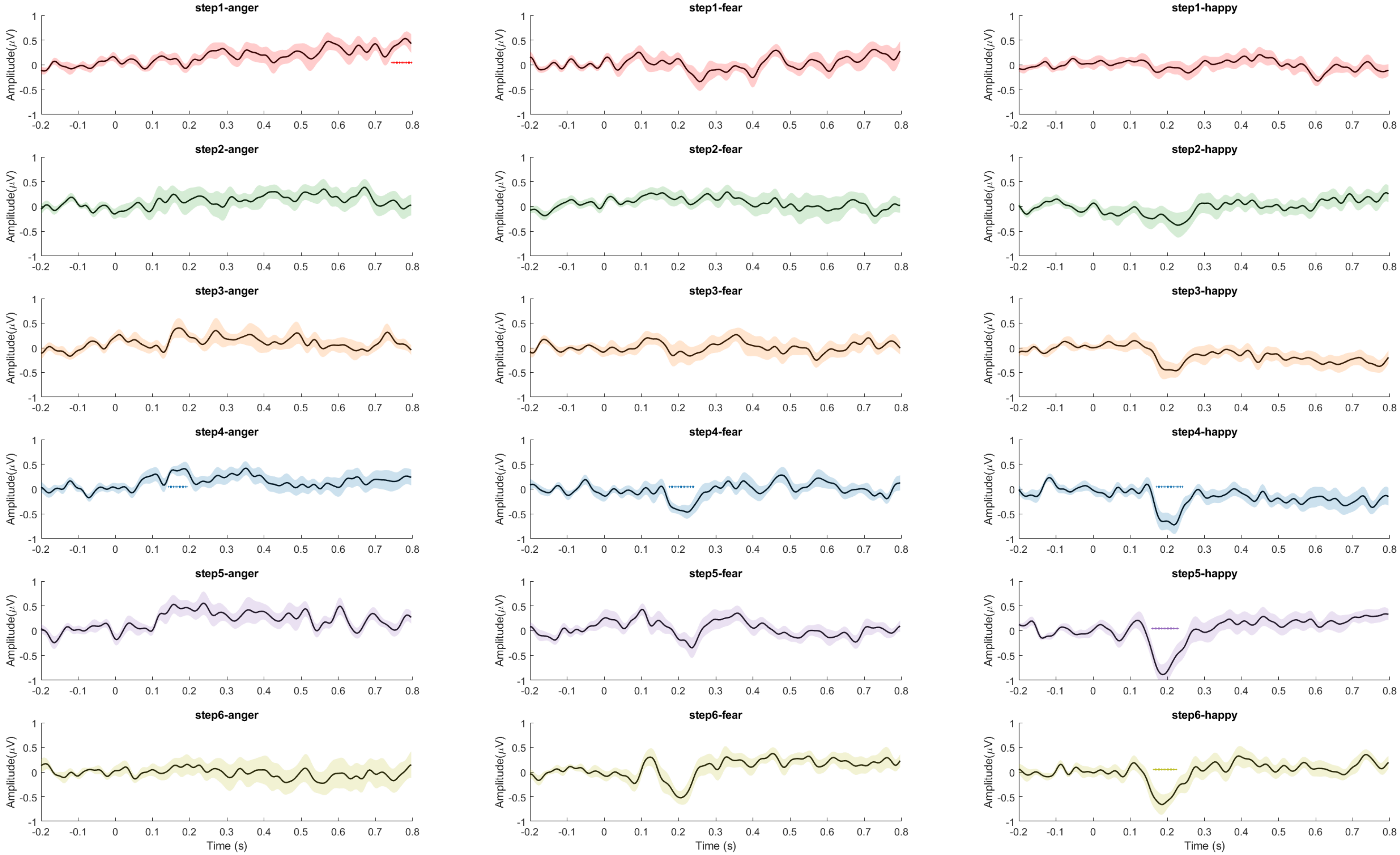


significant responses indicated with *

- No right hemisphere dominance.
- Early detection of fear at 13.37cpi only. Detection of happy faces start to 20cpi. No significant response of anger.
- No difference between fear and happy expression across image frequencies.

