

104 Figures

EEG concatenation averages out P300

- Previous Exclusion of Recordings
 - I included too many slow ERP between 300ms-1.5s which distorted P300
 - EEG signals show significant variability; concatenated ERP color plots (time vs. trials) fails to clearly plot P300 components.
 - Average ERP peaks may be too small to visualize positivity, often shown in red on the plot.
- Updated Approach
 - Use stricter criteria to exclude noisy recordings by examining both ERP and ERSP.
 - Identify and exclude potential muscle artifacts.

Exclusion workflow

1. Analyze individual recordings and generate ERP color plots for each component.

2. Identify ICs that exhibit a prominent P300 response.

3. Assess Theta & Alpha Activity:

1. Frontal Region (300-500 ms):

1. **increased theta**: attentional control and executive function
2. **decreased alpha**: heightened focus

2. Parietal Region (300-500 ms):

1. **Theta increase**: working memory updating
2. **Alpha decrease(goes first)**: active task processing
3. **Alpha increase(goes after)**: prevents distractions , focused internal attention and task shielding, a shift towards minimizing external distractions, prevent reorienting to external stimuli.
4. **Check for muscle artifacts** (positivities >30 Hz); if detected, exclude the component.

Stage 1 of Memory Process: Encoding

- Encoding (alpha decreases):
- During the encoding stage, stimuli (images) are presented, and the brain begins to process and register these inputs.
- At this point, attention is generally **externally focused** because the subject is taking in and interpreting stimuli from the external environment.

Stage 2 of Memory Process: Maintenance

- Maintenance (**alpha increases**)
- (Internalization of Attention)
- In the n-back task, after each stimulus is presented, there is a period where the subject must hold that stimulus in working memory while continuing to monitor incoming stimuli. This is where **internalization of attention** occurs.
- During this stage, **attention shifts away from external inputs** and focuses on internally rehearsing or maintaining the relevant stimulus for the task. The subject is not actively encoding new information, but rather holding and comparing the current stimulus to previous ones (e.g., comparing the current stimulus with the one presented n-back).
- Alpha synchronisation reflects the **suppression of irrelevant sensory information** and a shift of cognitive resources toward internal processes.

In the neurofeedback game, The participants internal attention was trained

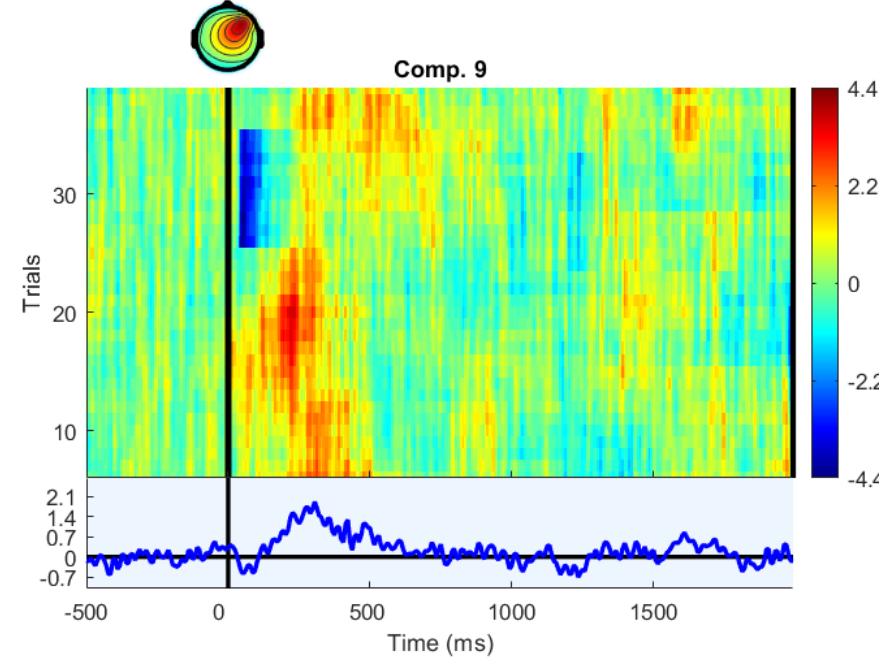
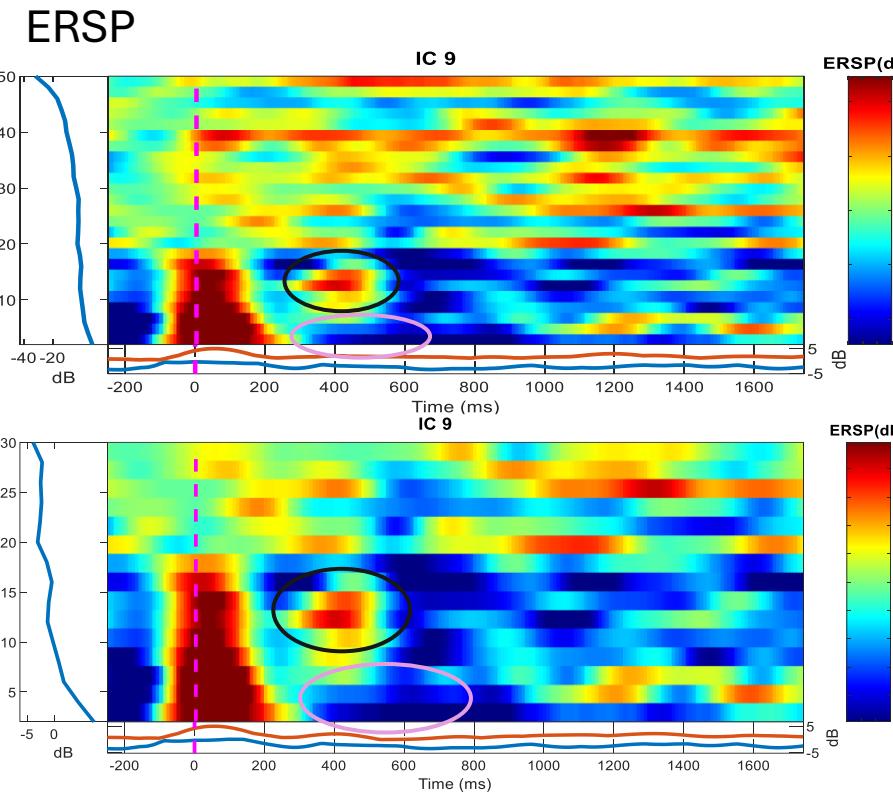
Stage 3 of Memory Process: Retrieval /Comparison

- During retrieval or comparison, the subject is asked to compare the currently presented stimulus with the one from n-back (e.g., the letter from 2 stimuli ago).
- This also involves internally directed attention as the subject must recall the stimulus from memory. This process is often supported by **beta synchronization**, which is associated with active cognitive processing and decision-making based on the comparison between internal representations and external stimuli.

101_5_3

Frontal F4

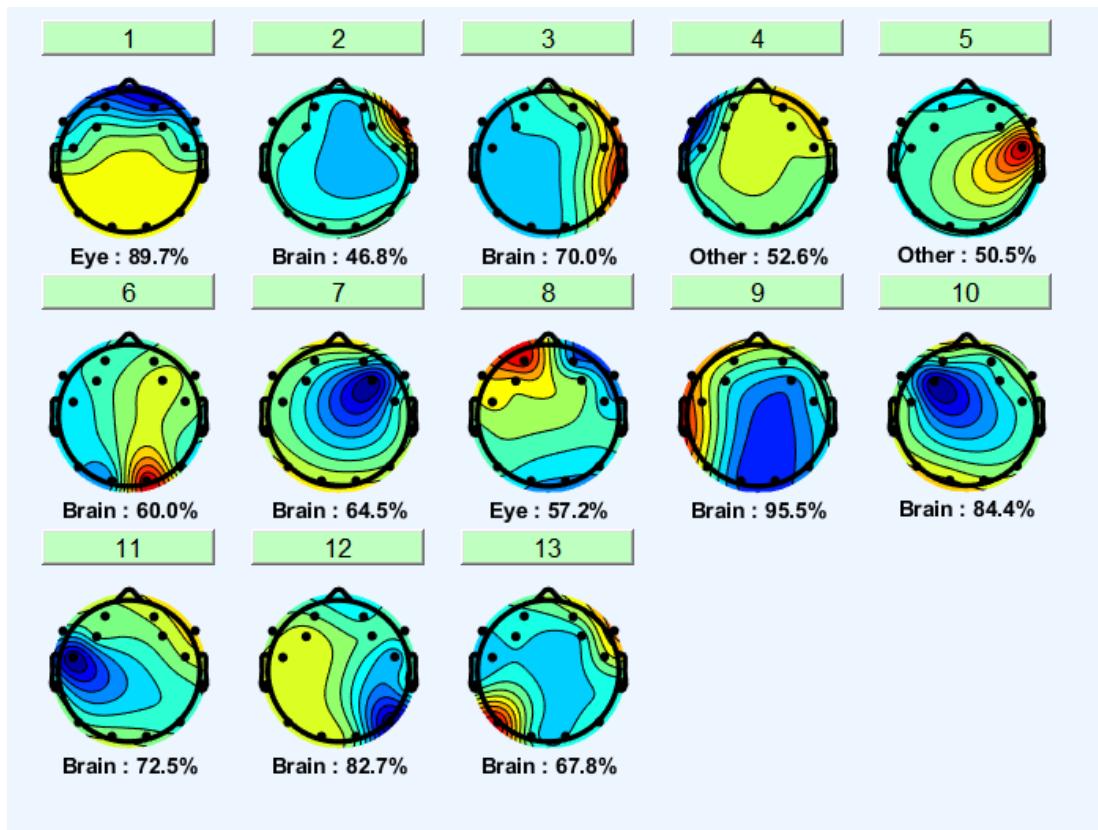
Time	+450ms
Theta	decrease
Alpha	increase



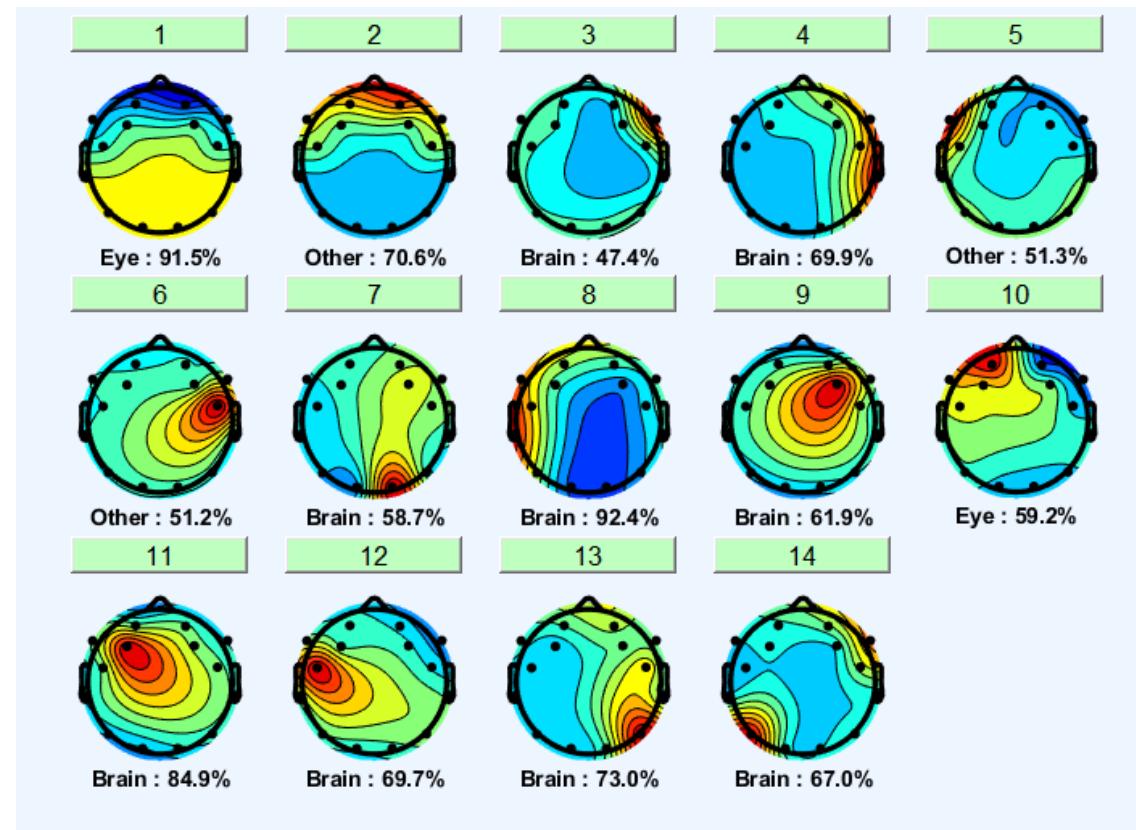
Early Stage

101_5_3

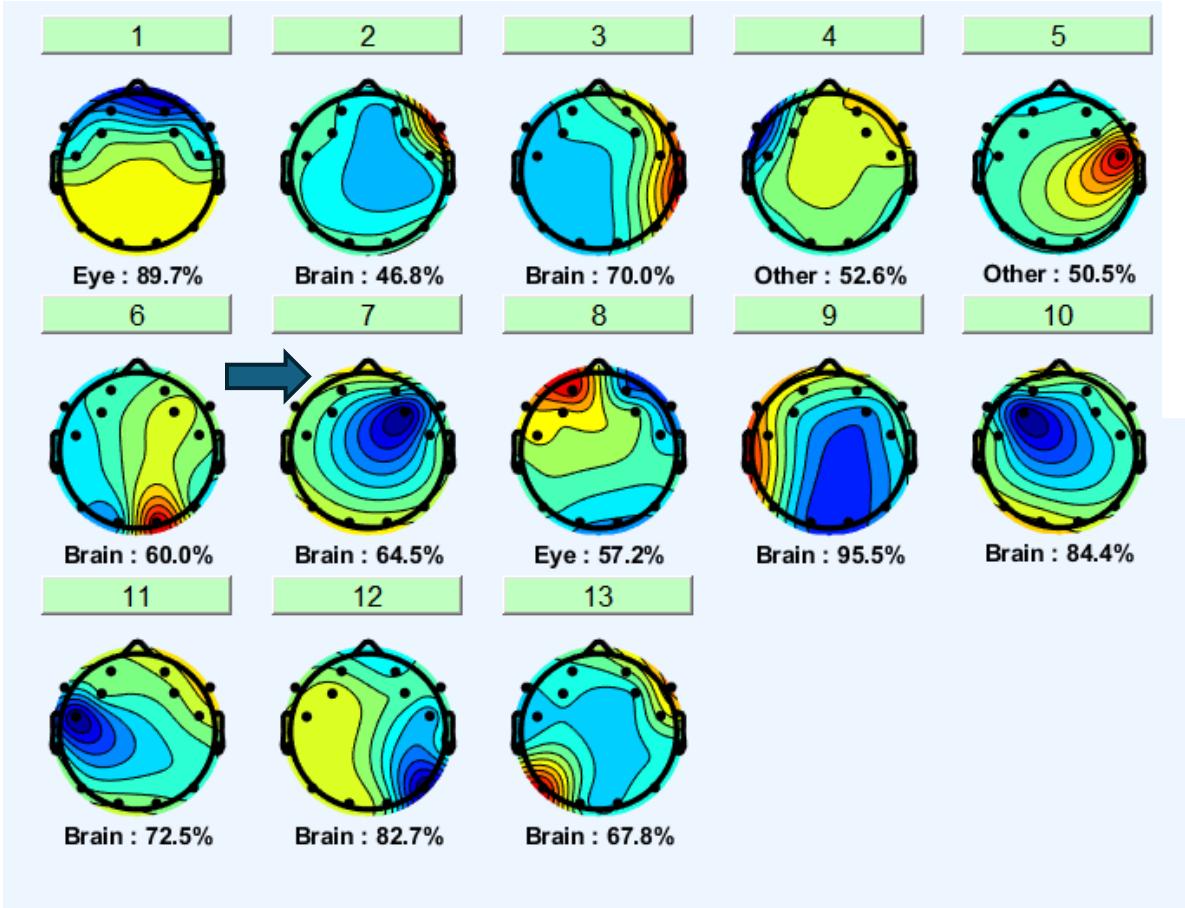
128Hz



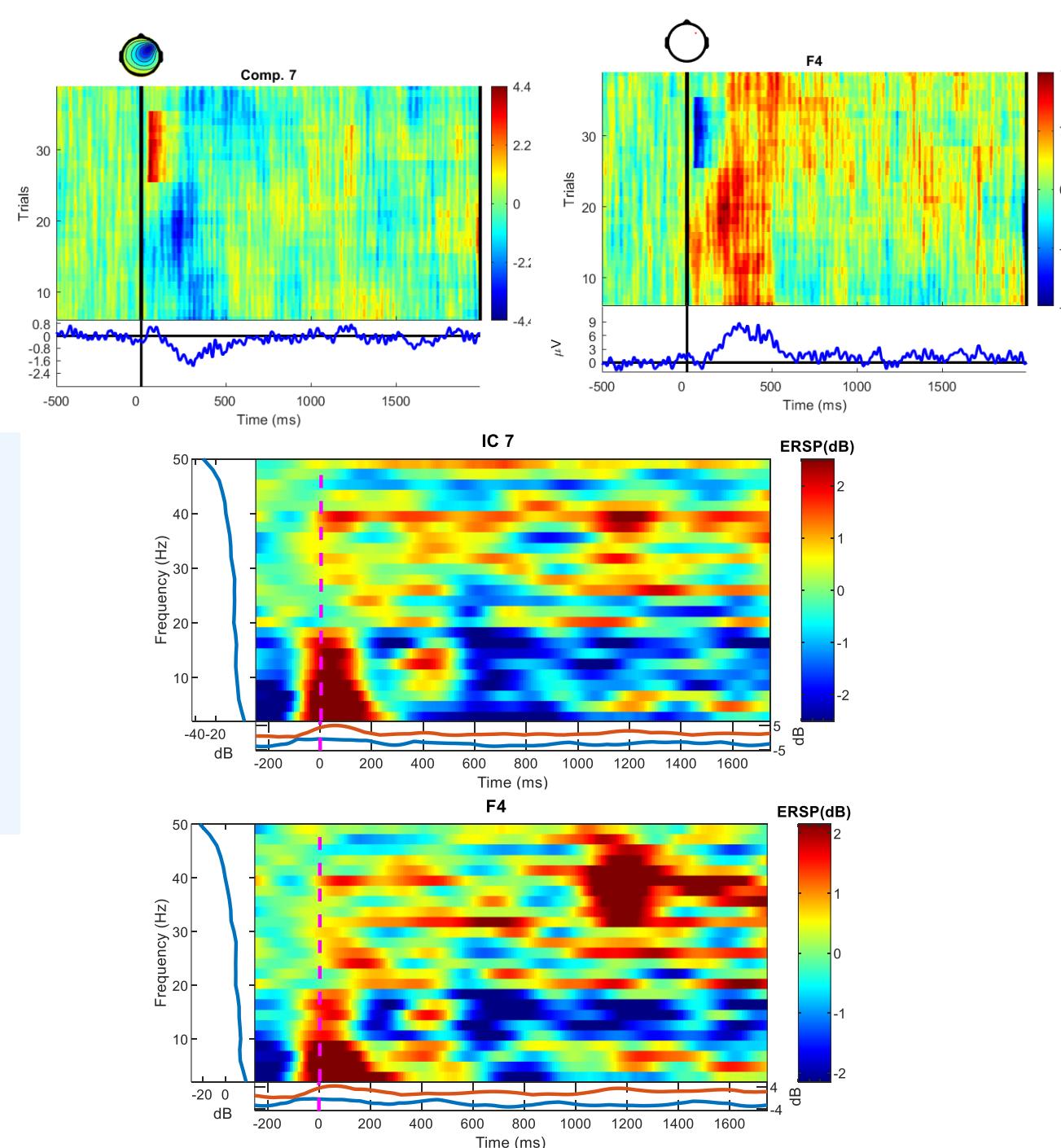
256Hz



101_5_3 (256Hz)



Was component 9



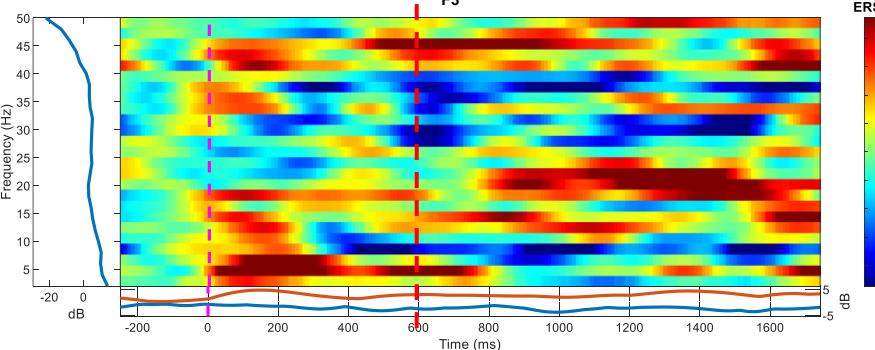
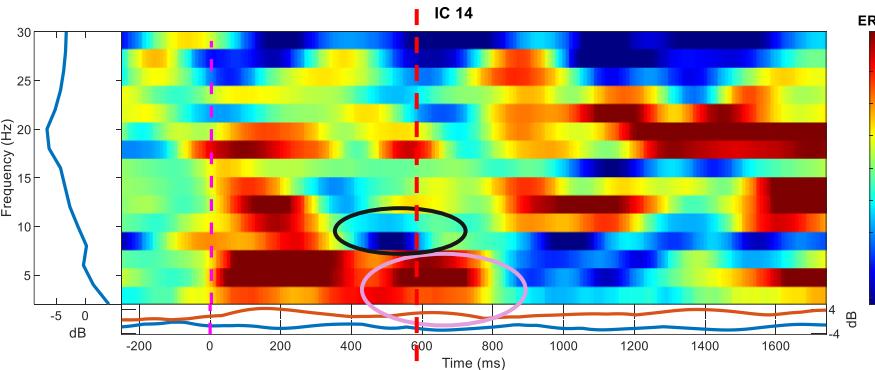
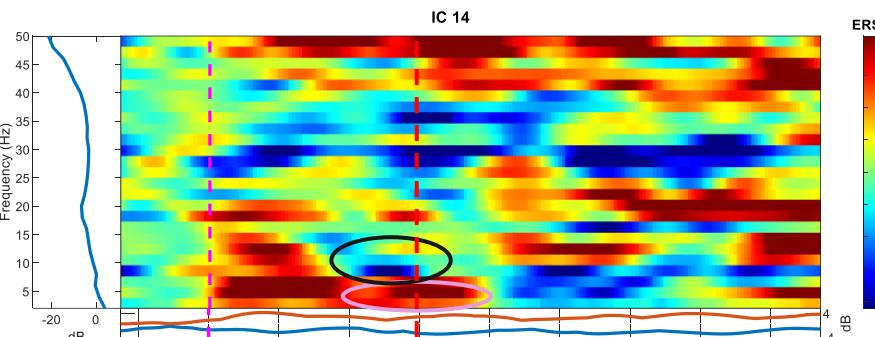
104_3_1

