Frontal Theta Phase Synchrony After Feedback Presentation Predicts Behavioral Engagement

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Abstract

Theta synchrony between medial and lateral EEG sites has previously been associated with behavioral adaptation [2,3].
This study assessed inter-trial phase synchrony between medial and lateral frontal EEG electrode sites while participants actively participated or passively observed a 4-choice gambling task. Increased phase locking was observed on LOSS relative to WIN trials, only when participants actively engaged in the task. This suggests that medial frontal inter-trial phase synchrony is a marker of behavioral engagement.

Introduction

- The Feedback Related Negativity (FRN) is a medial-frontal event-related potential (ERP) in the theta (4-7 Hz) range that occurs in response to worse-than-expected feedback.
- A previous study using the current dataset showed a diminished FRN when participants passively observed the task, not participating in choice-selection [1].
- It has previously been shown that theta synchrony between medial and lateral frontal sites predicts theta power, which in turn predicts behavioral adaptation [2,3].
- This study compared inter-trial phase synchrony when participants actively participated or passively observed a 4-choice gambling task.

Method

Subjects

- 43 participants (25 female)
- Mean age of 19.2 (±1.6 SD)

Procedure

- Participants were asked to choose between four different ovals on each trial.
- When participants actively engaged in the task, they made their selections on a standard USB number pad.
- In the passive condition, participants watched as choices were made by the computer. They were told to observe as if they were watching another person playing.
- Each task consisted of 144 trials, with three blocks of 48 trials each.
- Probability of winning was fixed to 60% across all conditions.

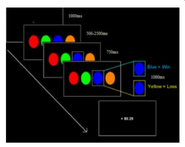


Figure 1. Typical trial structure. Stimuli were presented for 500-2500 ms, during which time the participant responds. Feedback was presented 750 ms after each choice.

EEG Recording and Processing

- Sixty-four channel Neuroscan Synamps2 EEG system
- Sampled at 1000 Hz
- Epoched -1500 to 2000 ms peristimulus
- Transformed offline to current source density (CSD) reference
- ICA ADJUST used for artifact rejection [4]
- Single-trial data were convolved with complex Morlet wavelets to extract instantaneous power and phase (parameters as they appear in [1])

Method (cont.)

Statistical Analyses

- Inter-trial phase coherence (ITPC) estimates the consistency of phase values over trials at a specific point in time-frequency space. Inter-channel phase synchrony (ICPS), in contrast, estimates the consistency of the difference between two phases over time.
- ITPC, ICPS and power Z-scores for medial and lateral frontal sites were computed by permutation t-tests, and compared between active and passive conditions.

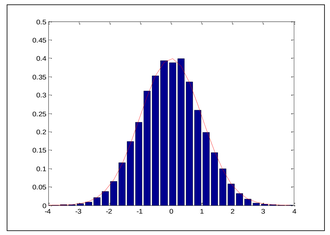


Figure 2. Example null distribution constructed for permutation testing. Data were shuffled between conditions and sampled 1000 times.

Results

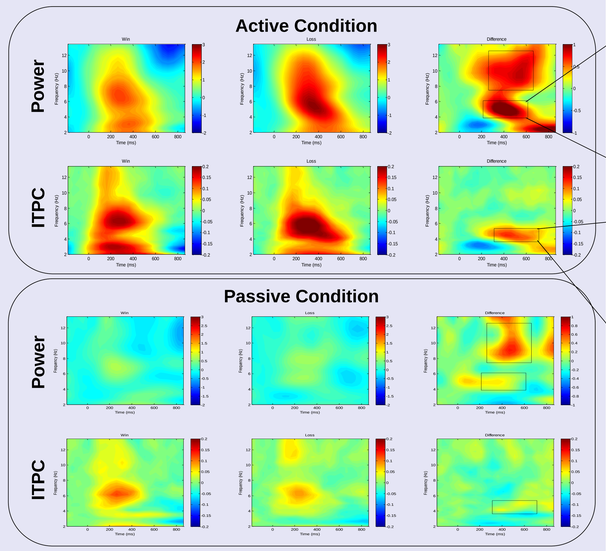


Figure 3. Time-frequency Power and ITPC for active and passive conditions. WIN, LOSS, and Difference average waveforms are plotted left to right. Morlet wavelets were convolved with single trial EEG from 2 to 50 Hz in 50 logarithmically spaced steps. Wavelet parameters are identical to [1]. WIN, LOSS, and Difference (LOSS-WIN) average waveforms are plotted left to right.