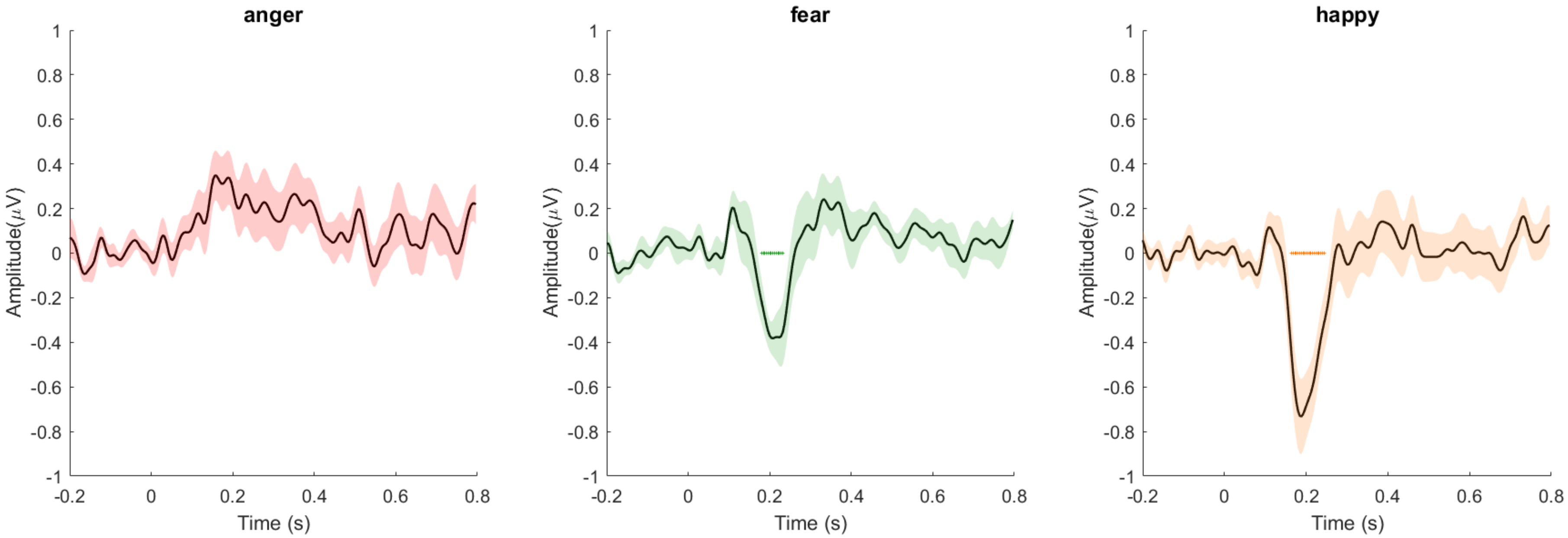


Time domain: OT



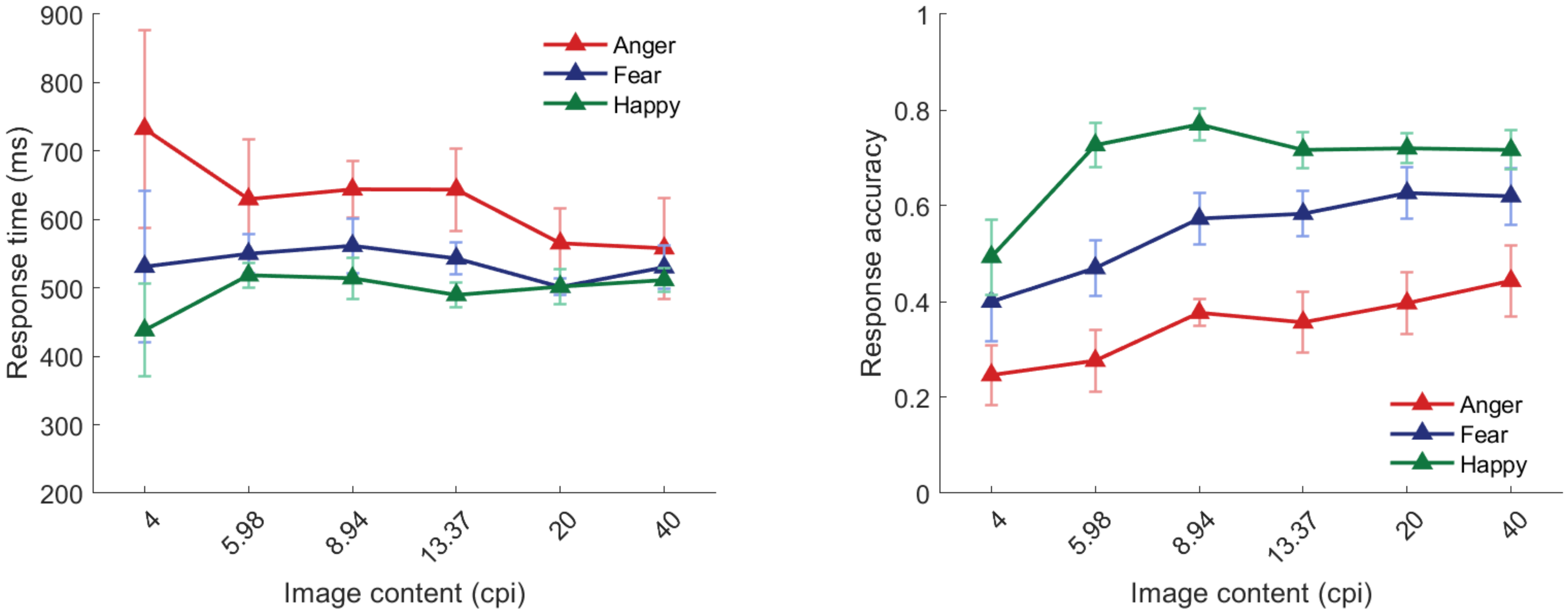
Average step4-step6

- When presentation frequency increased to 30 Hz, anger did not reach a significance level.