Frontal F4

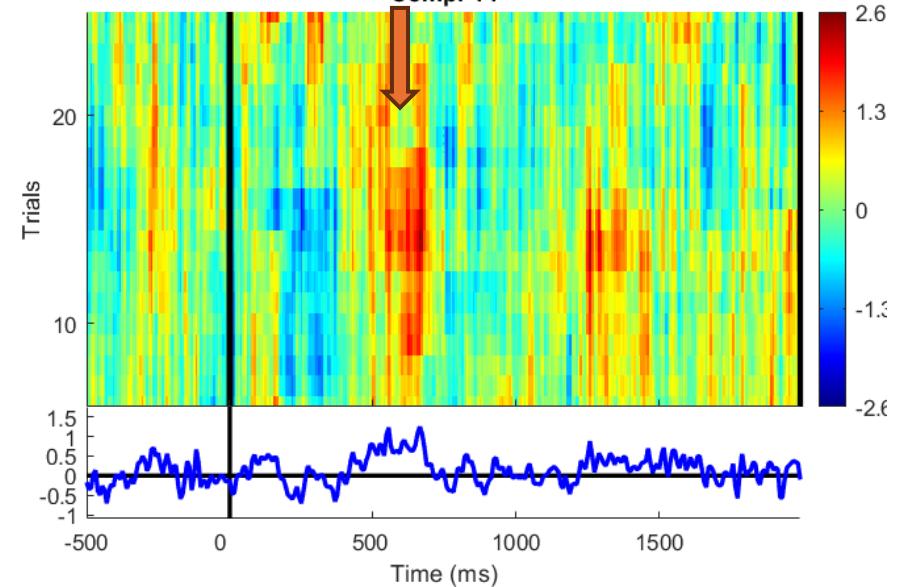
Time	+600ms
Theta	increase
Alpha	decrease

distorted

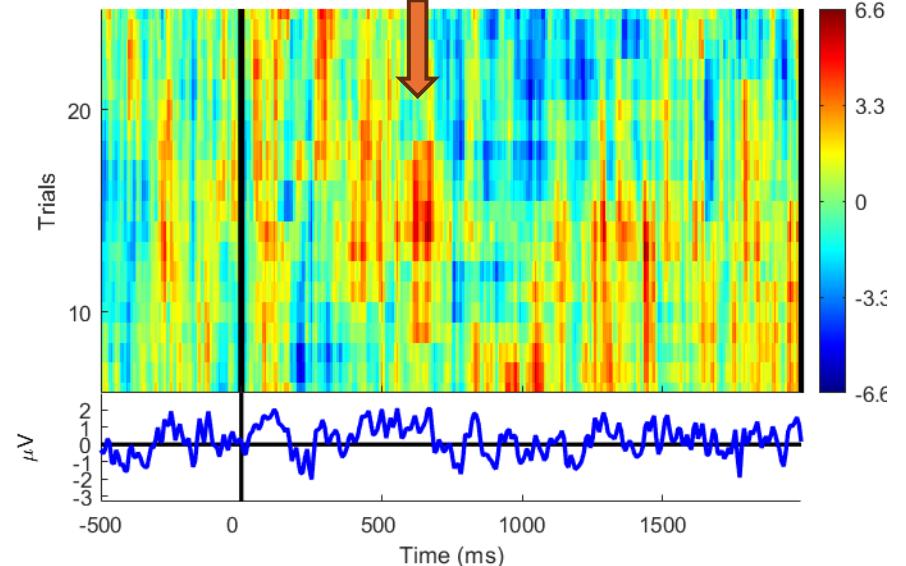
ERSP



ERP Image for Component 14



F3



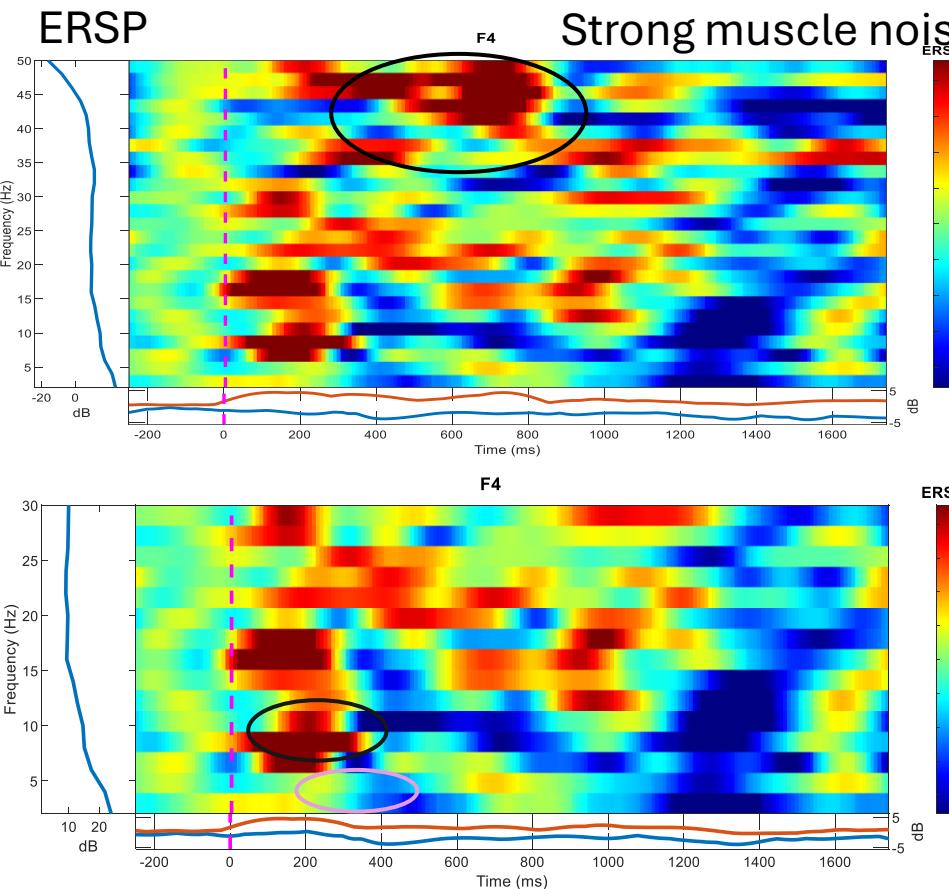
Early Stage

104_3_2

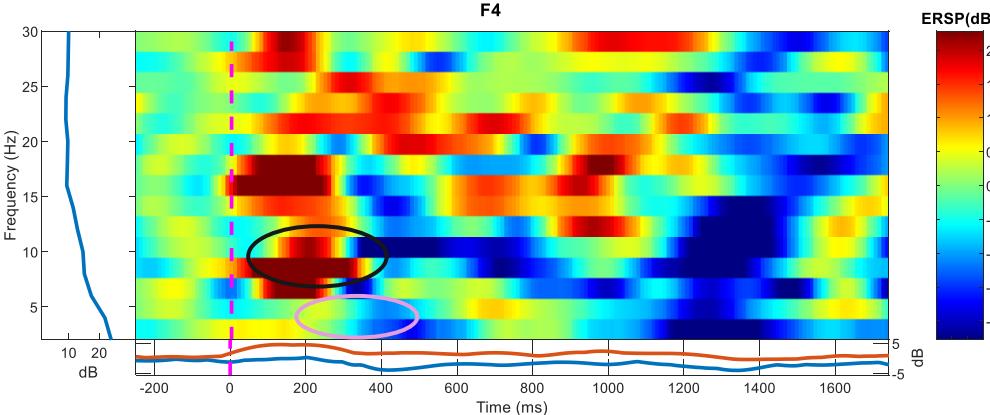
Frontal F4

Time	+300ms	
Theta	decrease	
Alpha	increase	

[0 50] Hz



[0 30] Hz

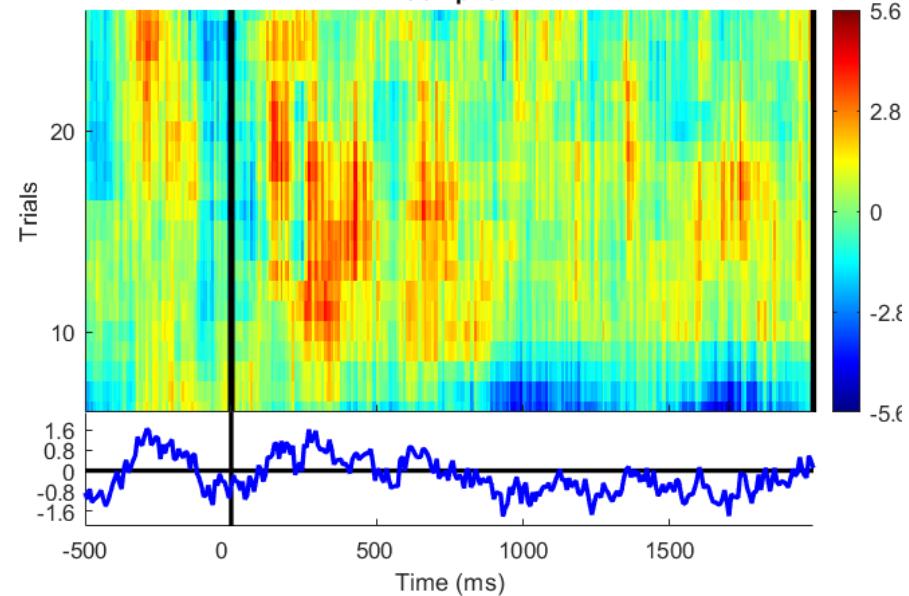


Not clear what happens around 300ms,
so the recording is excluded

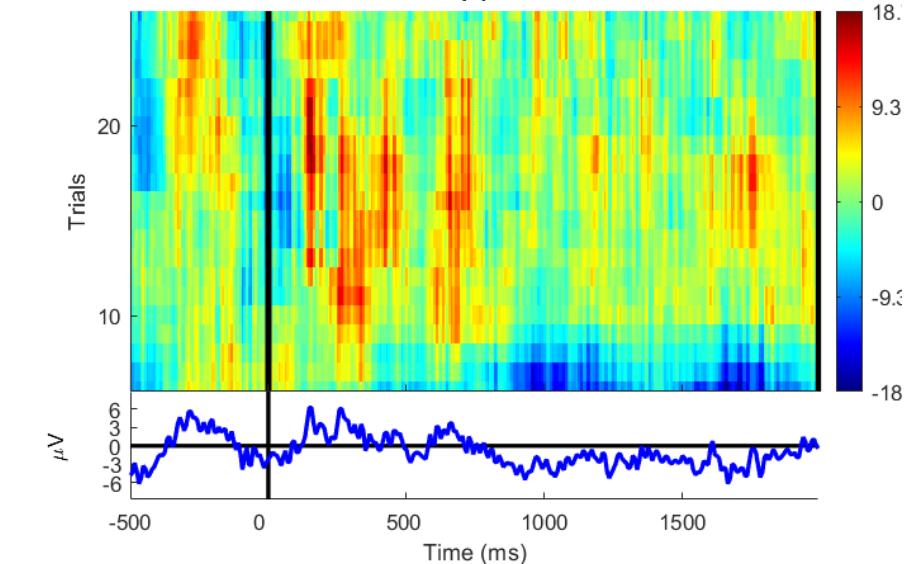


ERP Image for Component 5

Comp. 5



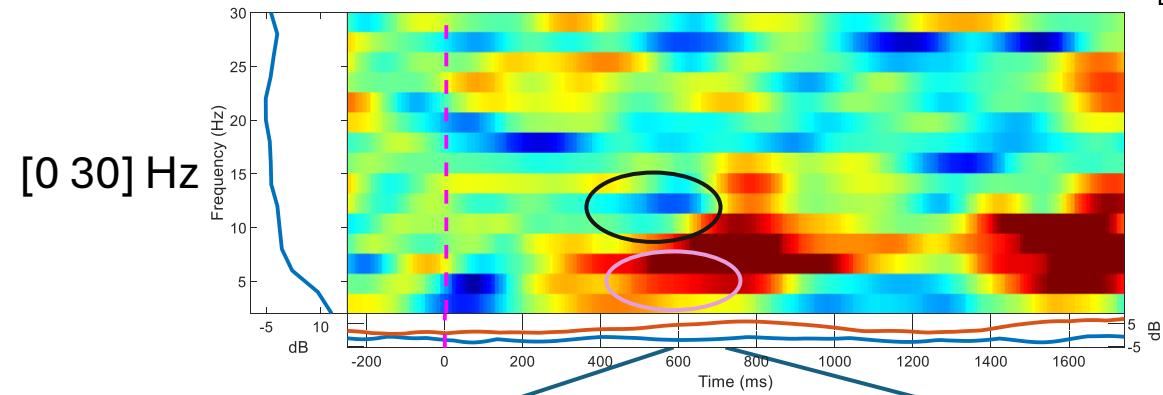
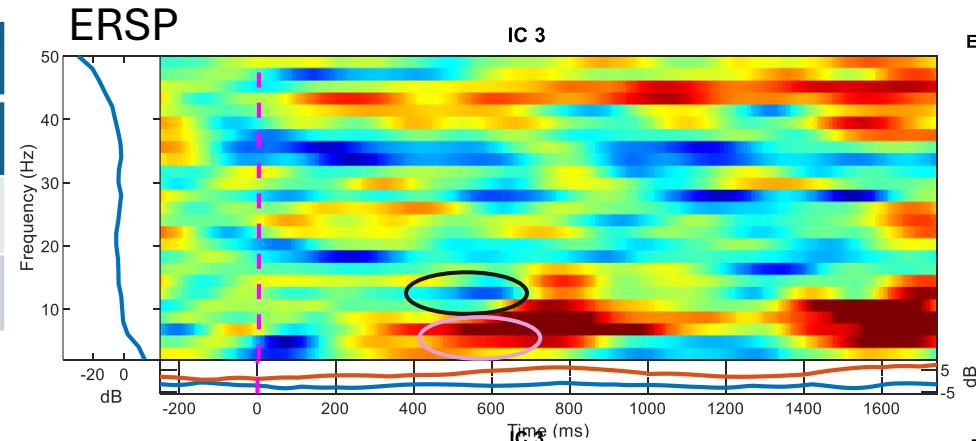
Stronger activity, so we
select F4 for ERSP plot



Early Stage

104_4_1

Frontal F4	
Time	+600ms
Theta	increase
Alpha	decrease



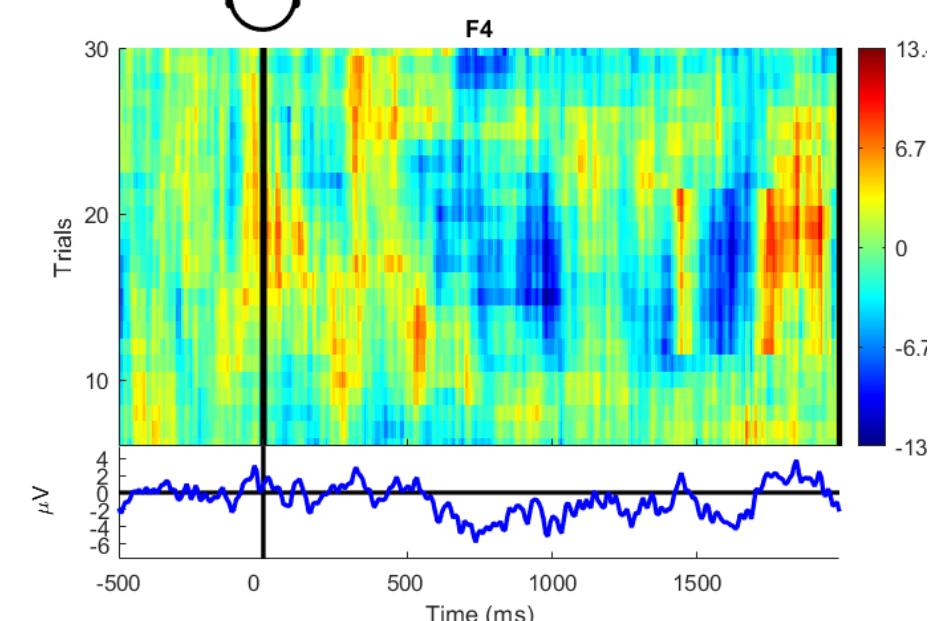
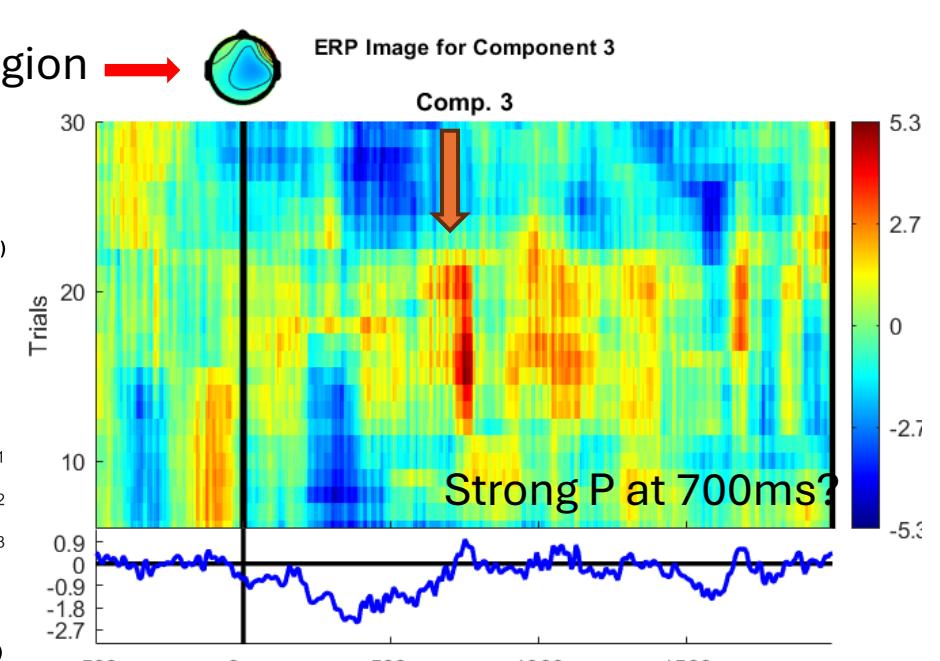
Distinct theta and alpha activities occurs around 500ms

Not prominent activities

ERP Positivity occurs around 700ms, but for ERSP, no distinct activities around 700ms.

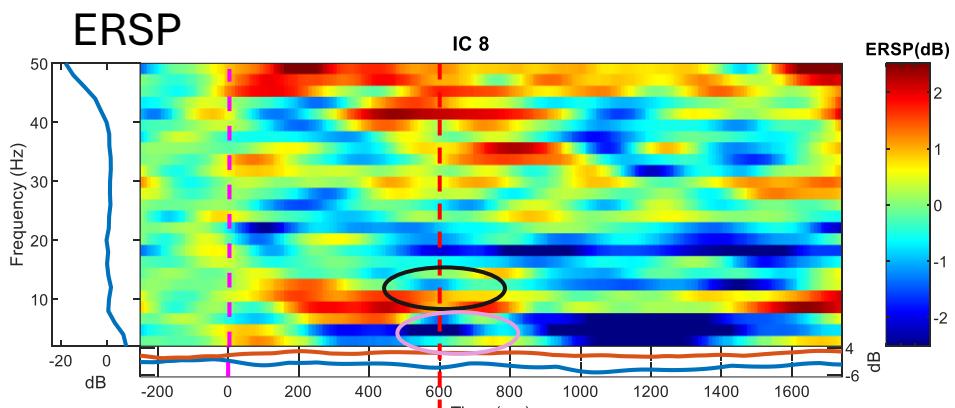
Source from central region →

ERP Image for Component 3

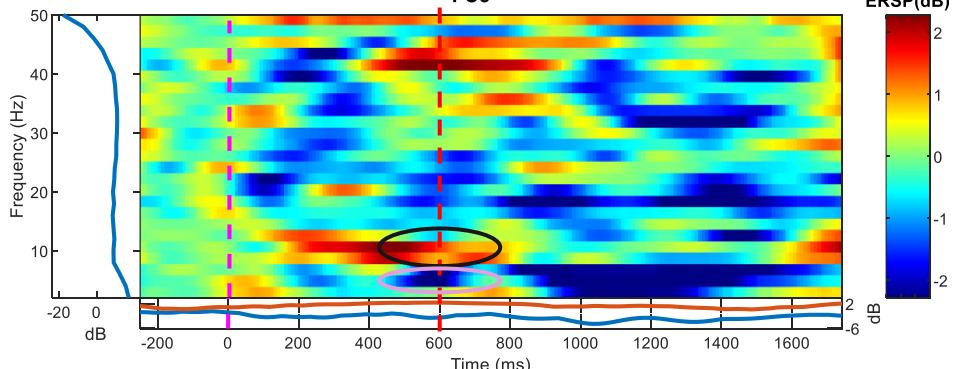
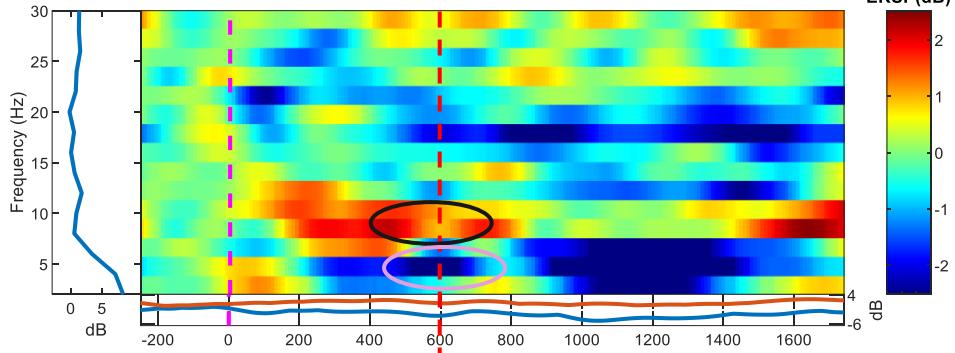


104_5_2

[0 50] Hz



[0 30] Hz



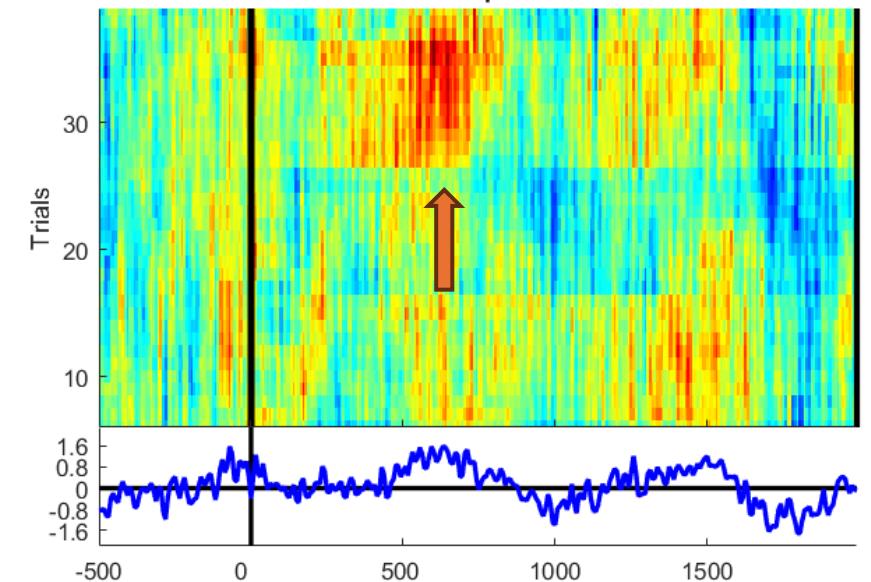
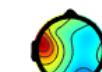
Frontal F4