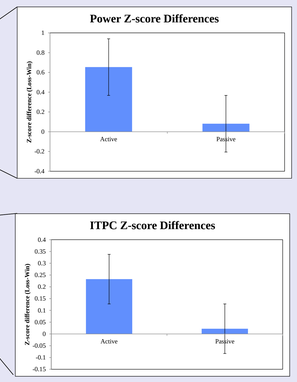


Figure 4. Theta power and ITPC difference scores (LOSS-WIN) for active and passive conditions.

Theta power was significantly greater during LOSS trials, only when the participant was actively engaged in the task. F(1,42) = 4.631, p = 0.037.

Similarly, theta ITPC was significantly greater during LOSS trials in the active group, F(1,42) = 6.813, p = 0.013.

Statistical Results

- For all analyses, time-frequency boxes were chosen based on visual inspection of the grand average across all conditions for null significance testing.
- Power and ITPC LOSS-WIN difference scores were entered into a one-way repeated measures ANOVA to compare between active and passive conditions. Both power and ITPC were increased on LOSS trials, relative to WIN trials, only in the active condition.
- ICPS was computed between medial electrode FCZ and lateral frontal sites, F5 and F6. These scores were entered into a mixed ANOVA, which showed increased synchrony between FCZ and F6 on LOSS trials, only in the active condition.

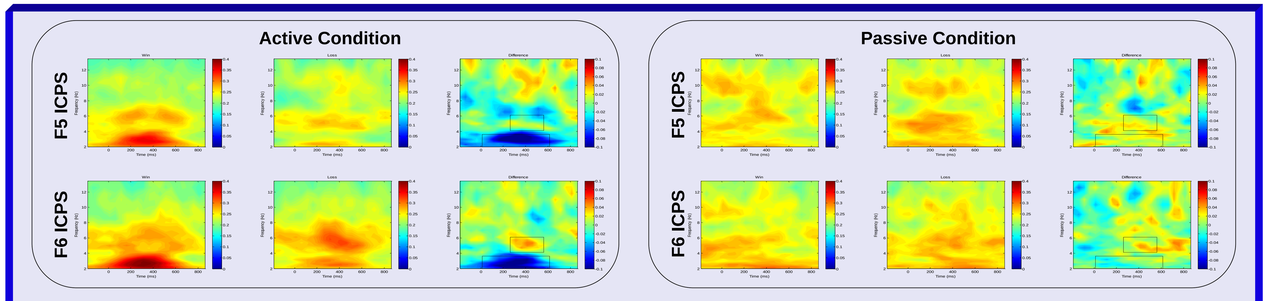
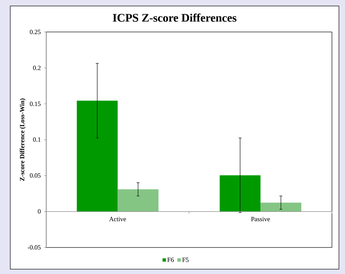


Figure 5. Time-frequency ICPS between electrode FCZ and lateral sites F5 and F6, for active and passive conditions. WIN, LOSS, and Difference (LOSS-WIN) average waveforms are plotted left to right.

Results (cont.)

Figure 6. ICPS scores between site FCZ and left and right lateral sites (F5 and F6, respectively) was assessed for each condition.

ICPS between F6 and FCZ was significantly greater during LOSS trials, only in the active condition. F(1,42) = 4.157, p = 0.048.



Discussion

- Results support previous claims that medial- lateral frontal synchrony is a marker of behavioral engagement.
- When participants did not actively engage in the task, or when feedback did not require a change of strategy, e.g., on Win trials, theta synchronization between medial and lateral sites did not occur.
- Because reward contingency was not varied, we cannot assess whether the synchronization effects facilitate changes to behavior or strategies.
- Future studies will vary reward contingency and quantify reward prediction errors using a computational model.

Appendix

$$ITPC = \frac{1}{N}\left|\sum_{x=1}^{N} e^{i\phi_{xt}}\right|$$

Where N is the number of trials for each time and frequency band. Values range from 0 to 1, where 1 indicates identical phase values at that time-frequency point across all trials, and 0 indicates random phases at that time-frequency point.

$$ICPS = \frac{1}{N}\left|\sum_{t=1}^{N} e^{i(\phi_{jt}-\phi_{kt})}\right|$$

Where ϕ_j and ϕ_k are phase angles of electrodes j and k. Values range from 0 to 1, where 1 indicates phase consistency across all time-frequency points, and 0 indicates random phase differences between electrodes.

References

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