Behavioral results: advantage in detection of happy faces

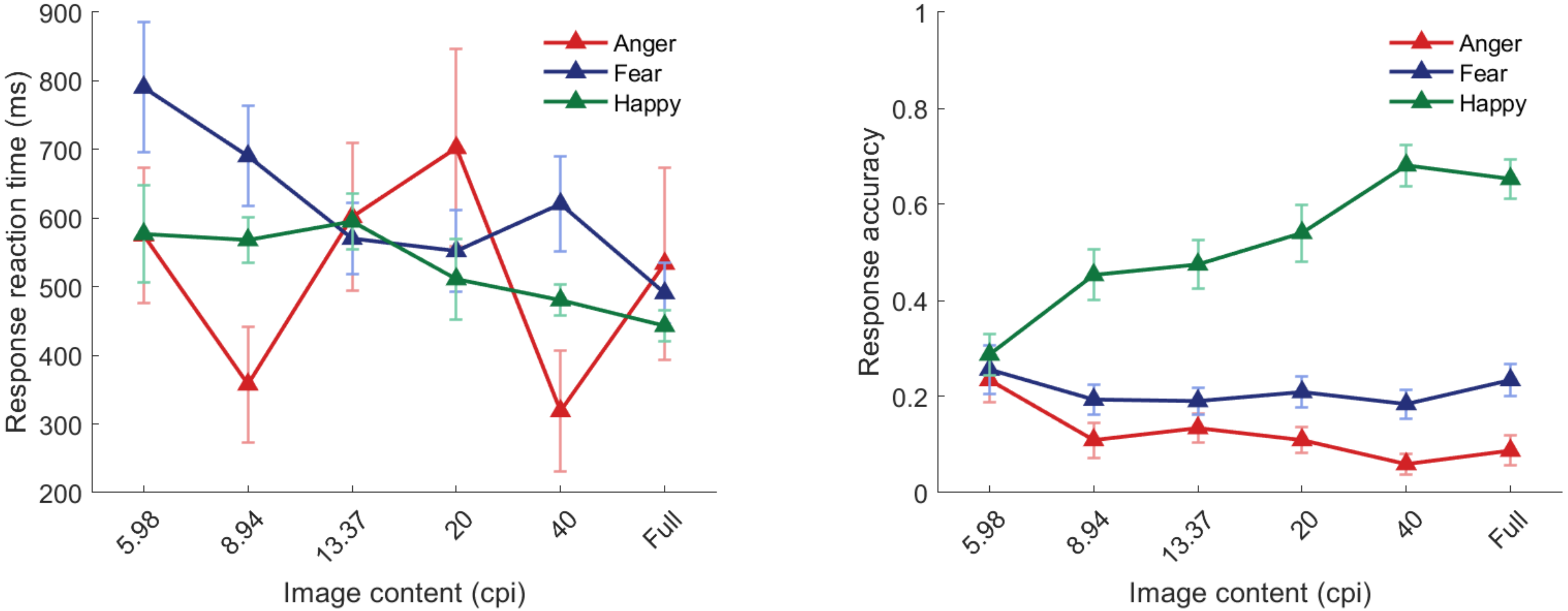
Exp1



- For RT, there are significant main effects of emotions, indicating that responses to happiness are faster than fear and anger, and responses to fear are quicker than anger.

- For accuracy, there are significant main effects of emotions, revealing that response accuracy for happy was significantly higher than fear, and anger. Accuracy for fear was also significantly higher then anger.

Exp2



- When frequency increase to 30 Hz, the reaction time for anger is no longer stable across image content. For reaction time (RT), there are significant main effects of expressions, indicating that responses to happiness are faster than fear.

- For accuracy, there are significant interaction between expression and spatial frequency, indicating that from 8.94cpi to full image spectrum, response accuracies to anger and fear are lower than those to happy.

- And only from 20 cpi to full image spectrum, the accuracy of angry is significantly lower than fear.

Summary

- **Implicit neural responses (SSVEPs)** showed remarkably similar amplitudes for fear and happiness across most spatial frequency conditions, with anger categorization yielding the weakest responses. A significant neural prioritization for fearful faces was observed only under limited conditions with blurred faces.

- In striking contrast, **behavioral results** demonstrated a clear and efficient recognition advantage for happy expressions over both fear and anger.

Future Directions

- 1. Use MEG to localize cortical/subcortical regions involved in detecting positive and negative facial expressions, especially the differences between implicit and explicit tasks.

- 2. Understanding psychopathology: recruit clinical patients (depression or anxiety) to compare with non-clinical populations.

- 3. Develop computational models that simulate neural mechanisms of emotional categorization, which could explain the dissociation between neural and behavioural results.