Time	+600ms
Theta	decrease
Alpha	increase

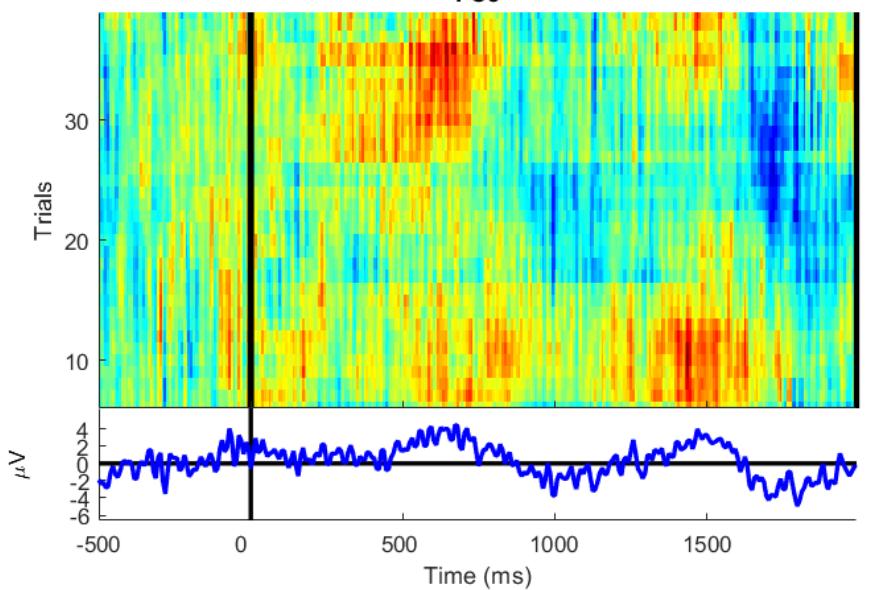
Early Stage

ERP Image for Component 8

Comp. 8



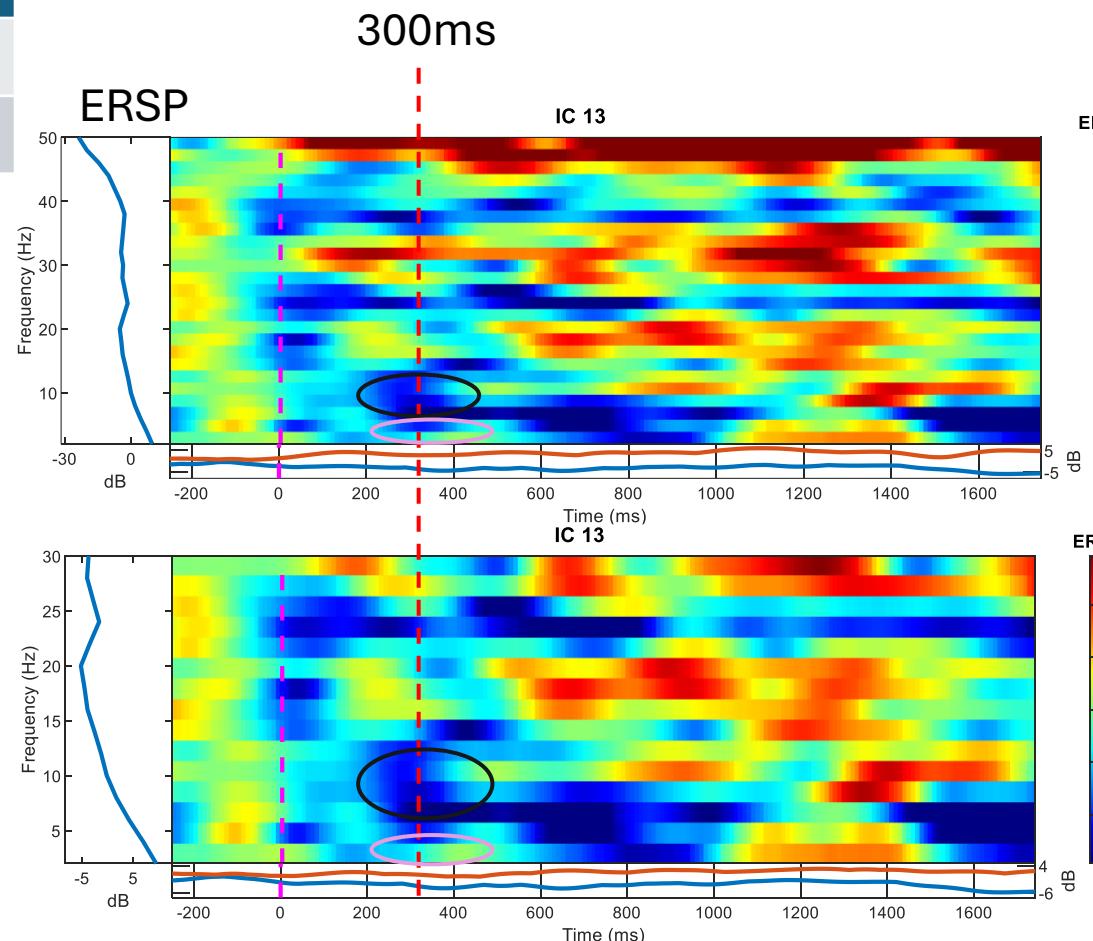
FC5



104_6_2

Frontal F3+F4		
Time	+300ms	
Theta	Increase?	
Alpha	Decrease	

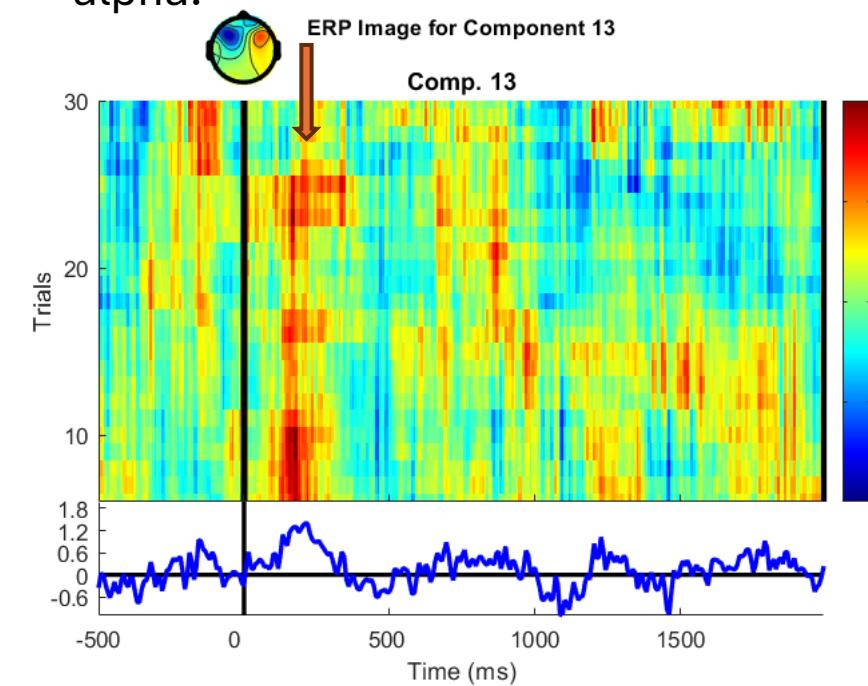
[0 50] Hz



[0 30] Hz

Early Stage

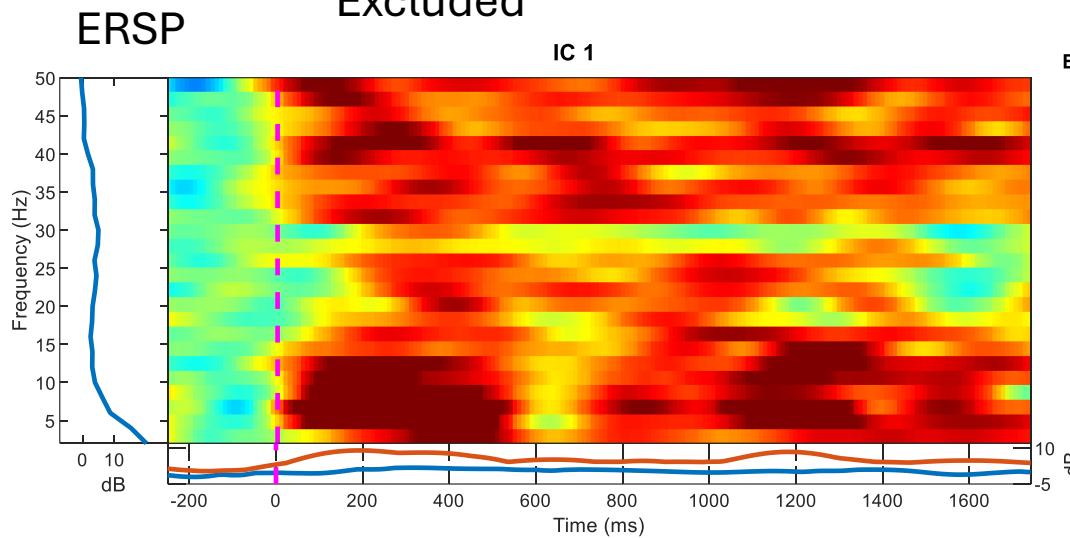
Might not be P300, because muscle noise is prominent, and there is no obvious difference between theta and alpha.



Not prominent ERSP activities, hence exclusion

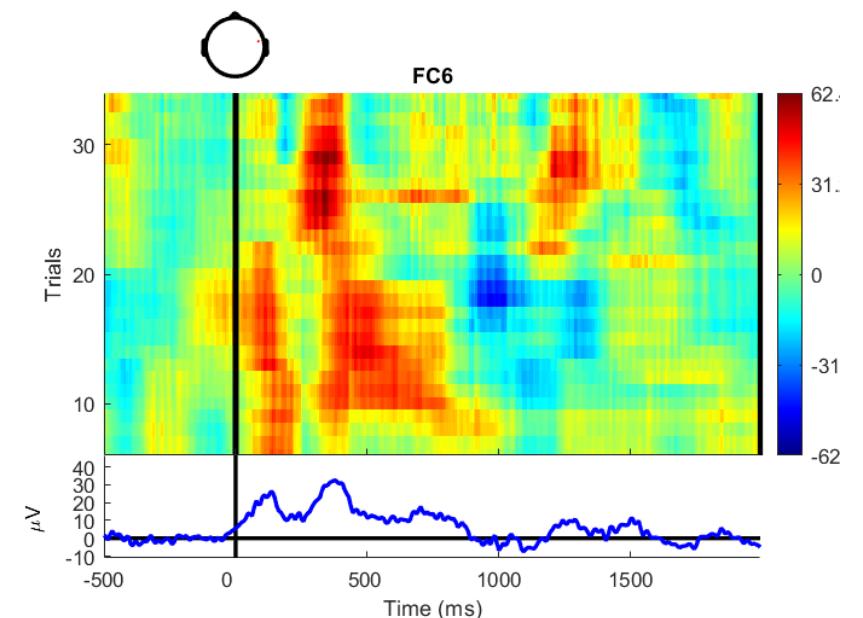
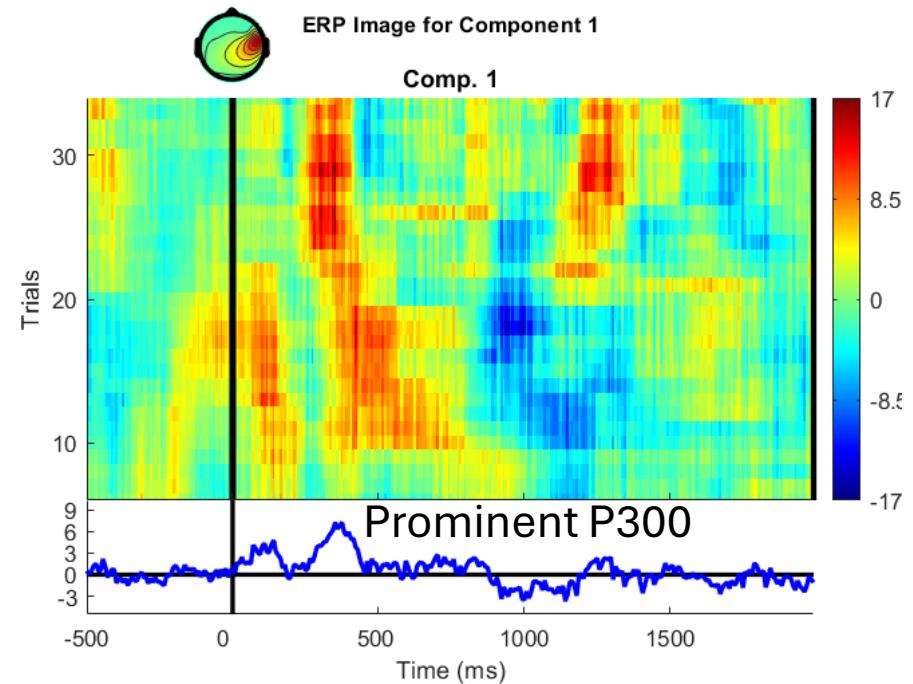
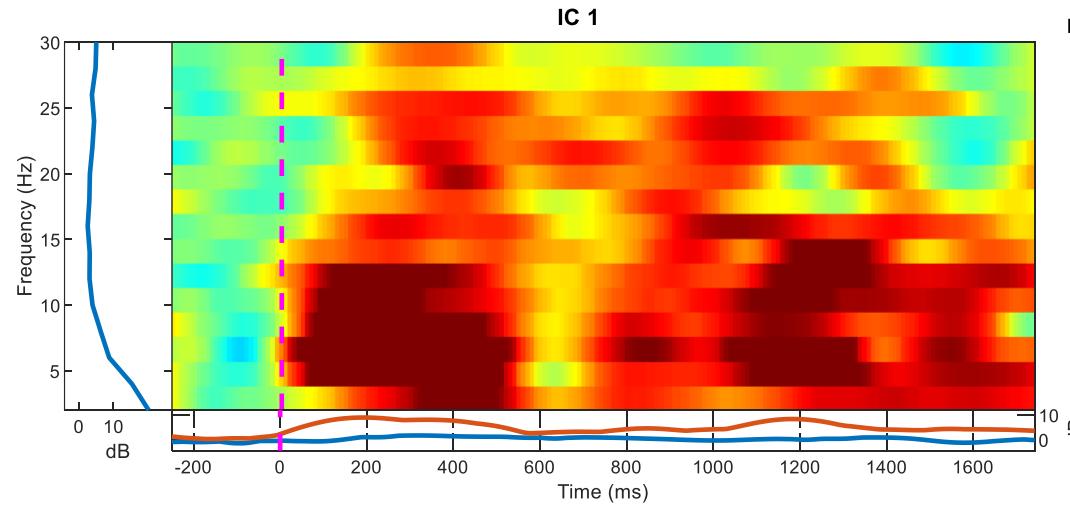
104_7_1

[0 50] Hz



No prominent desynchronisation?
Excluded

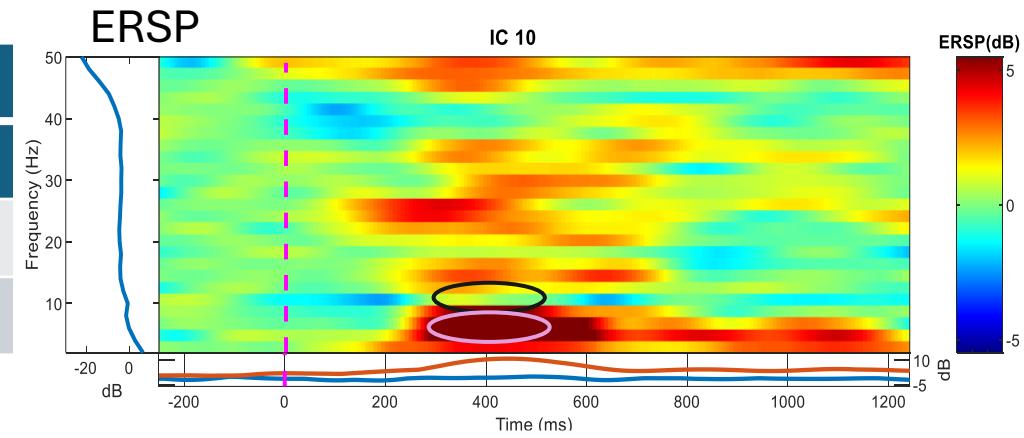
[0 30] Hz



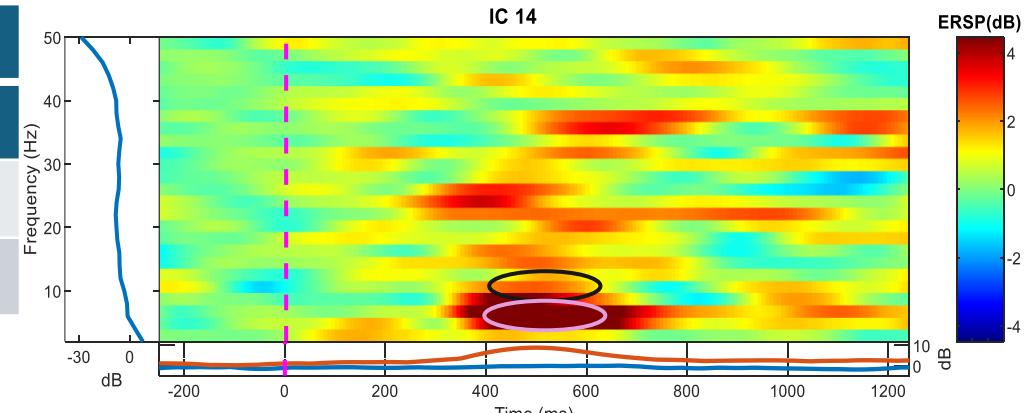
Early Stage

104_8_1

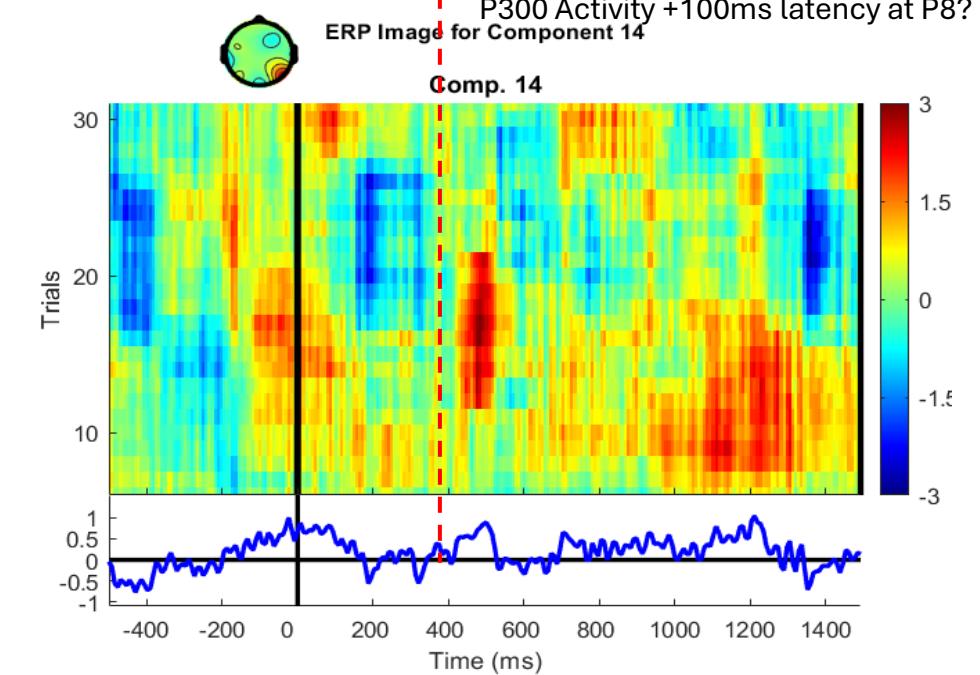
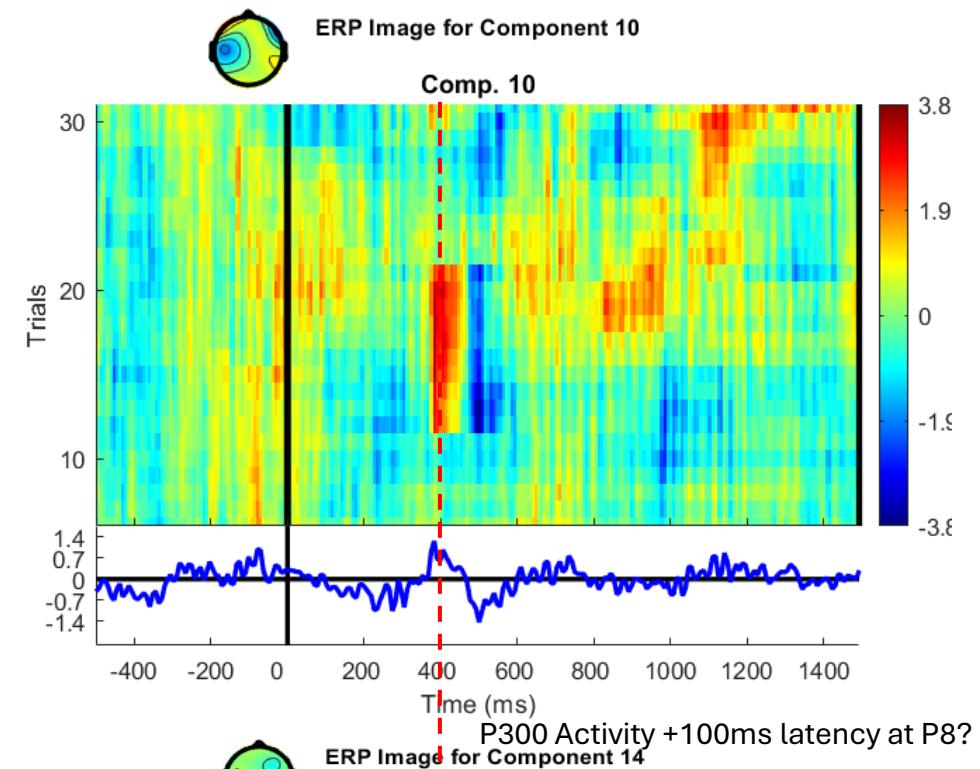
Frontal FC5		
Time	+400ms	
Theta	increase	
Alpha	decrease	



Parietal P8		
Time	+500ms	
Theta	increase	
Alpha	decrease	



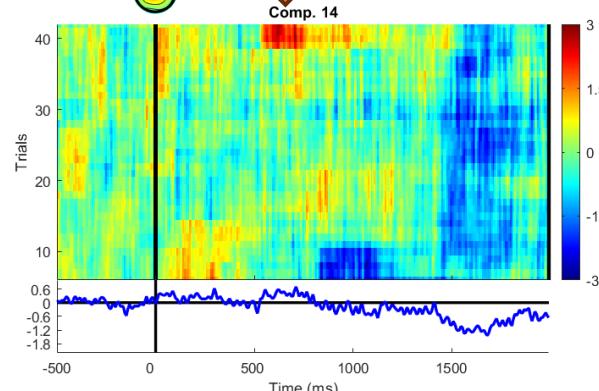
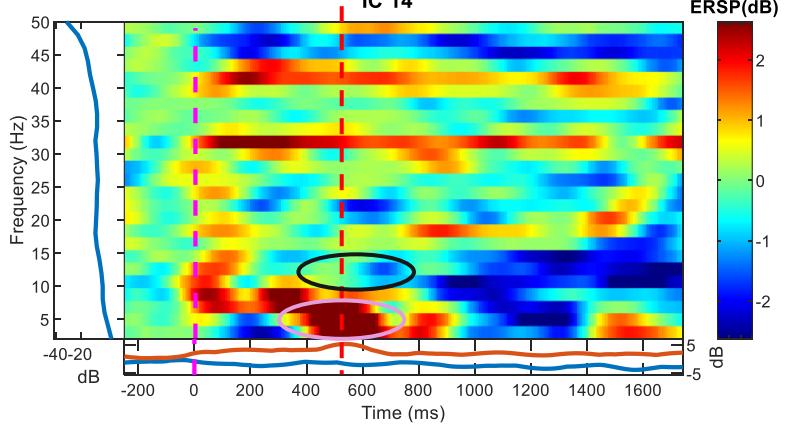
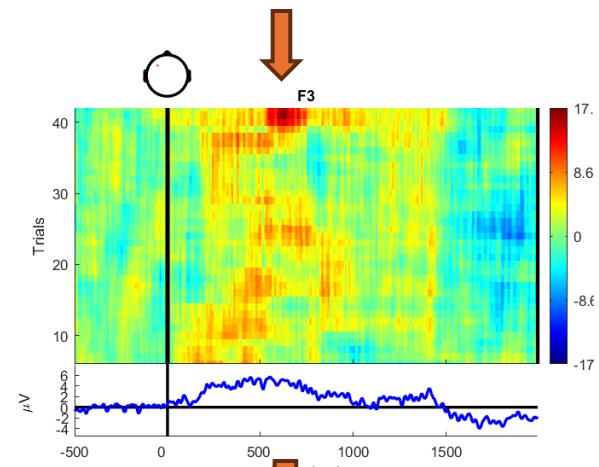
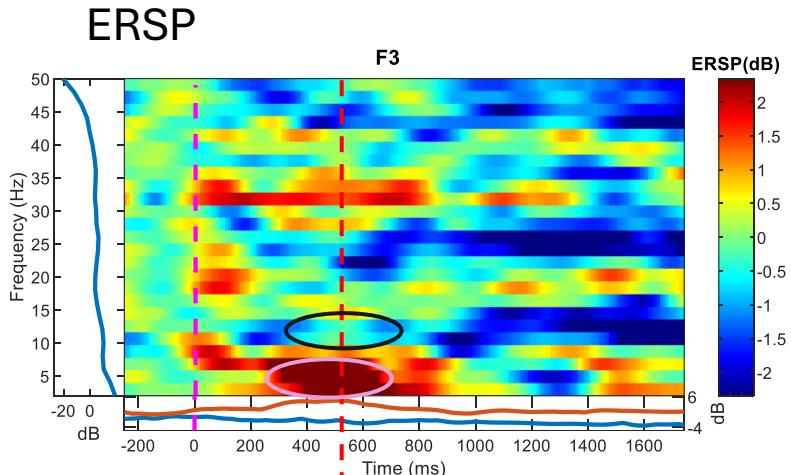
Early Stage



104_8_2

Frontal F3

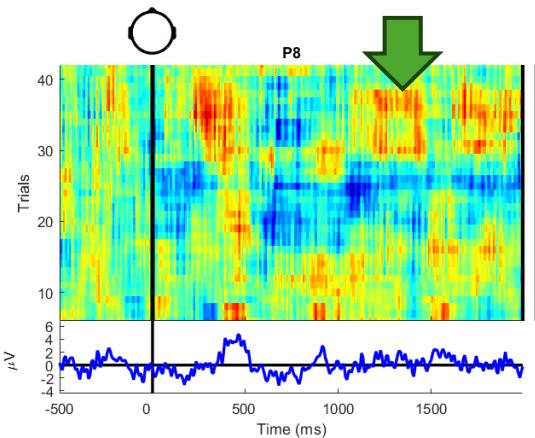
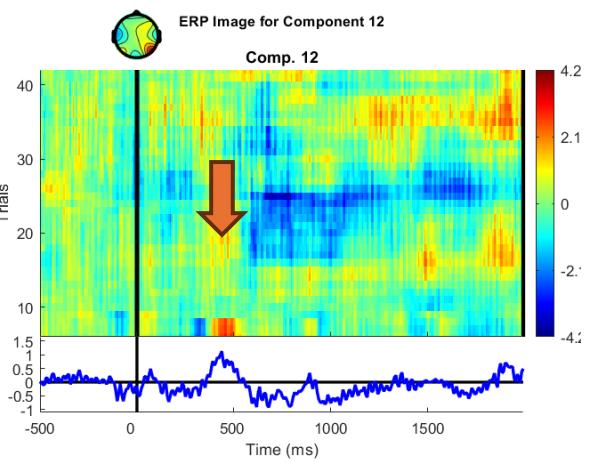
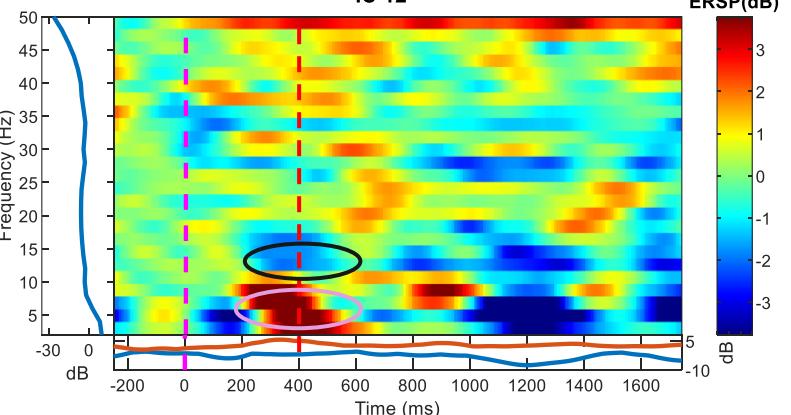
Time	+500ms
Theta	increase
Alpha	decrease



Parietal P8

Time	+400ms
Theta	increase
Alpha	decrease

Early Stage

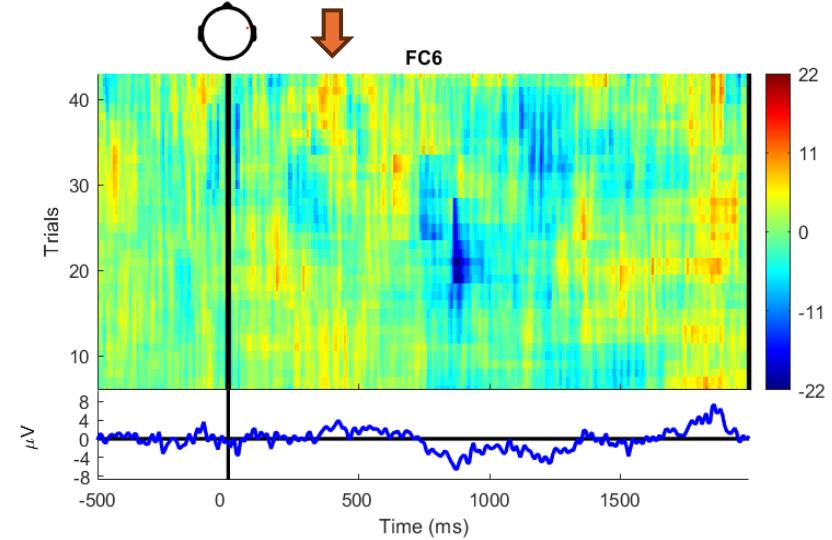
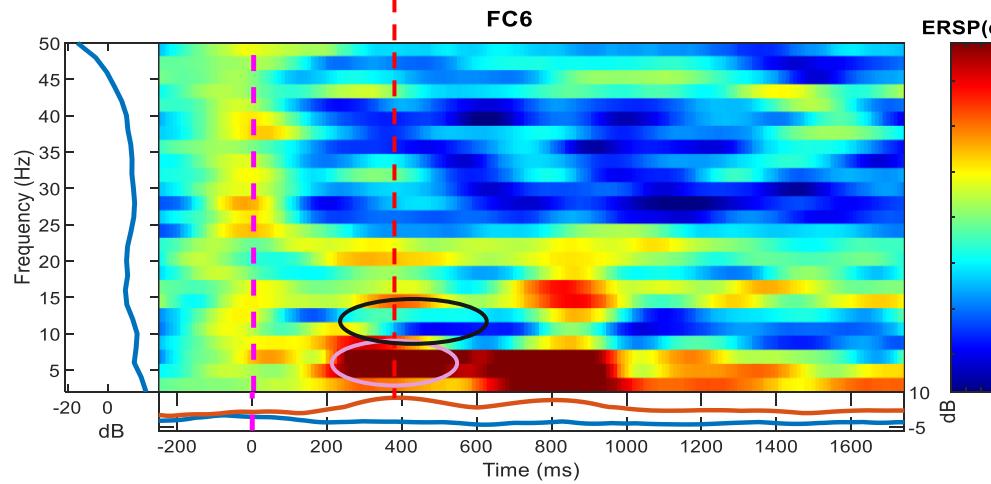
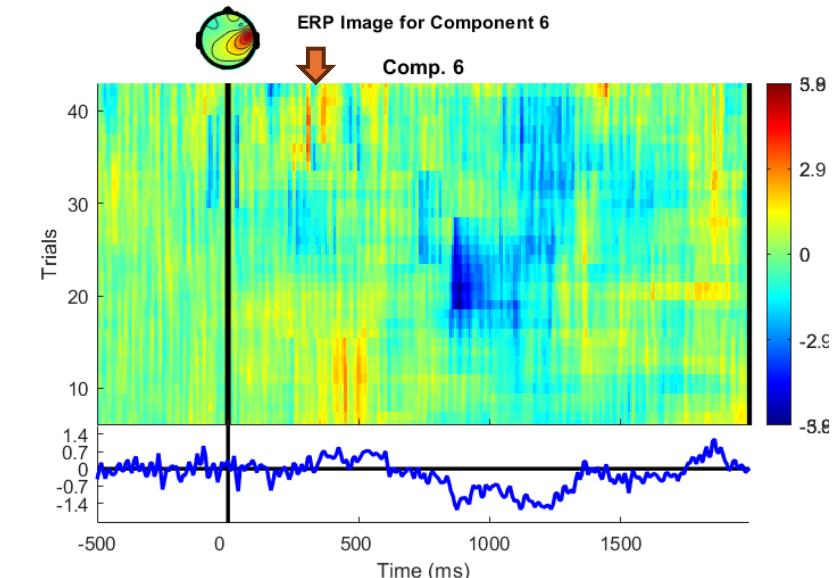
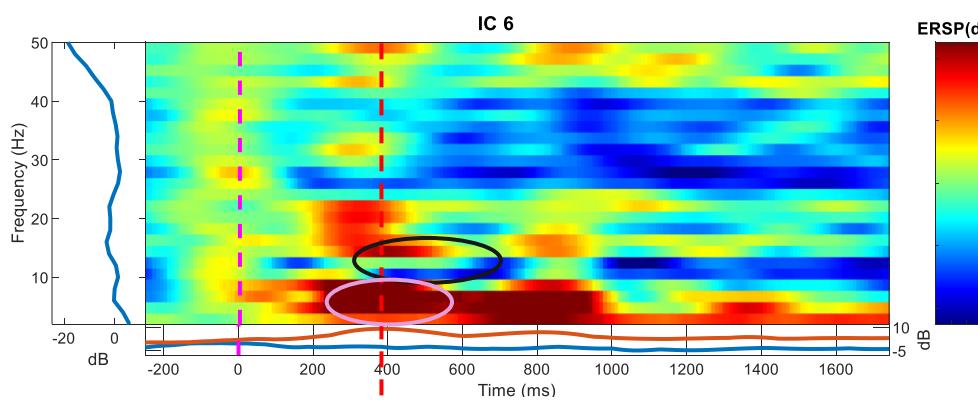


Irregularities in the data surrounding the **P8** electrode

104_9_3

Frontal FC6

Time	+390ms
Theta	increase
Alpha	decrease

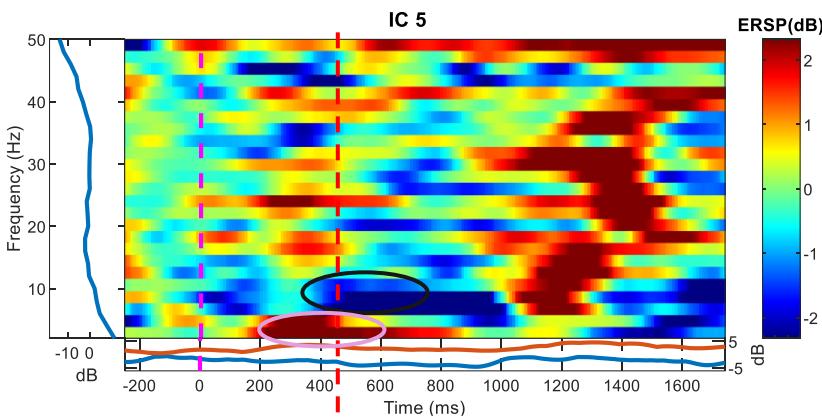


Middle Stage

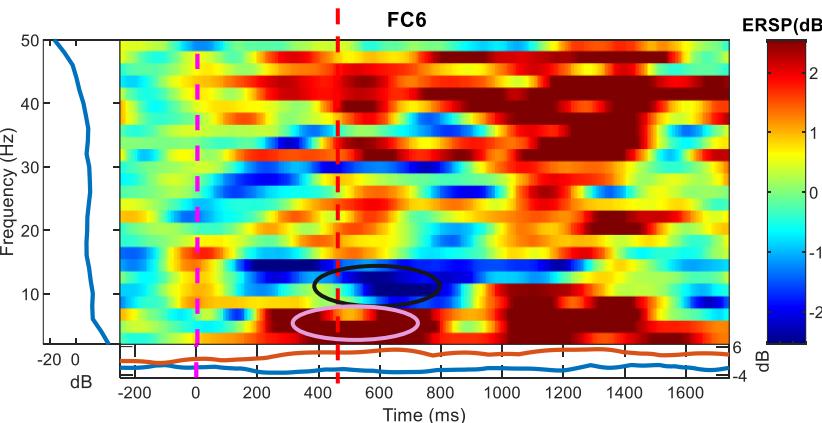
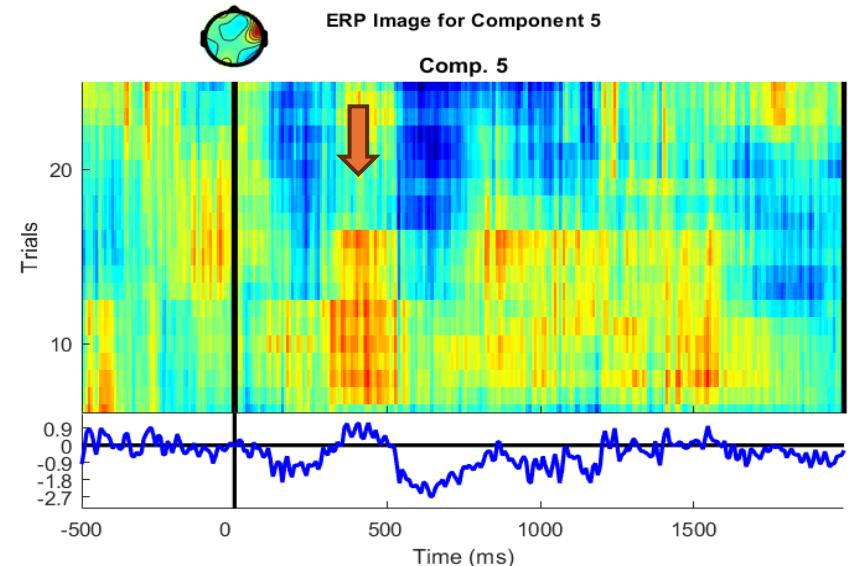
104_11_1

Frontal FC6

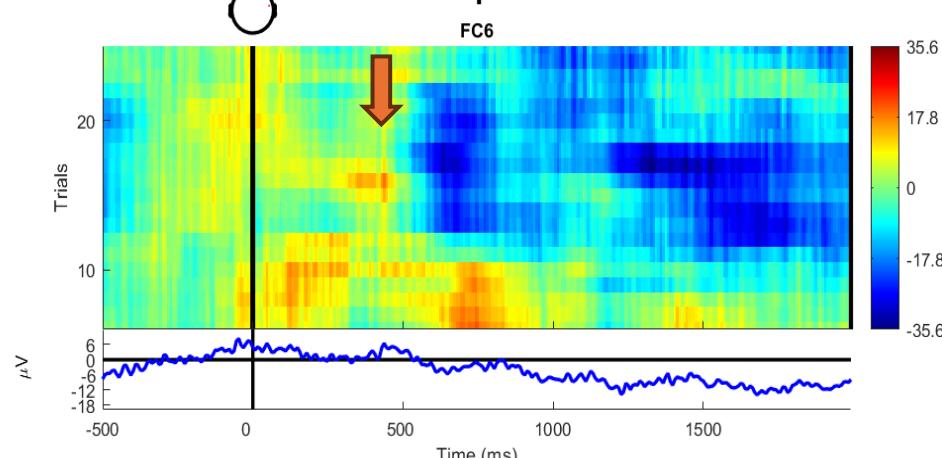
Time	+450ms
Theta	increase
Alpha	decrease



Clearer potential



Unclear potential



time = 0ms

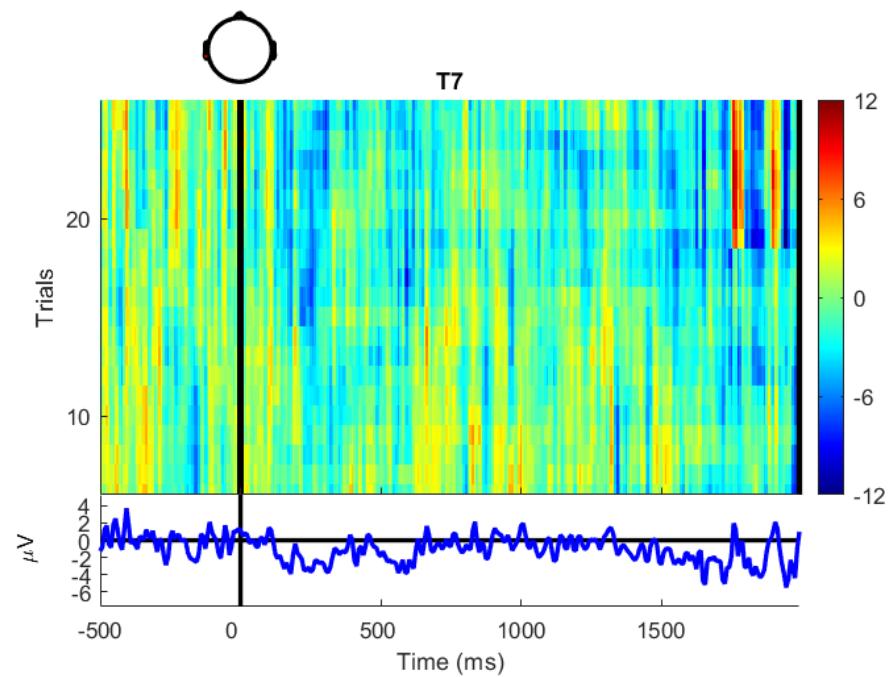
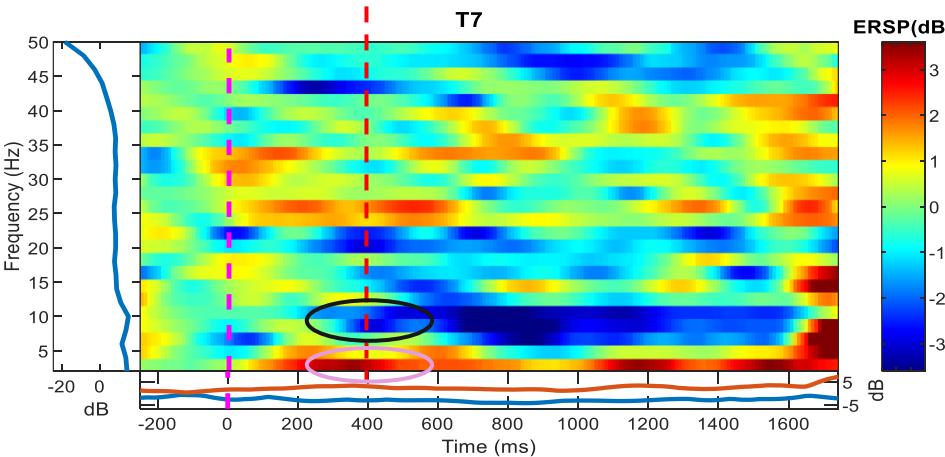
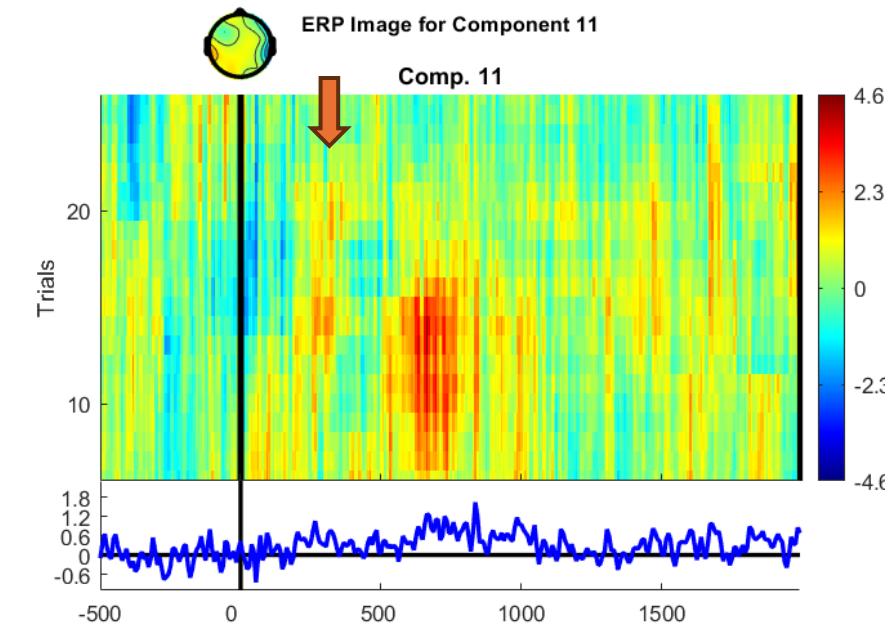
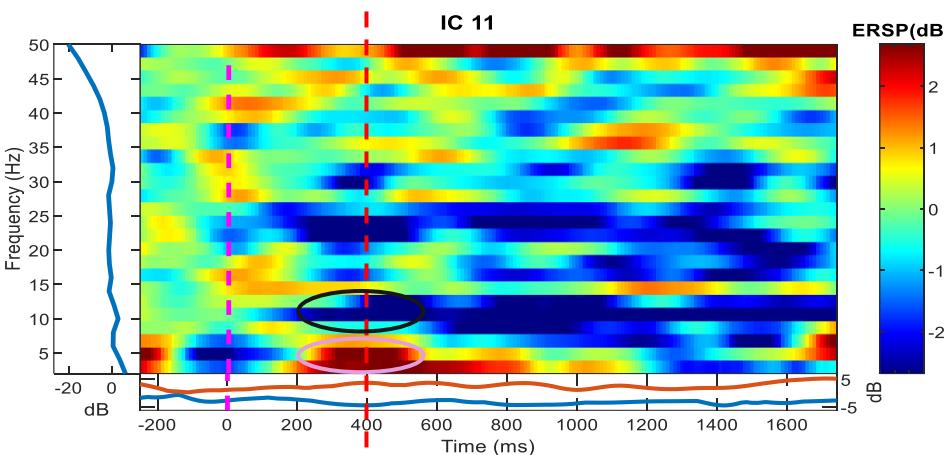
N-back stimulus onset

Middle Stage

104_12_1

Temporal T7

Time	+450ms
Theta	increase
Alpha	decrease

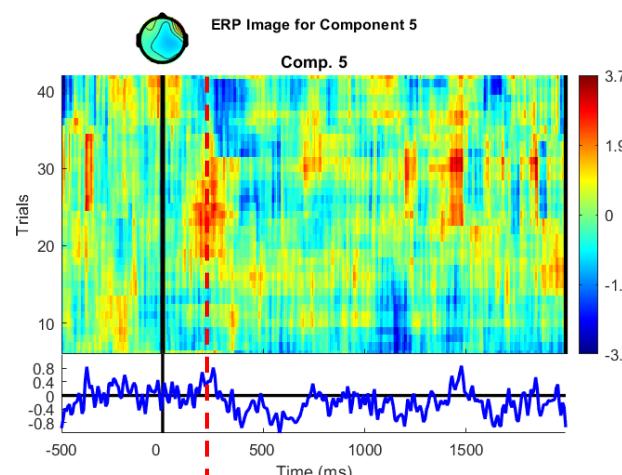
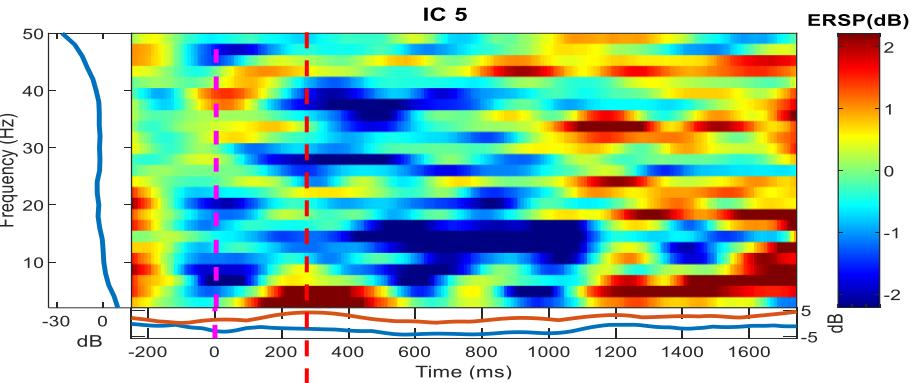


Middle Stage

104_12_2

Frontal F8

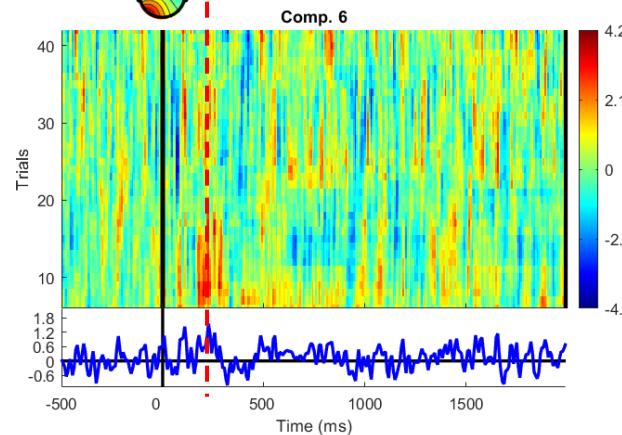
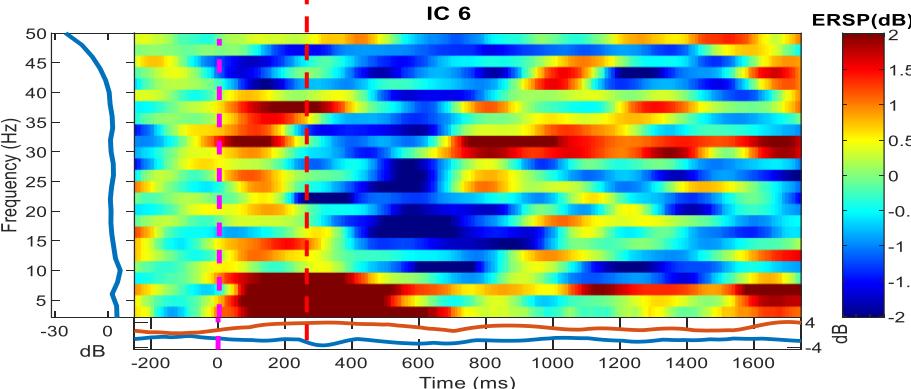
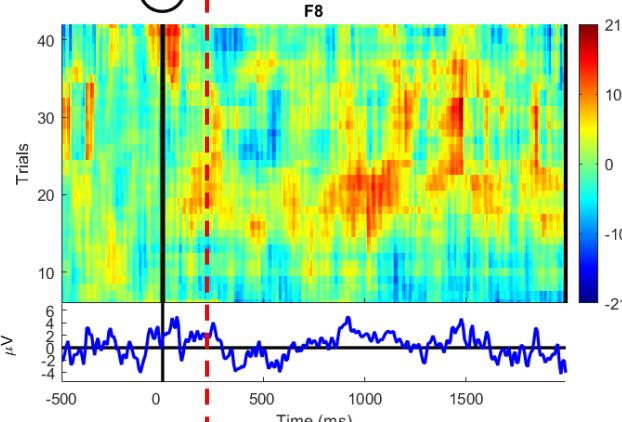
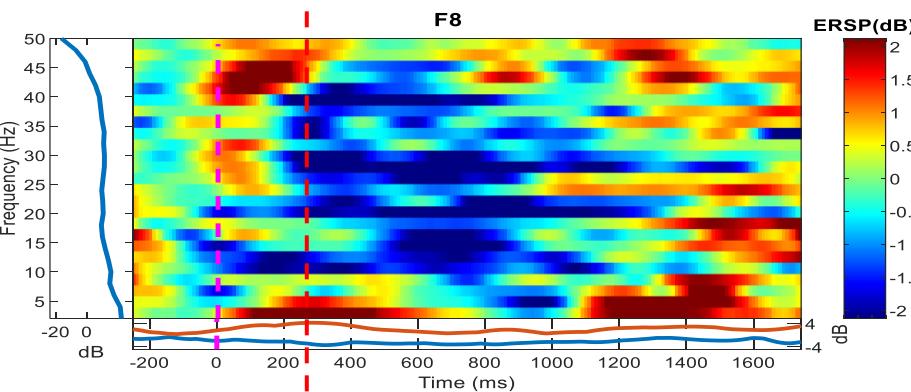
Time	+300ms	
Theta	increase	
Alpha	decrease	



Parietal P7

Time	+300ms	
Theta	increase	
Alpha	decrease	

Not obvious
desync for alpha
at 300ms

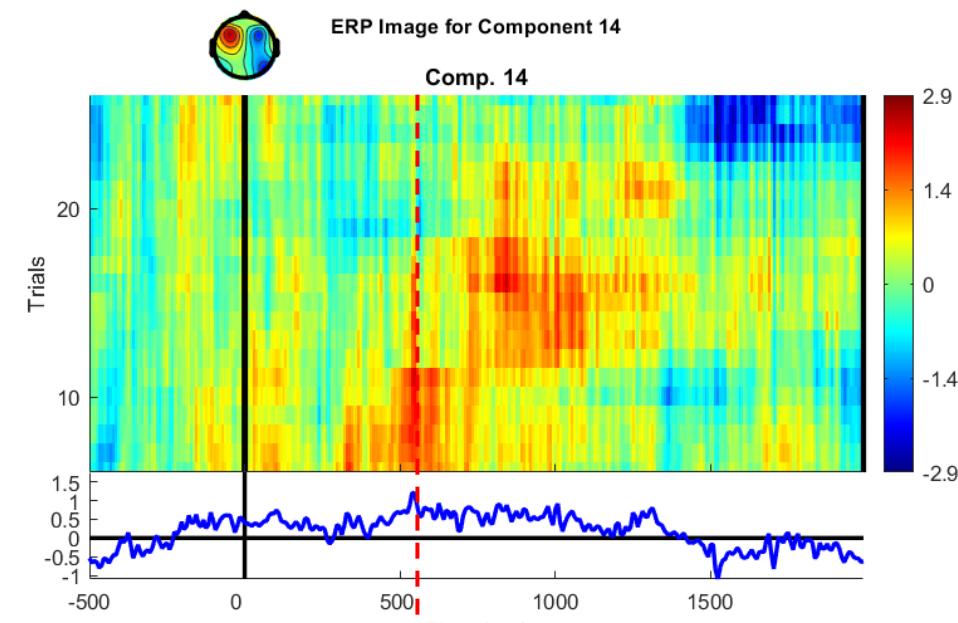
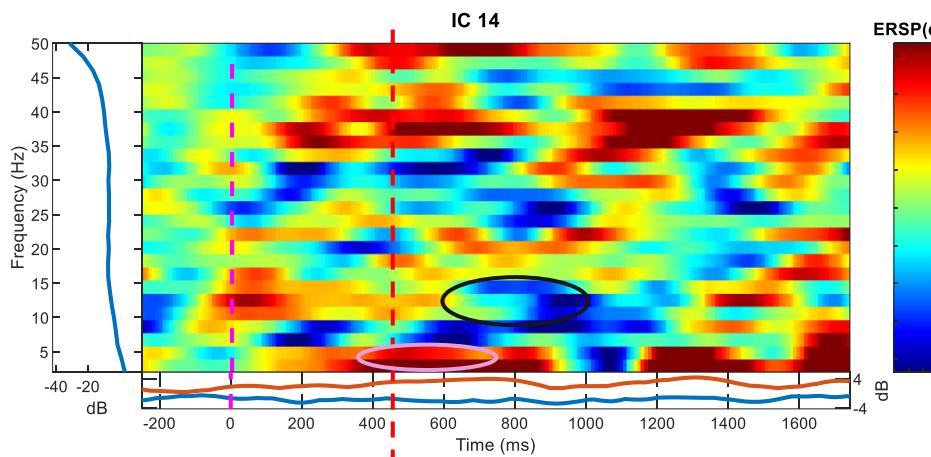


Middle Stage

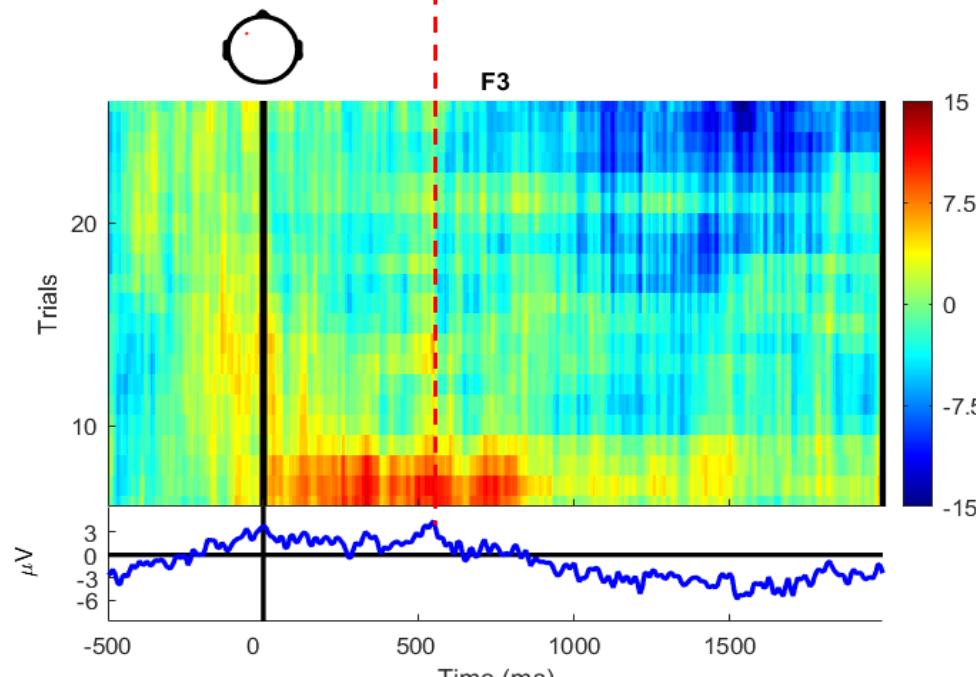
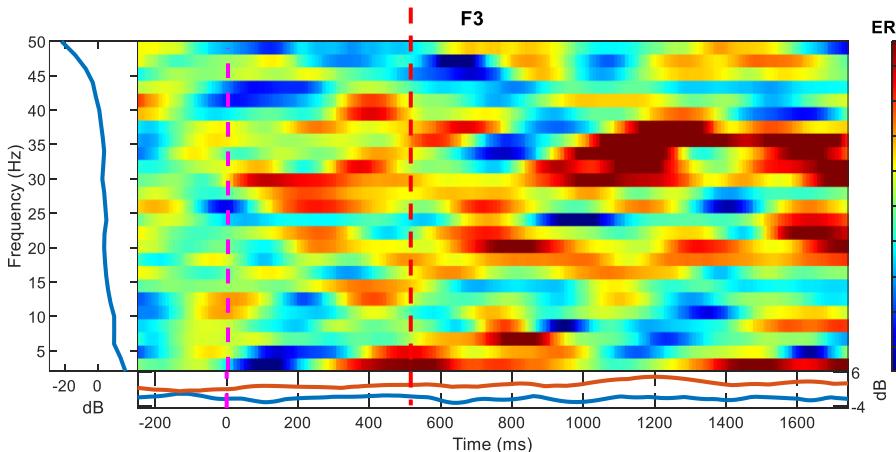
104_13_1

Frontal F3

Time	+510ms
Theta	increase
Alpha	decrease



Theta shift to lower Hz

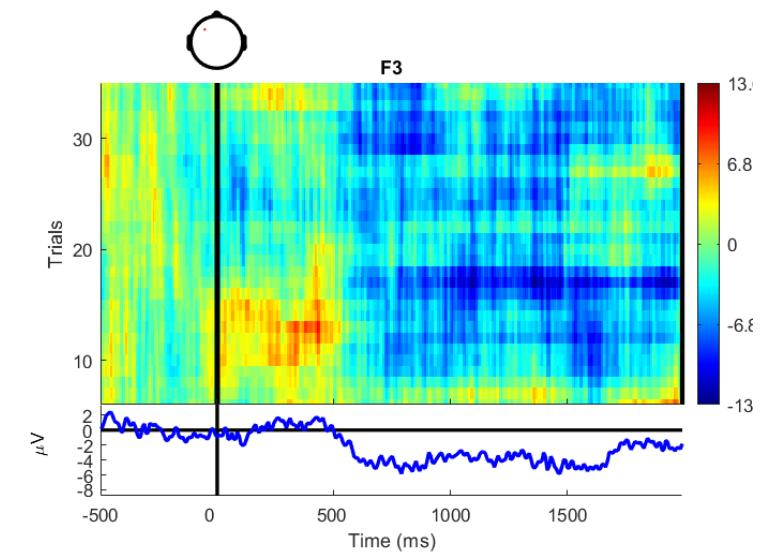
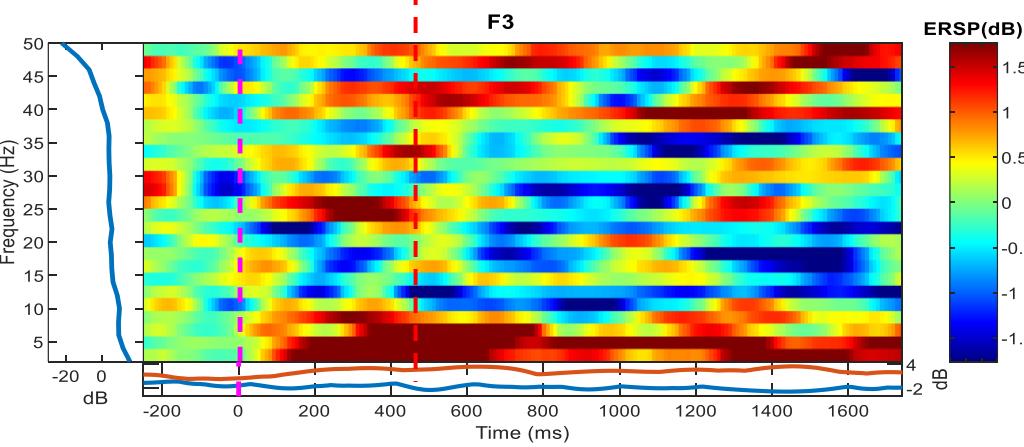
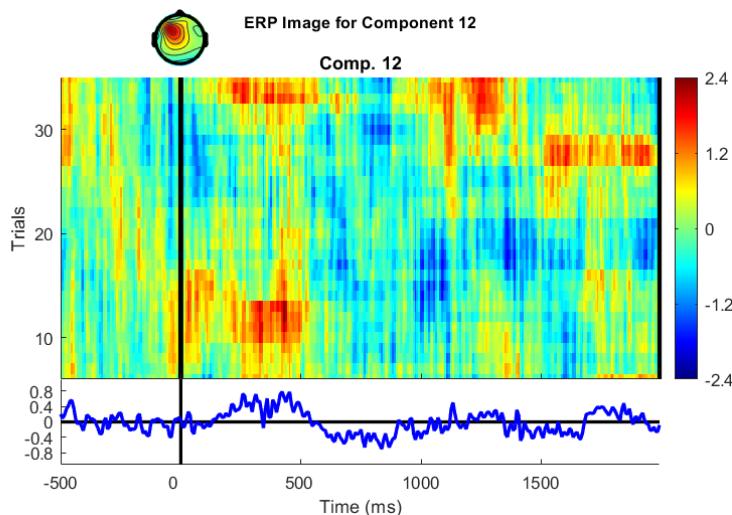
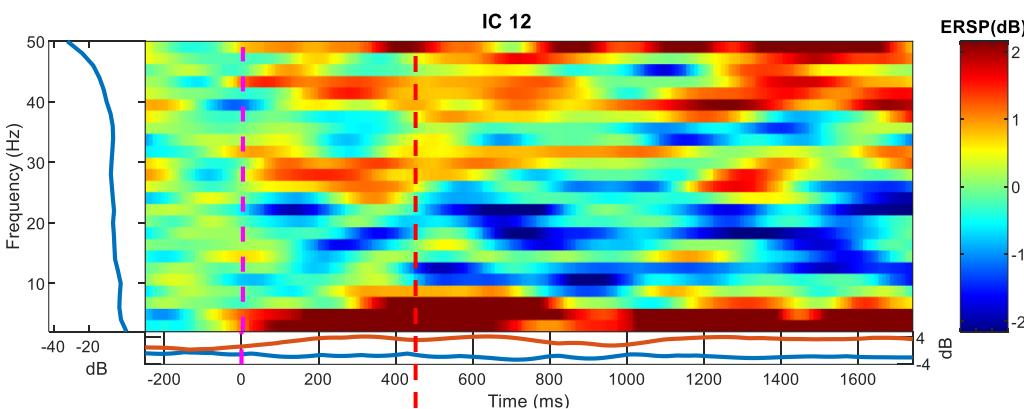


Middle Stage

104_13_2

Frontal F3

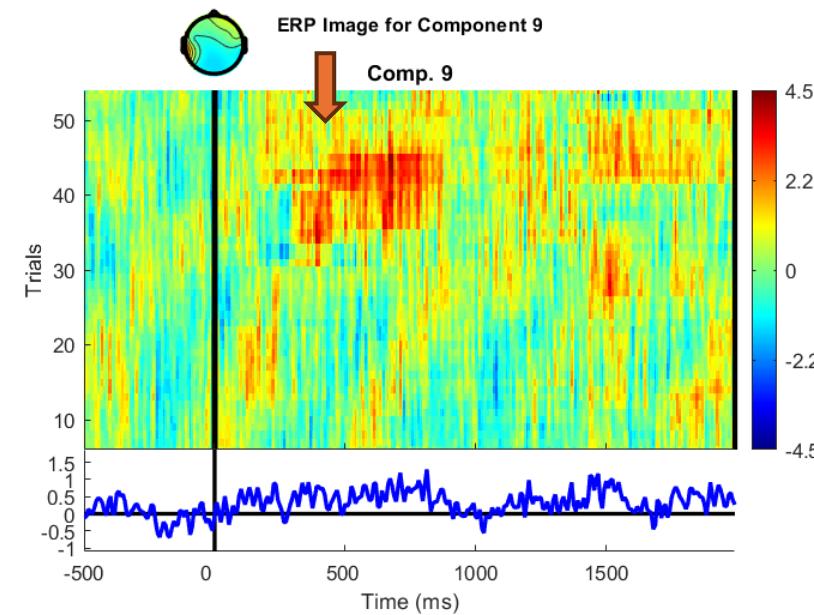
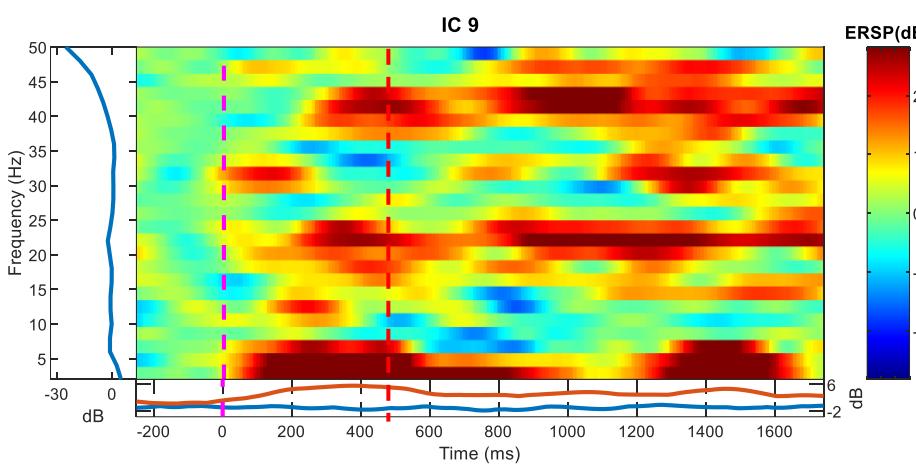
Time	+450ms
Theta	increase
Alpha	decrease



Middle Stage

104_13_3

Temporal T7		
Time	+450ms	
Theta	increase	
Alpha	decrease	

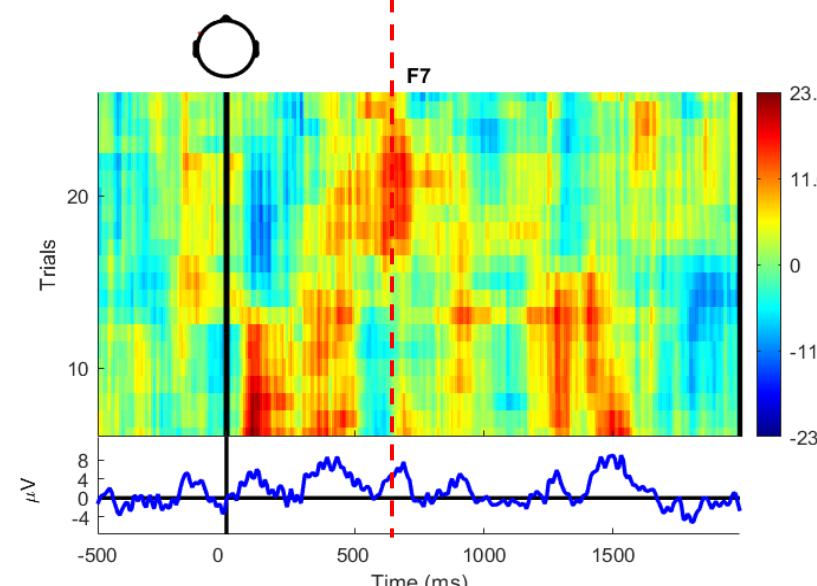
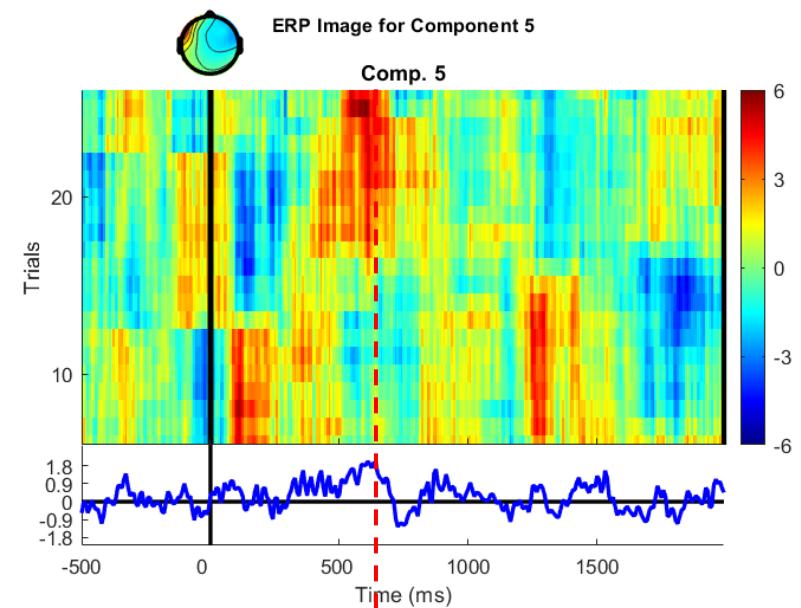
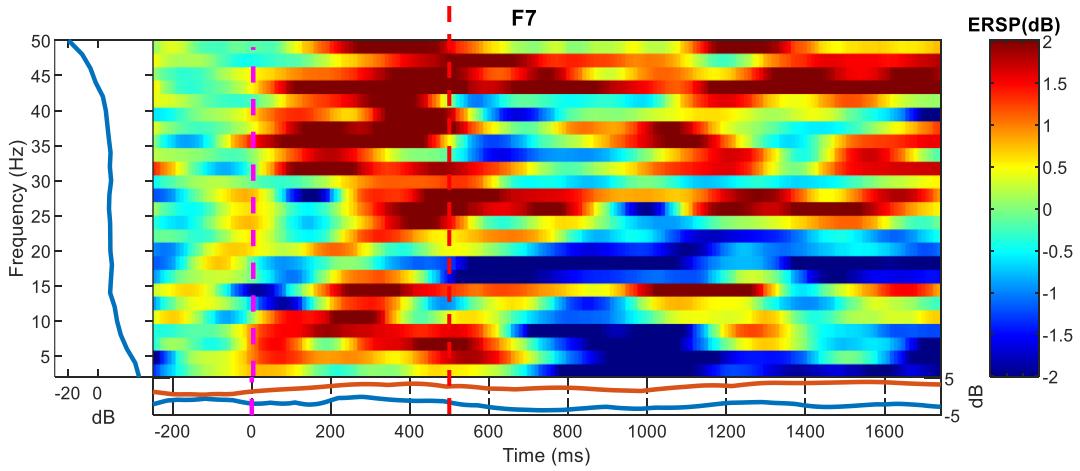
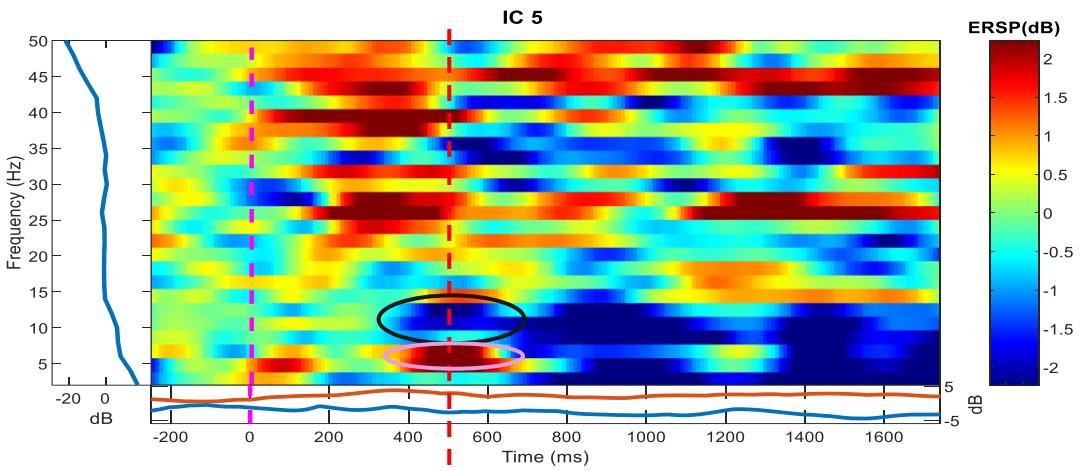


Middle Stage

104_14_2

Temporal T7

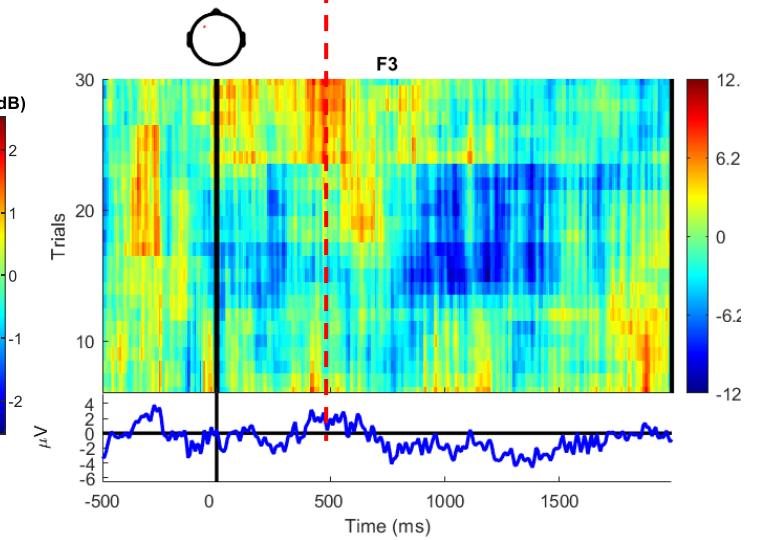
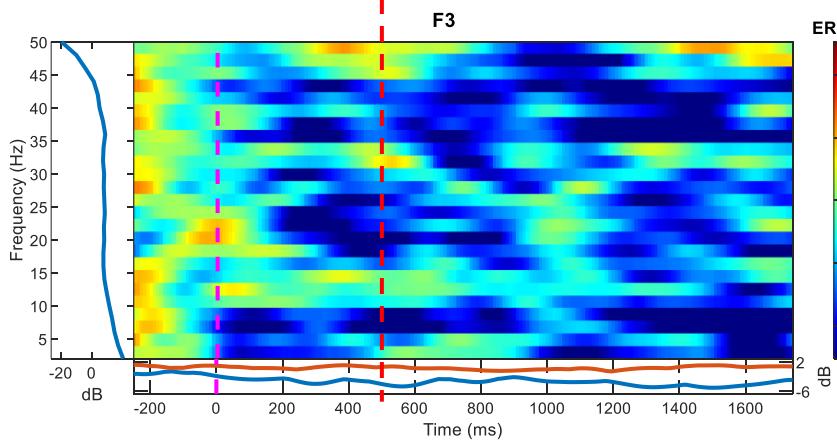
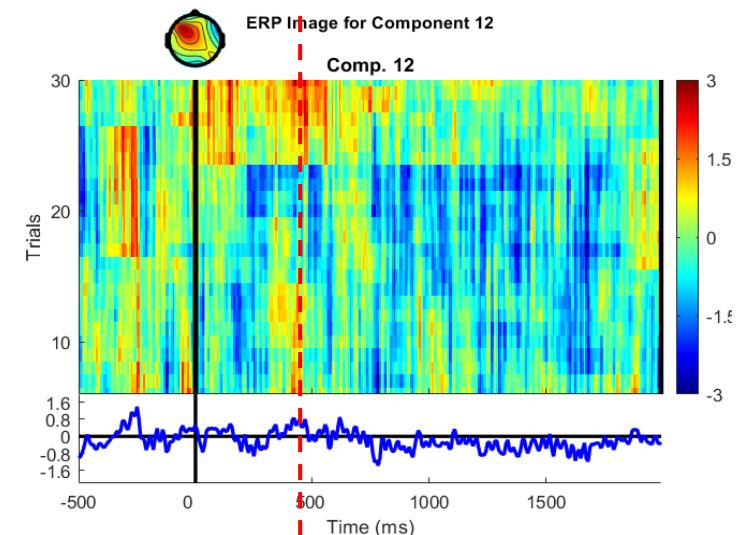
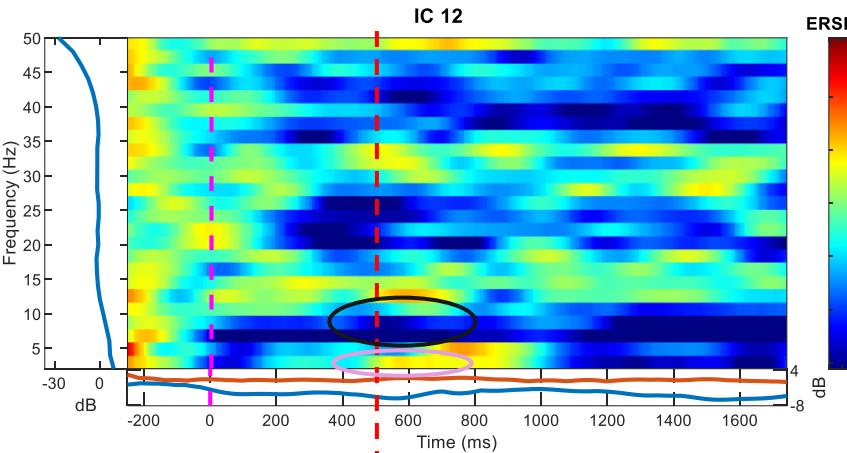
Time	+500ms
Theta	increase
Alpha	decrease



Middle Stage

104_14_3

Frontal F3		
Time	+500ms	
Theta	increase	
Alpha	decrease	

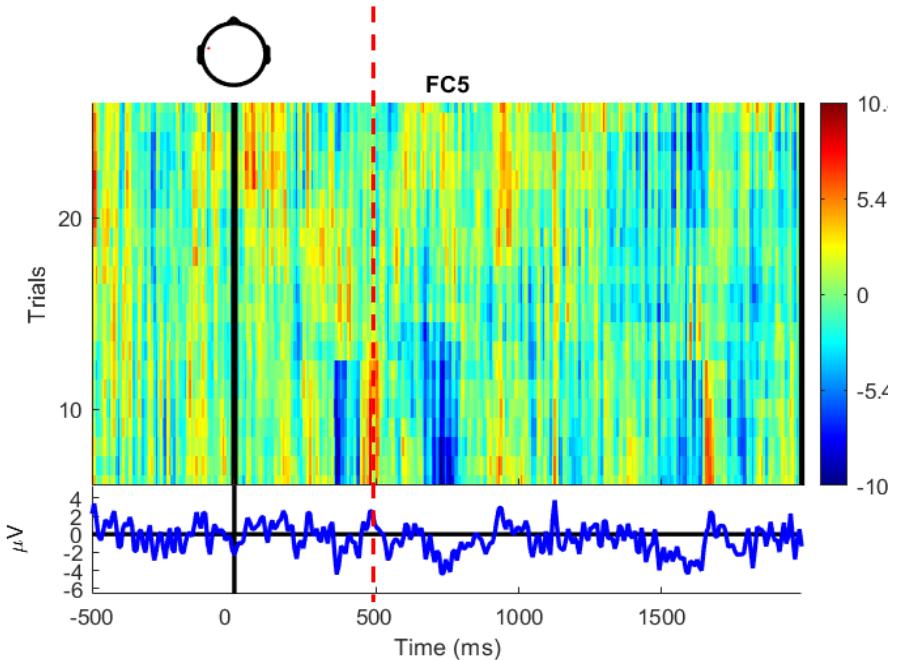
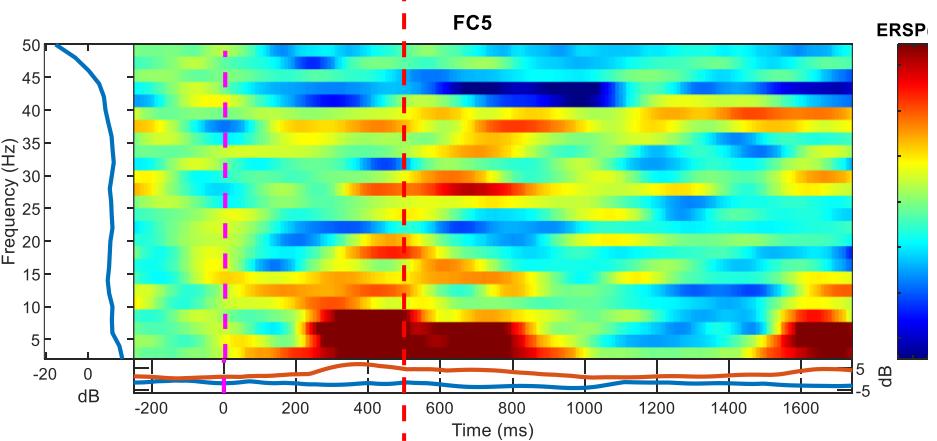
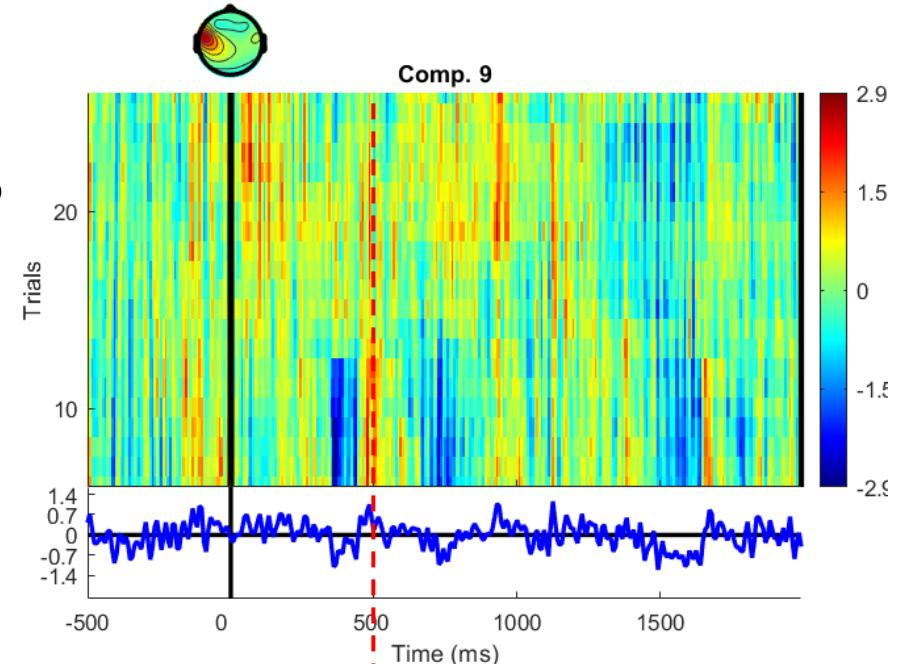
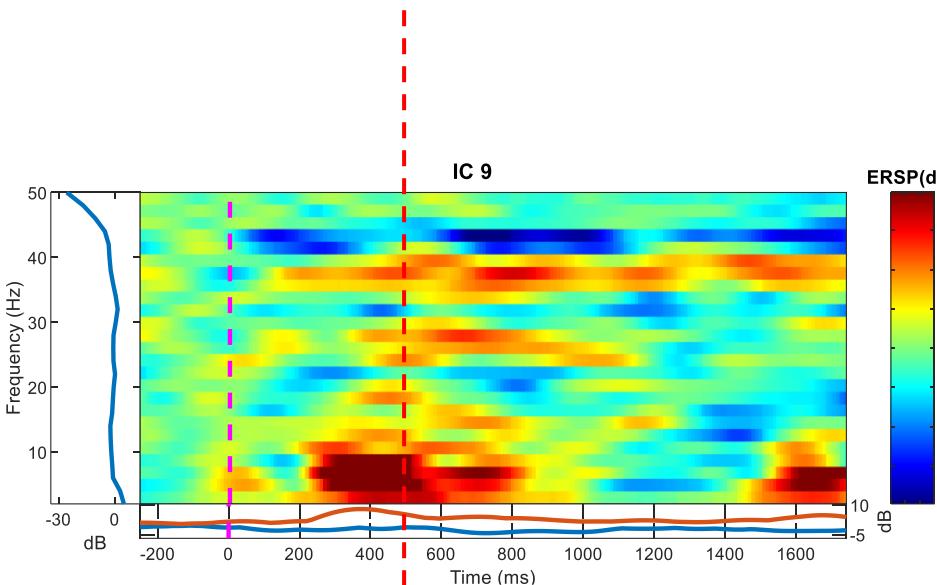


Middle Stage

104_15_3

Frontal FC5

Time	+500ms
Theta	increase
Alpha	-



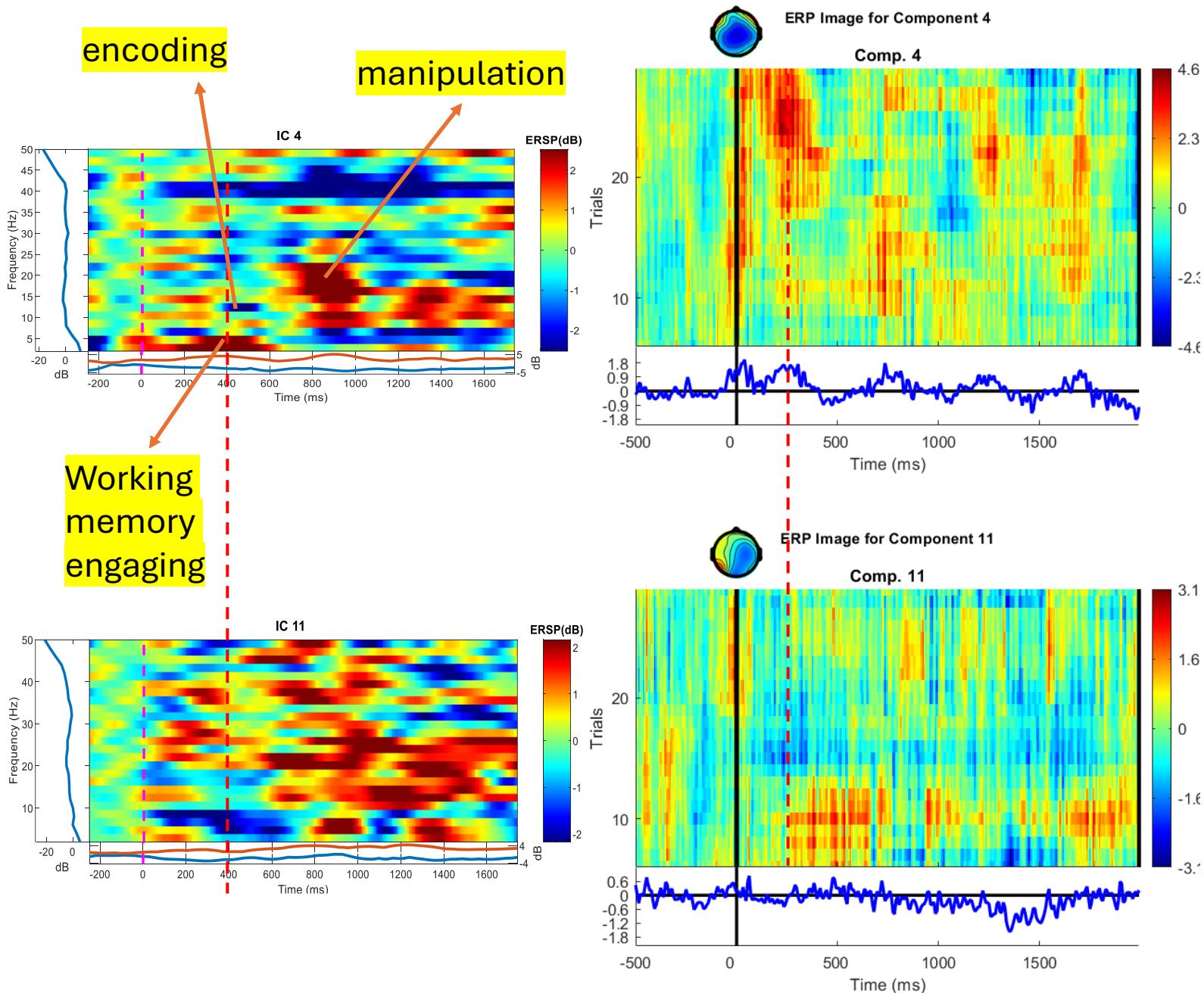
Middle Stage

104_16_3

Central Cz	
Time	+400ms
Theta	increase
Alpha	decrease

Not included in P300 observation

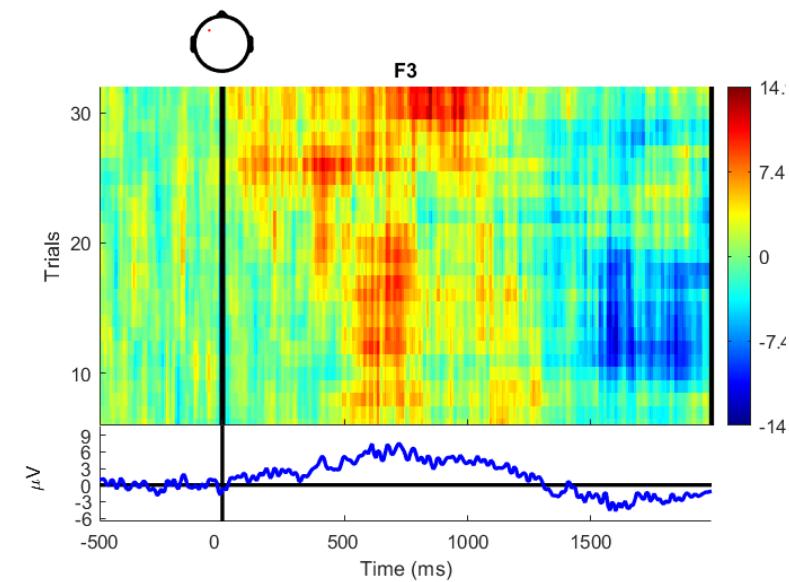
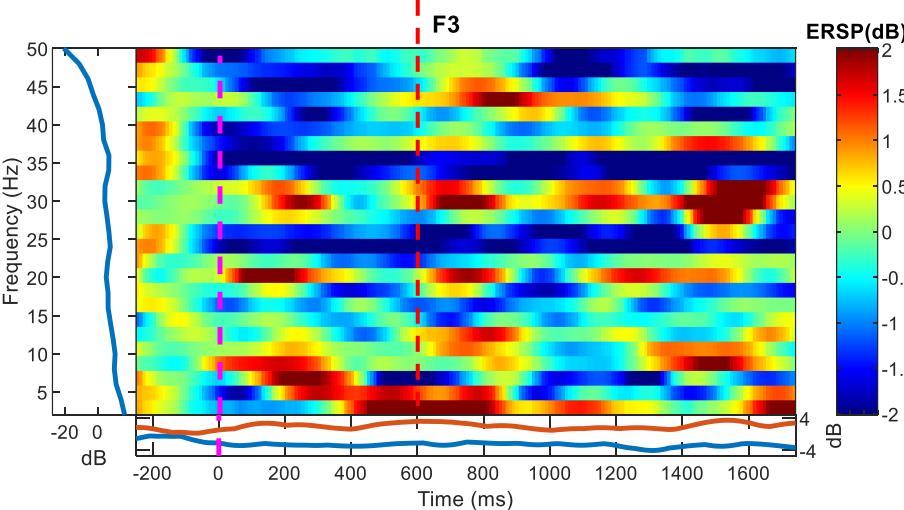
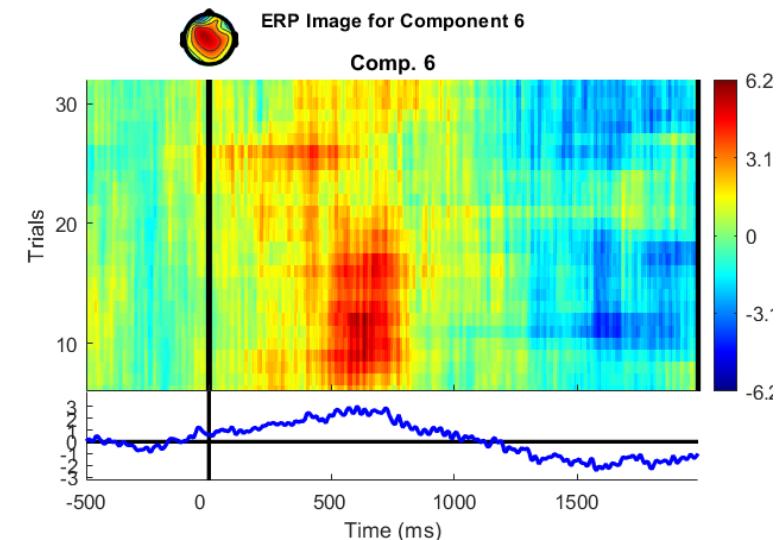
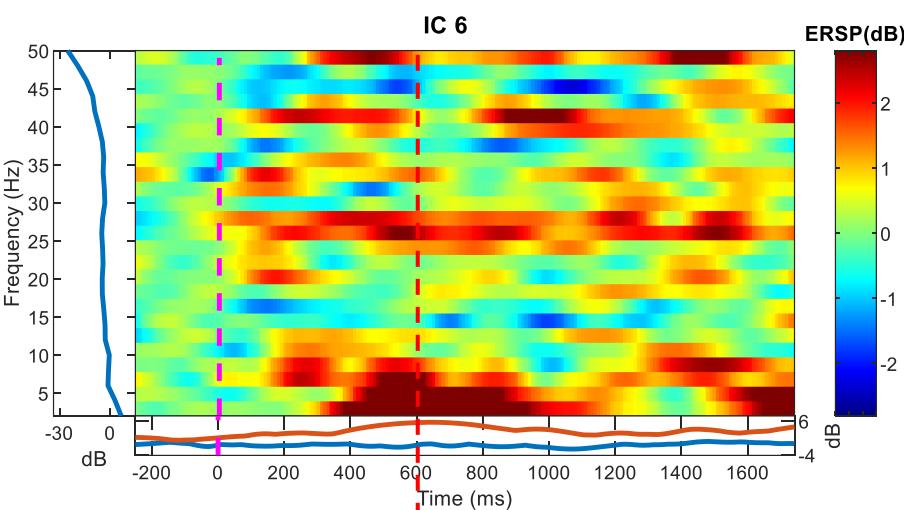
Parietal P7	
Time	+400ms
Theta	decrease
Alpha	-



Middle Stage

104_17_1

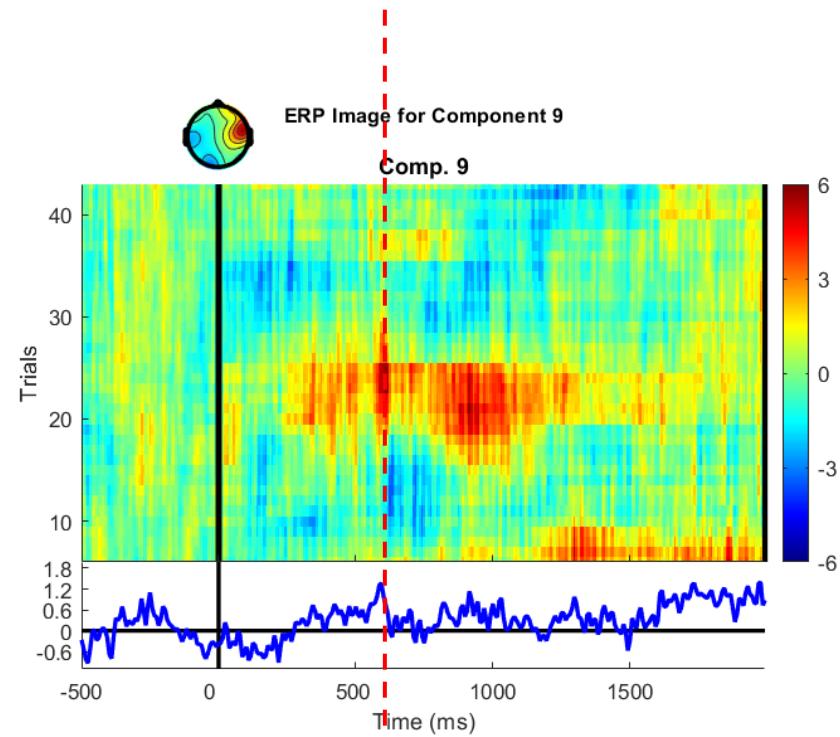
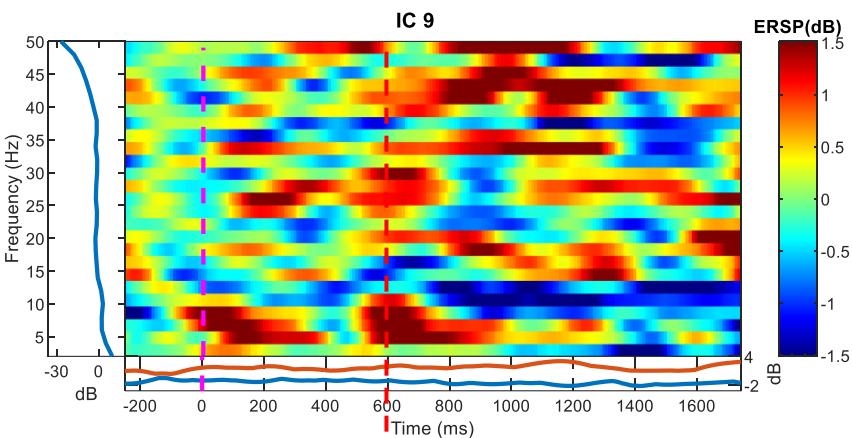
Frontal F3	
Time	+600ms
Theta	increase
Alpha	-



Later Stage

104_17_2

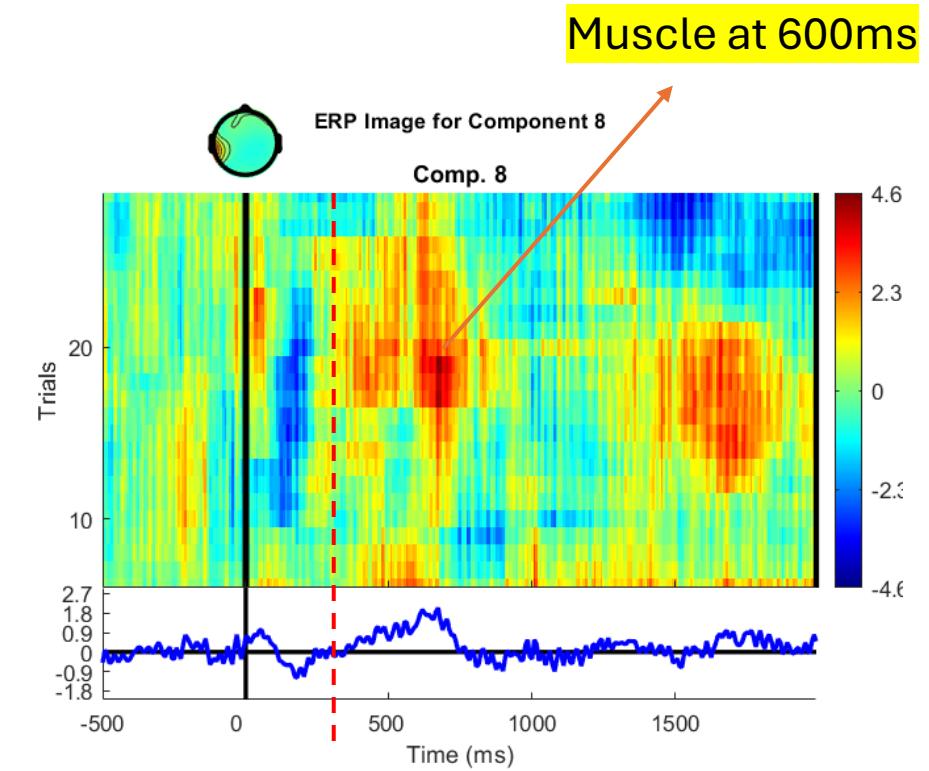
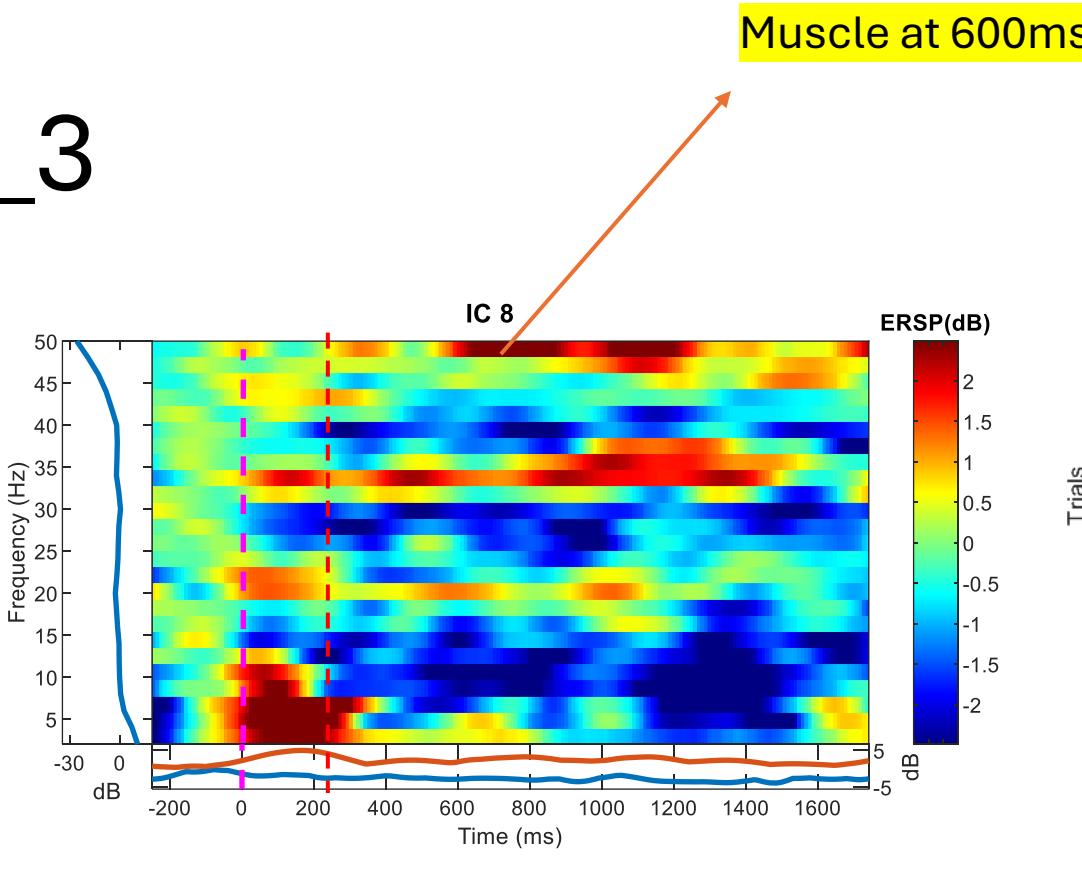
Frontal FC6	
Time	+600ms
Theta	increase
Alpha	decrease



Later Stage

104_18_3

Temporal T7		
Time	+600ms	
Theta	increase	
Alpha	decrease	



Later Stage

104_19_1

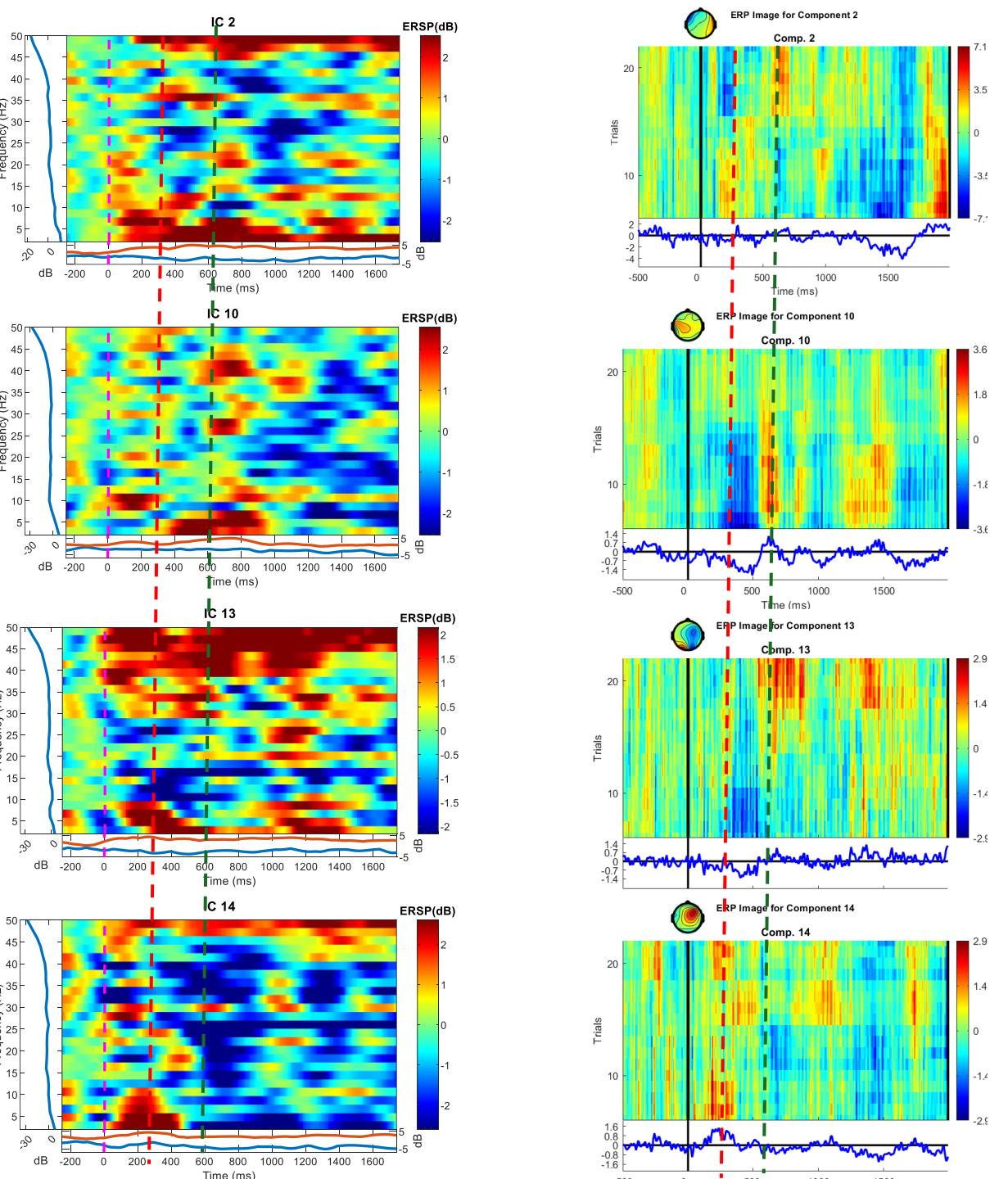
Frontal F8		
Time	+600ms	
Theta	increase	
Alpha	decrease	

Frontal FC5		
Time	+600ms	
Theta	increase	
Alpha	decrease	

Parietal P7		
Time	+300ms	
Theta	increase	
Alpha	decrease	

Frontal F4		
Time	+600ms	
Theta	decrease	
Alpha	decrease	

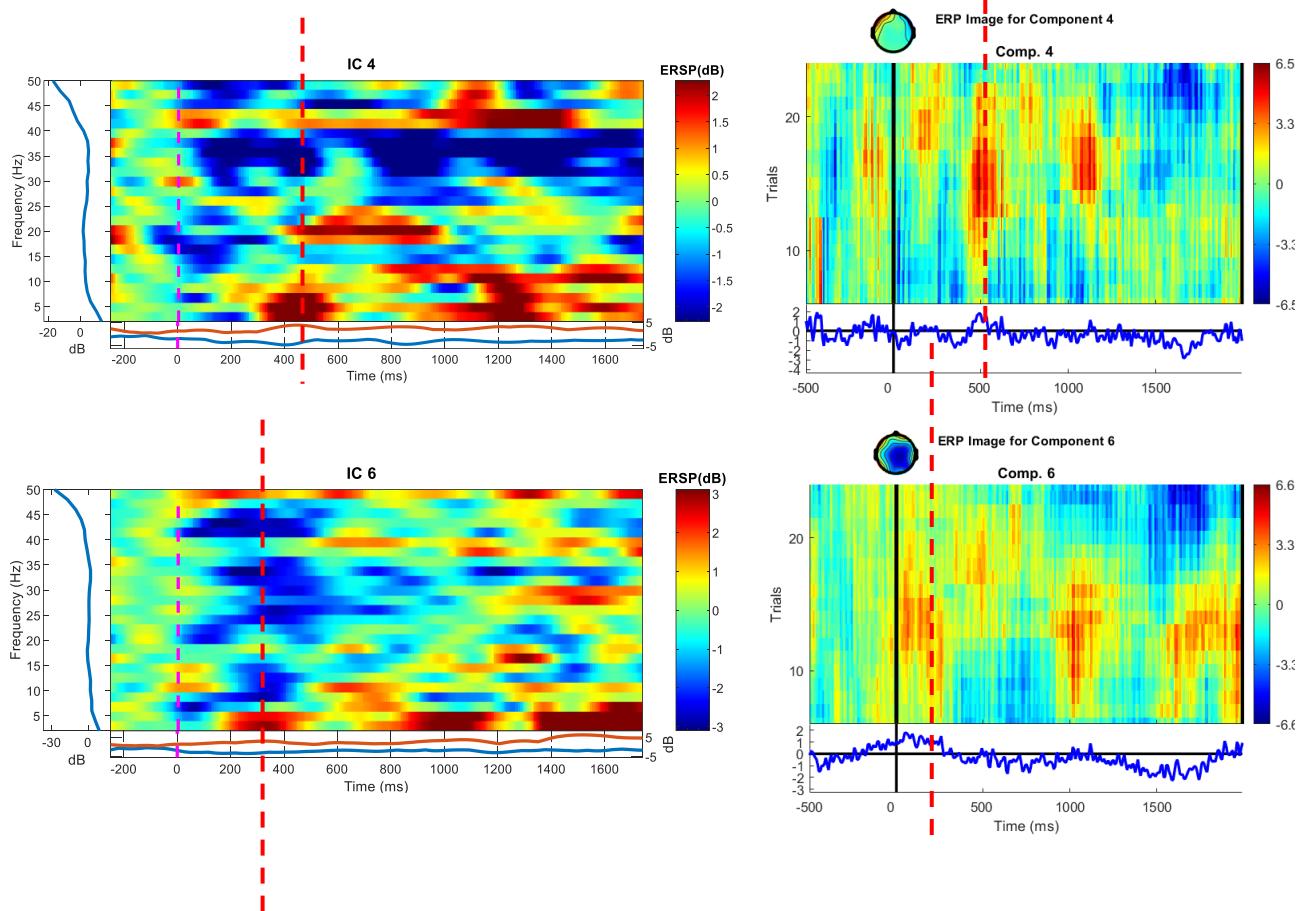
Later Stage



104_19_2

Frontal F3		
Time	+500ms	
Theta	increase	
Alpha	decrease	

Central Cz		
Time	+300ms	
Theta	increase	
Alpha	decrease	

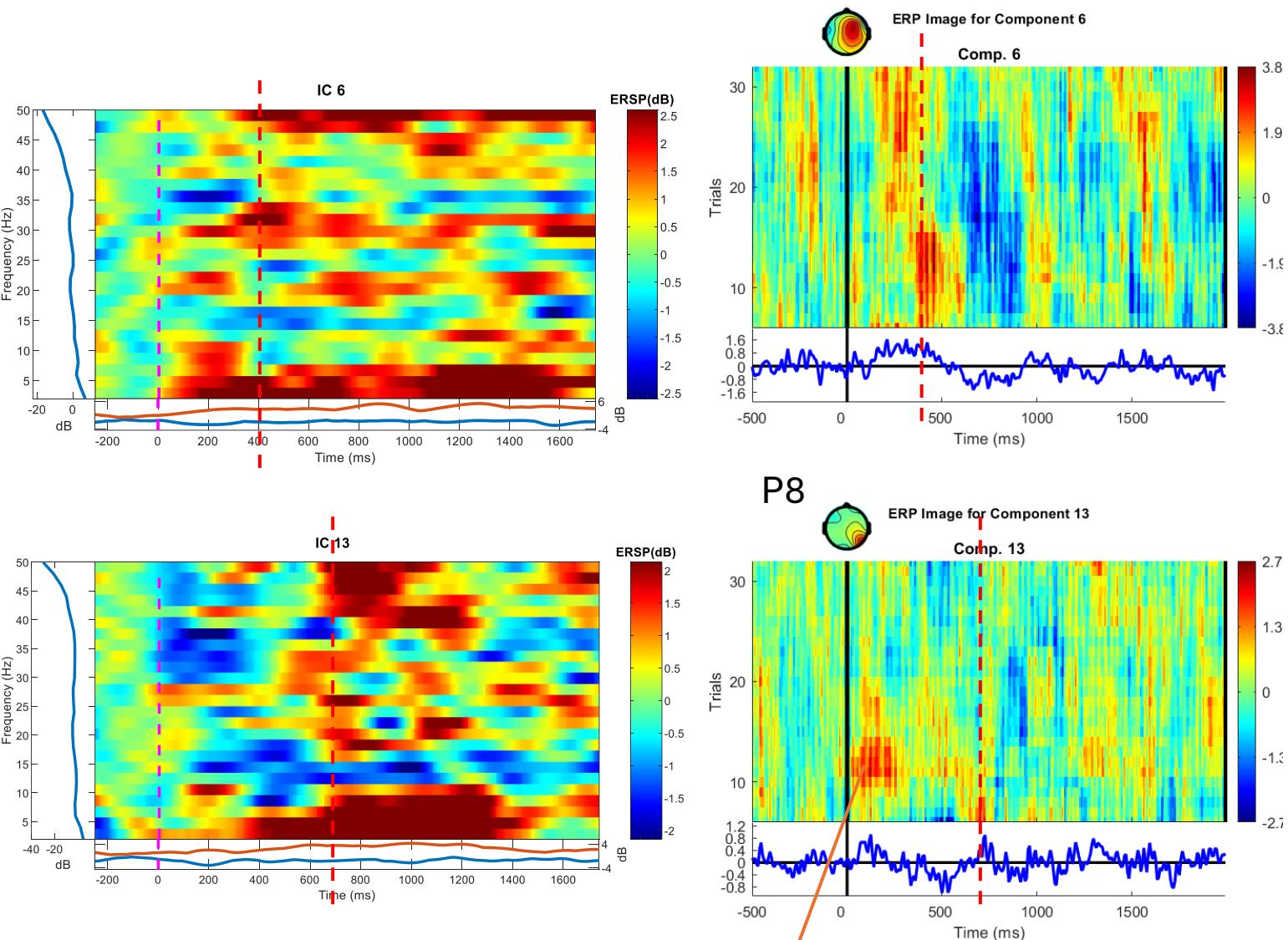


Later Stage

104_19_3

Frontal F4		
Time	+400ms	
Theta	increase	
Alpha	decrease	

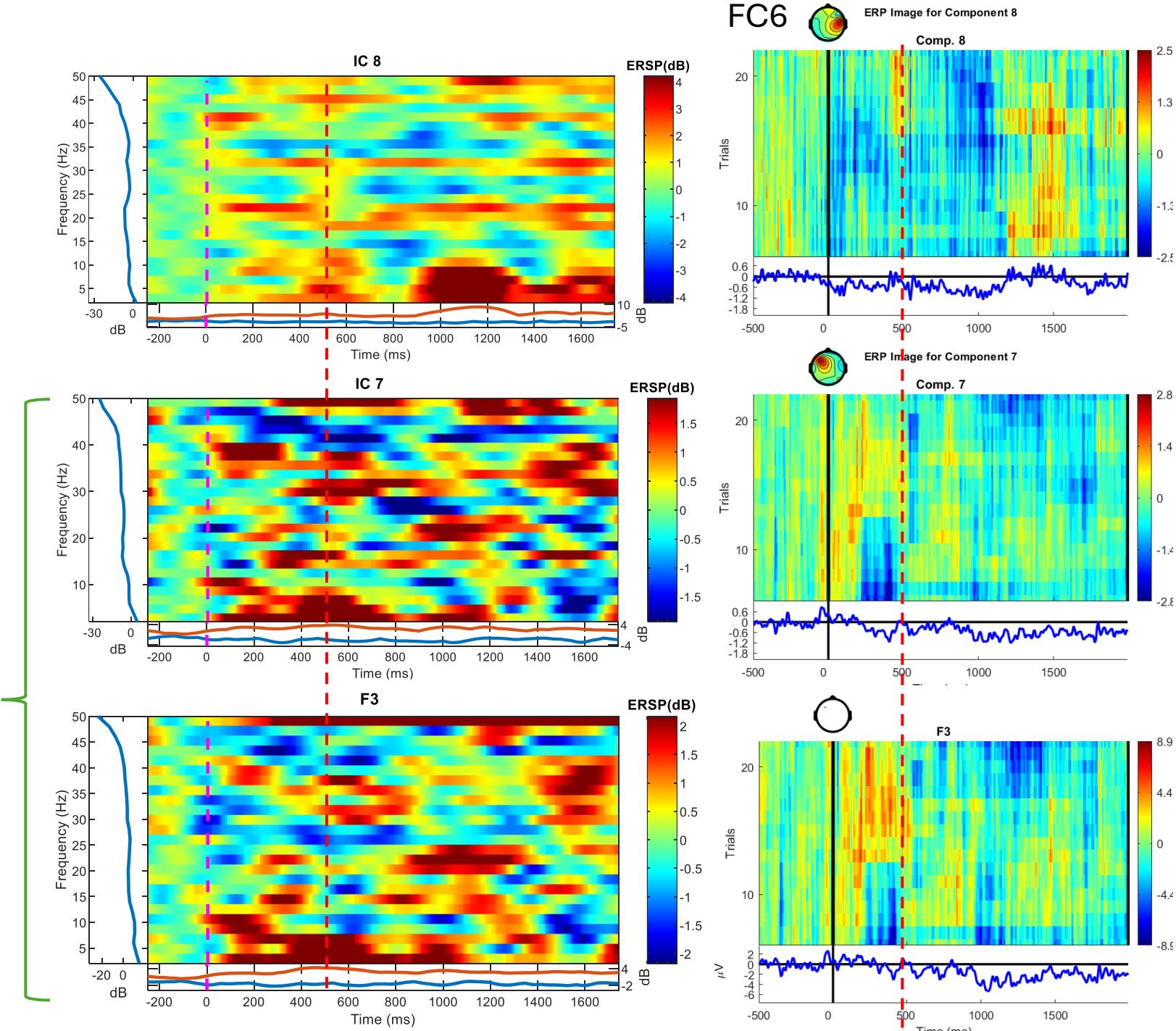
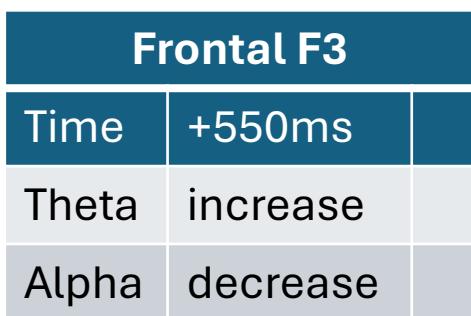
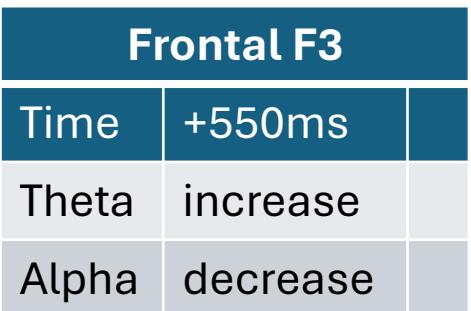
Parietal P8		
Time	+650ms	
Theta	increase	
Alpha	decrease	



Visual attention

Later Stage

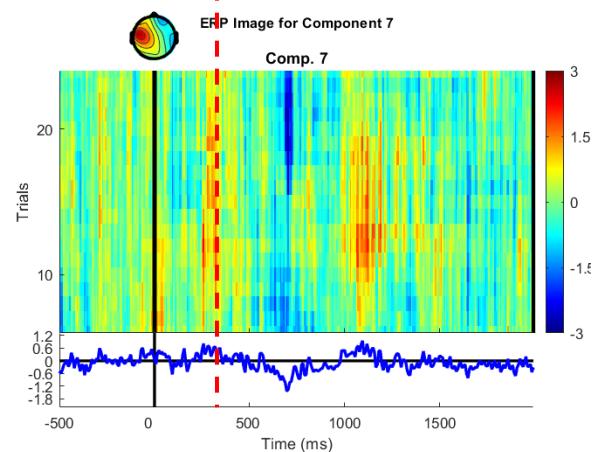
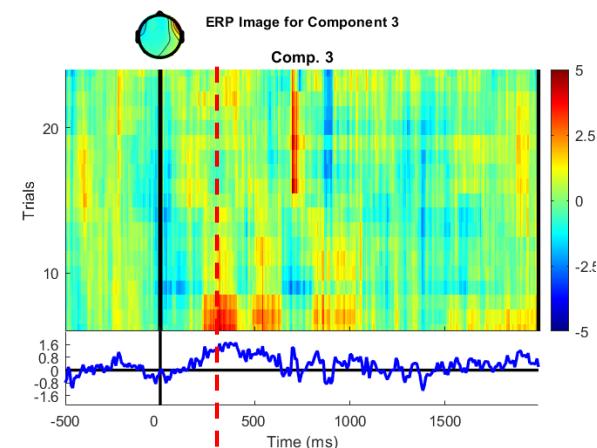
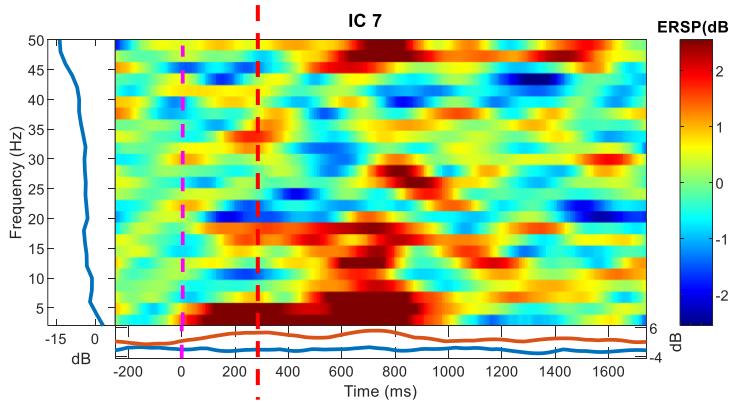
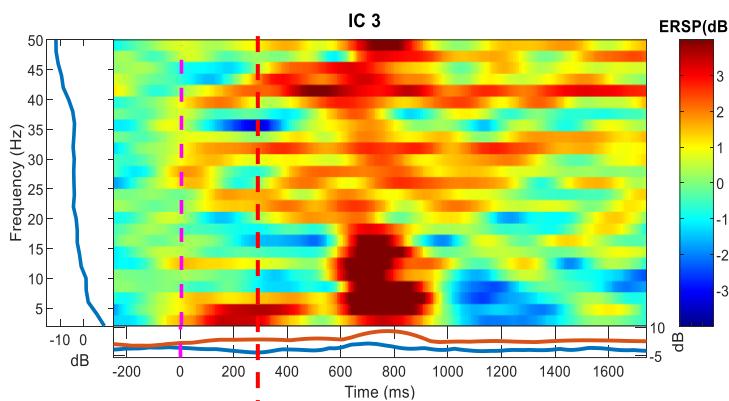
104_20_1



104_20_2

Frontal F8		
Time	+300ms	
Theta	increase	
Alpha	decrease	

Frontal FC5		
Time	+300ms	
Theta	increase	
Alpha	decrease	

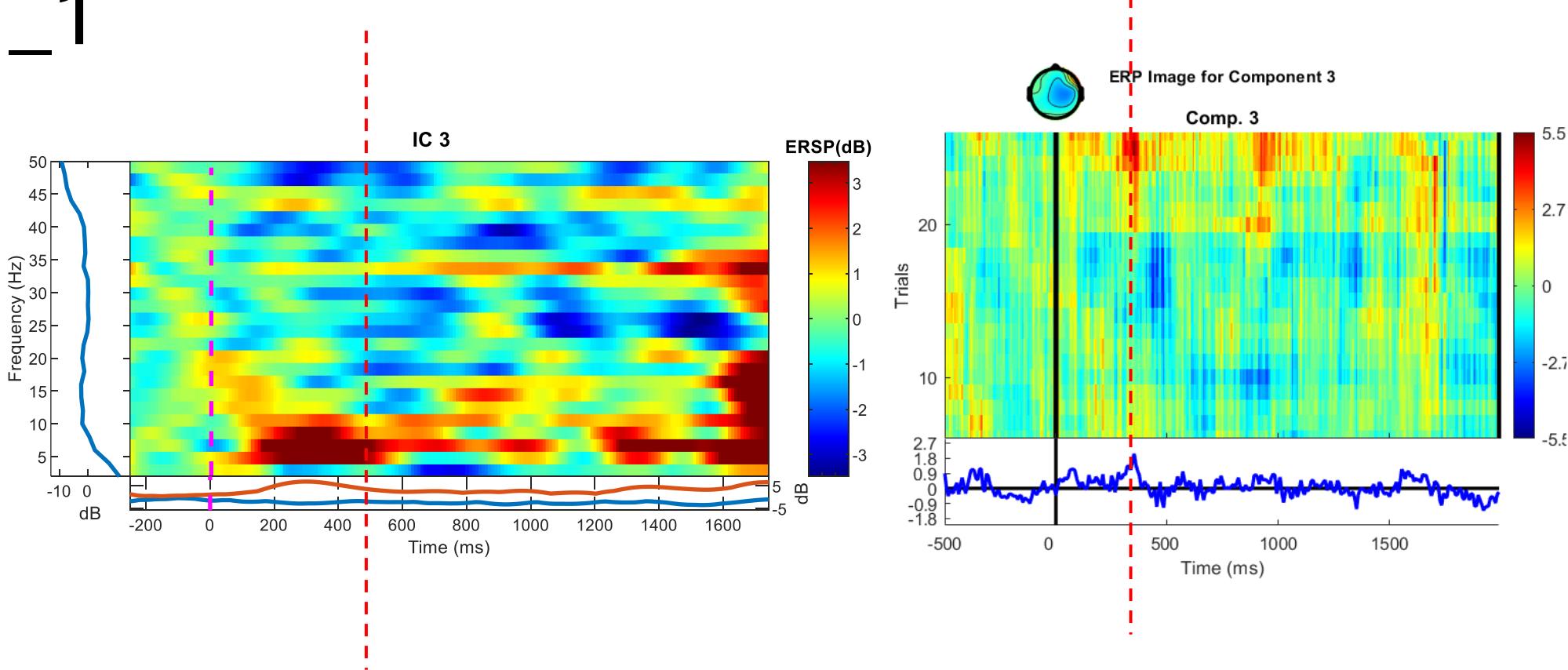


Later Stage

104_21_1

Frontal F8

Time	+410ms
Theta	increase
Alpha	decrease

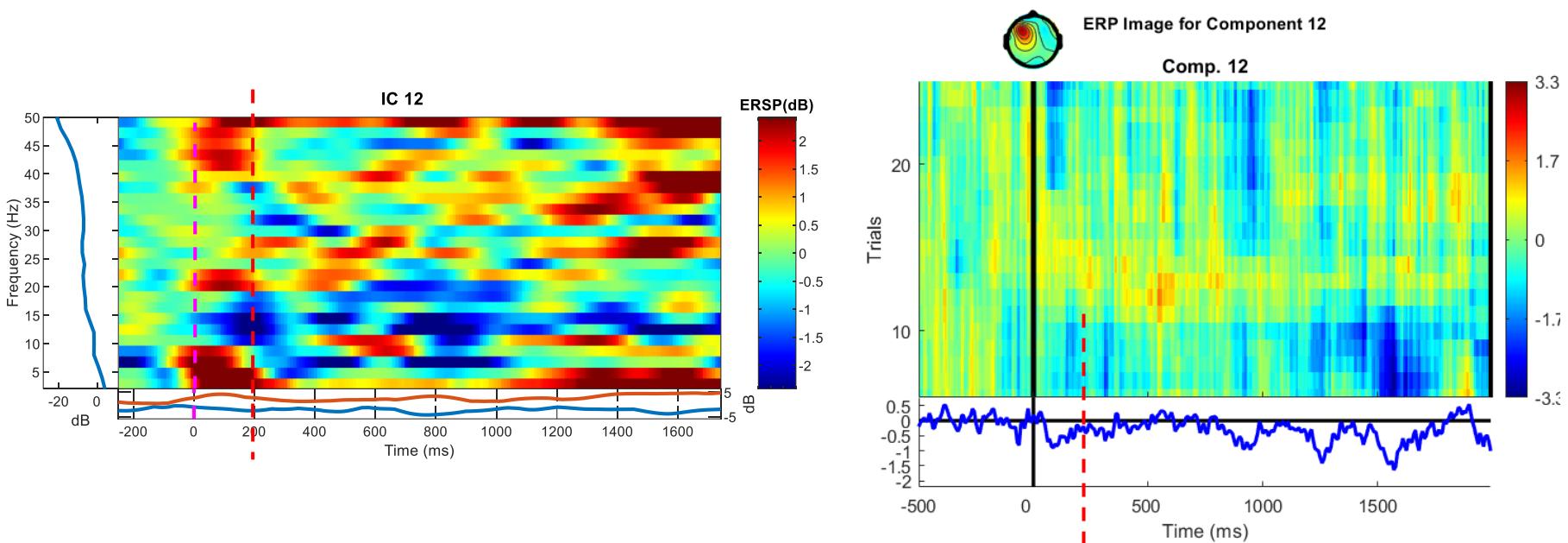


Later Stage

104_21_2

Frontal F3

Time	+200ms	
Theta	increase	
Alpha	decrease	



Later Stage

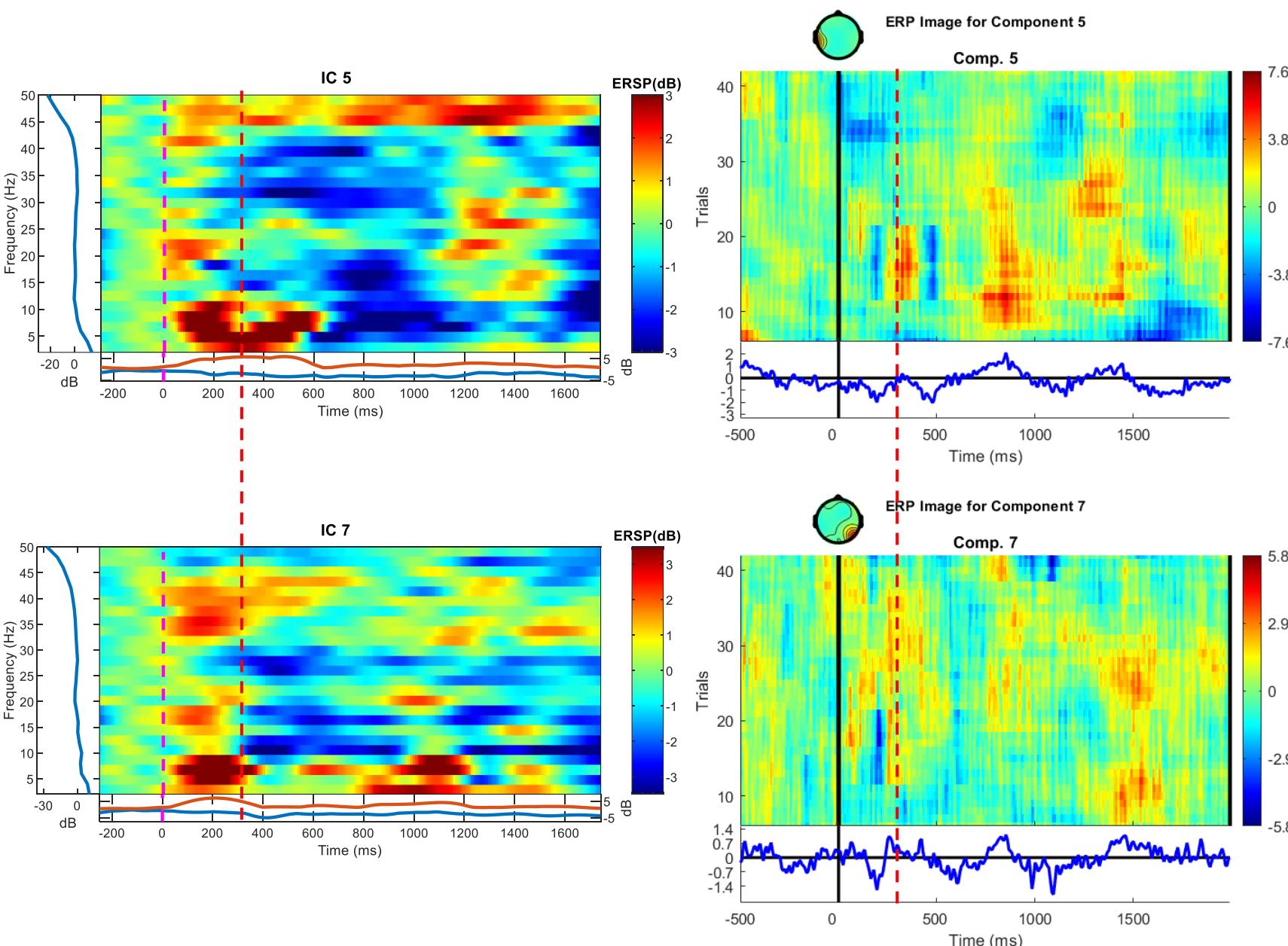
104_21_3

Temporal T7

Time	+350ms
Theta	increase
Alpha	decrease

Parietal P8

Time	+350ms
Theta	increase
Alpha	decrease

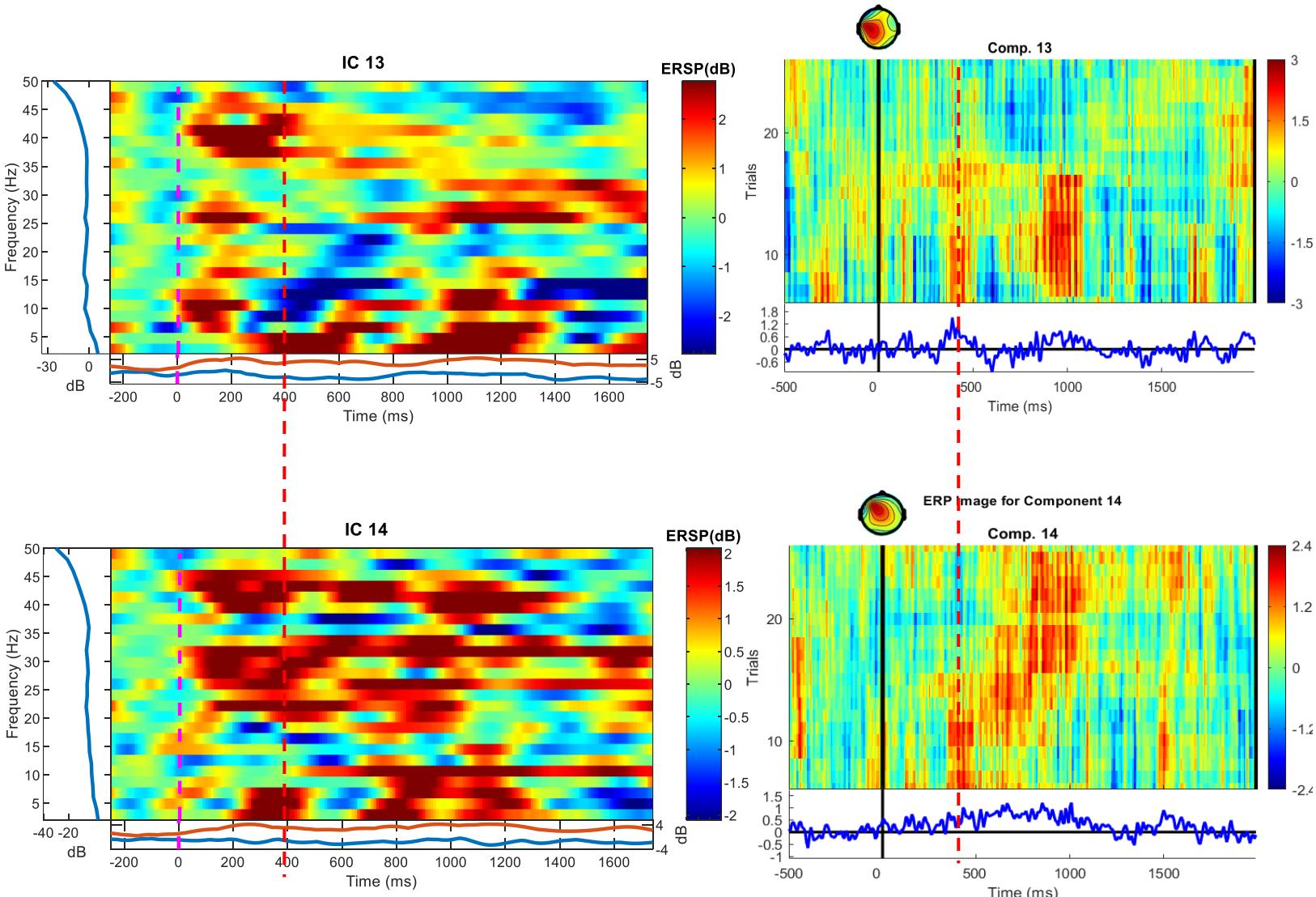


Later Stage

104_23_1

Frontal FC5	
Time	+400ms
Theta	increase
Alpha	decrease

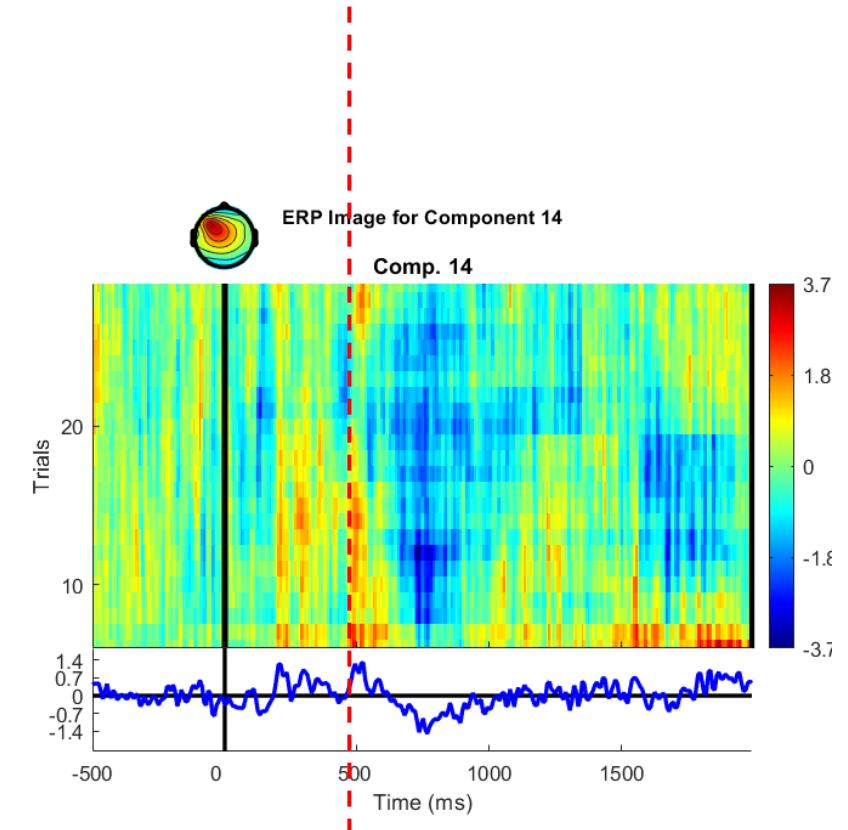
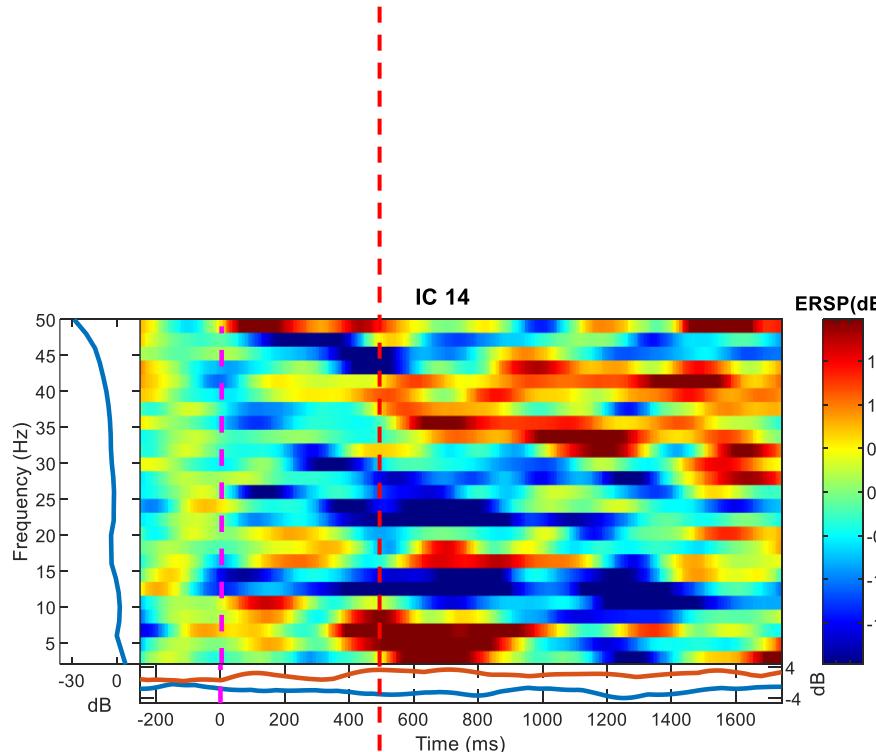
Frontal F3	
Time	+400ms
Theta	increase
Alpha	decrease



Later Stage

104_23_2

Frontal F3		
Time	+500ms	
Theta	increase	
Alpha	decrease	

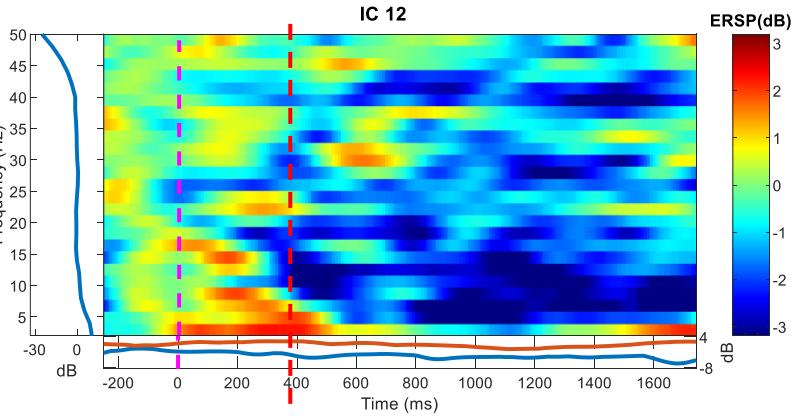


Later Stage

104_23_3

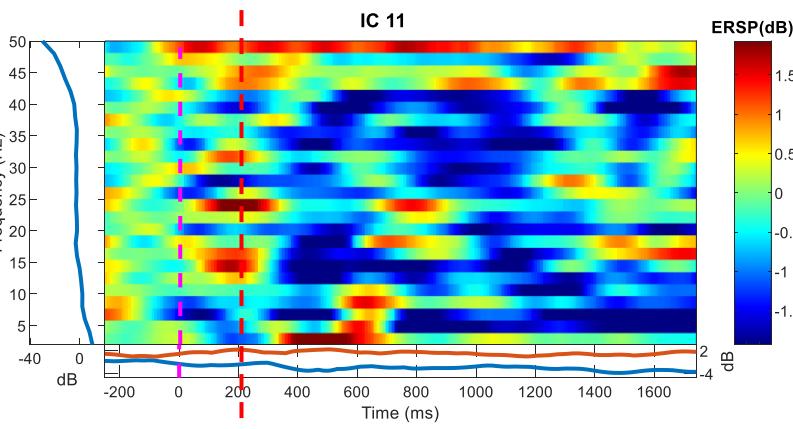
Frontal FC5

Time	+390ms
Theta	increase
Alpha	decrease



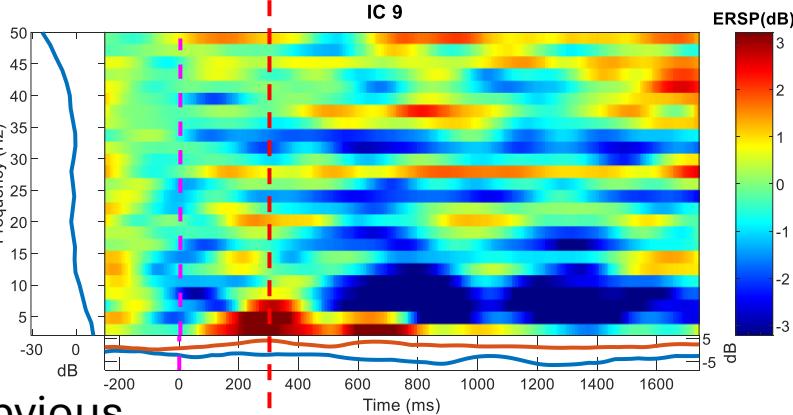
Frontal F4

Time	+200ms
Theta	increase
Alpha	decrease



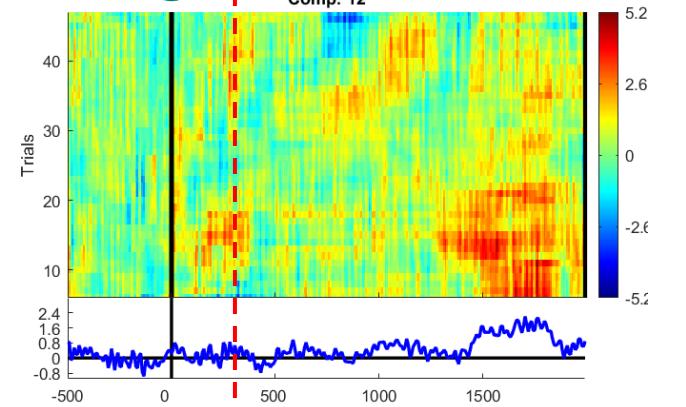
Temporal T7

Time	+300ms
Theta	increase
Alpha	decrease

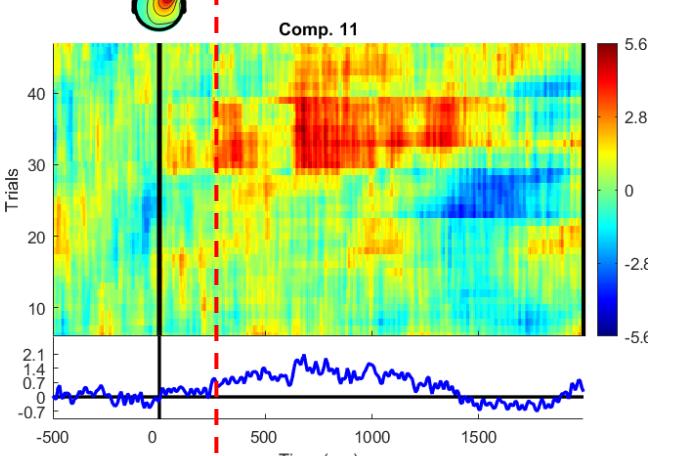


Not obvious

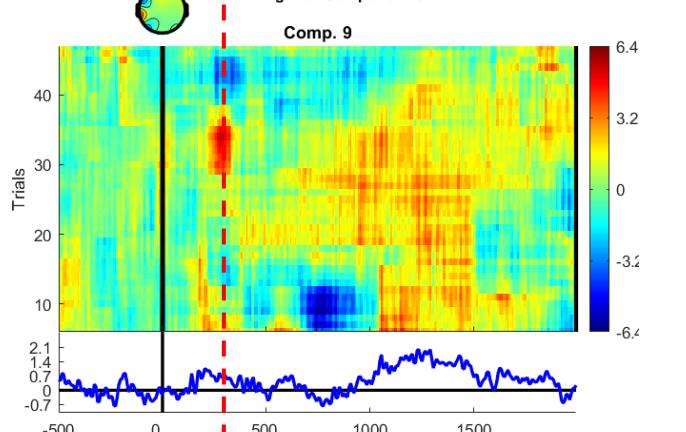
ERP Image for Component 12



ERP Image for Component 11



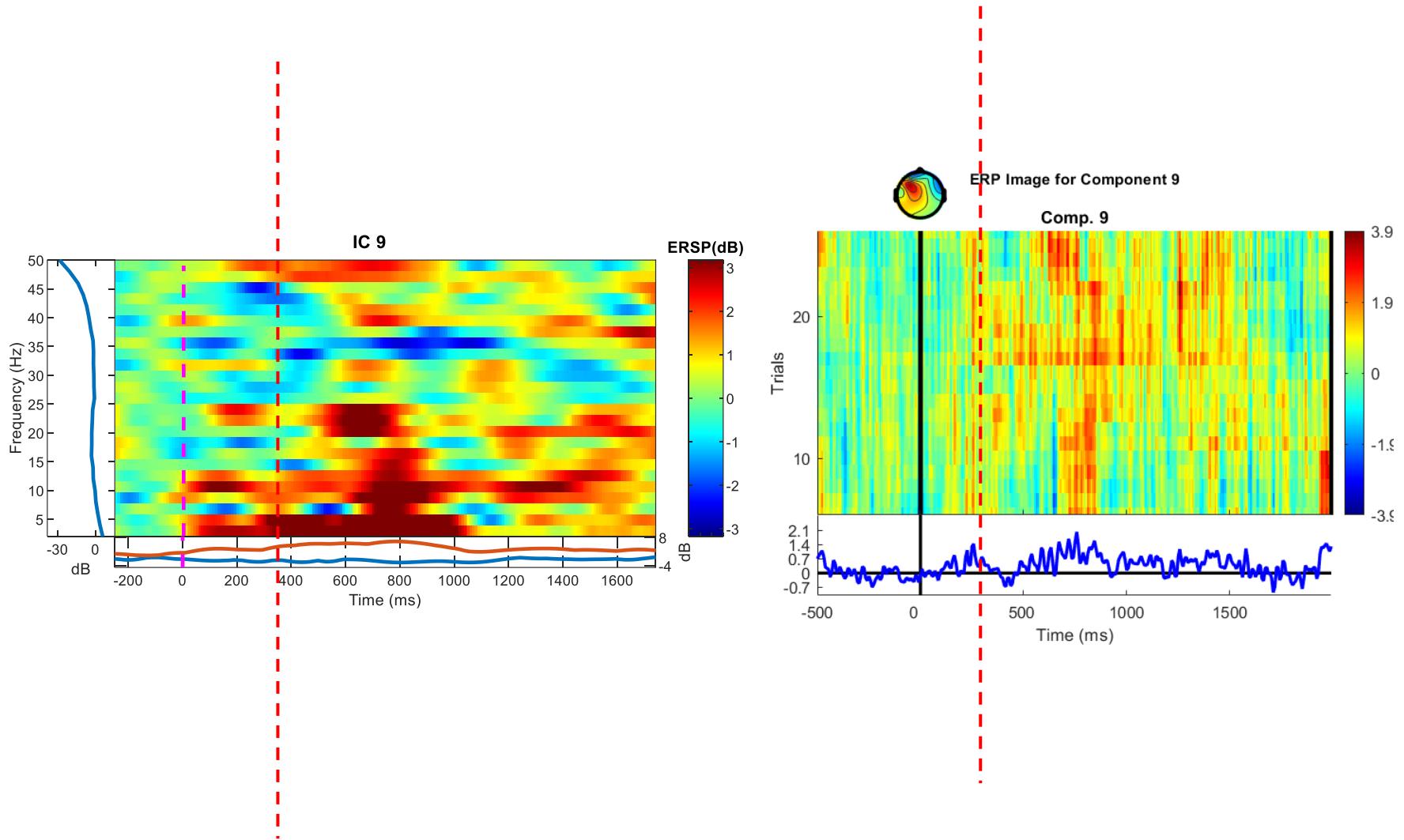
ERP Image for Component 9



Later Stage

104_24_1

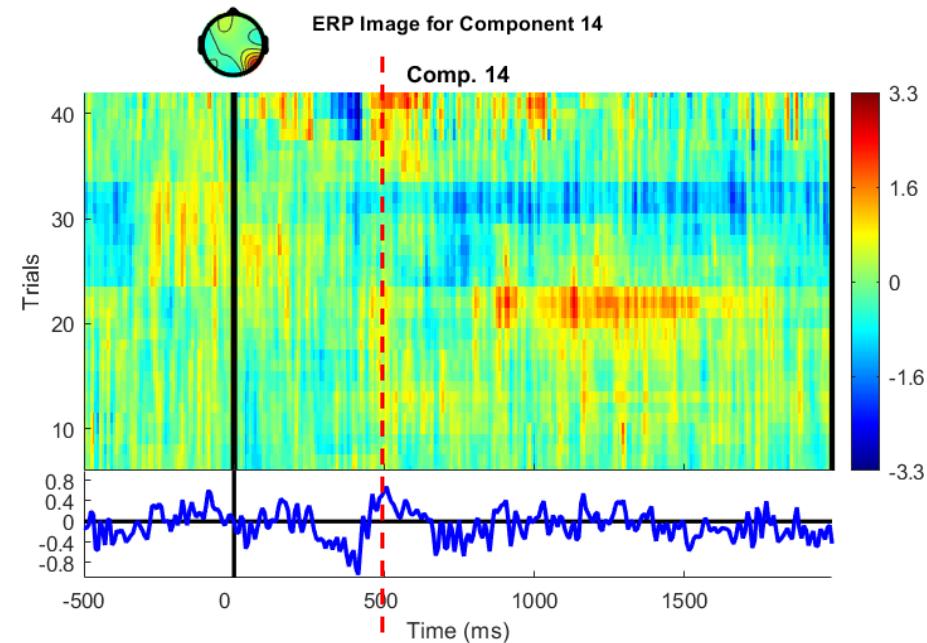
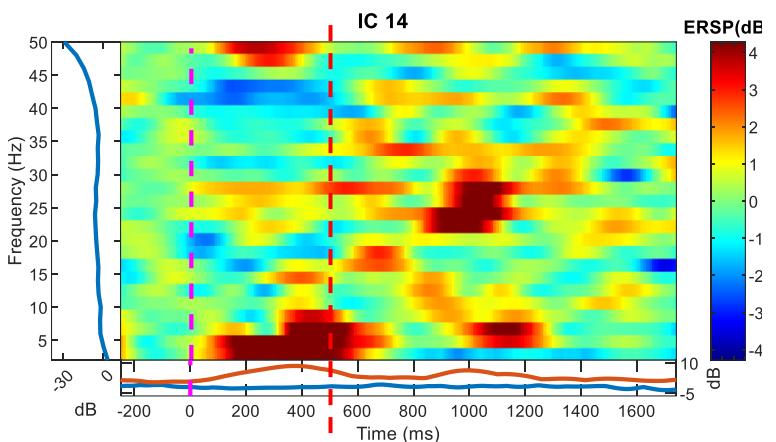
Frontal F3		
Time	+300ms	
Theta	increase	
Alpha	decrease	



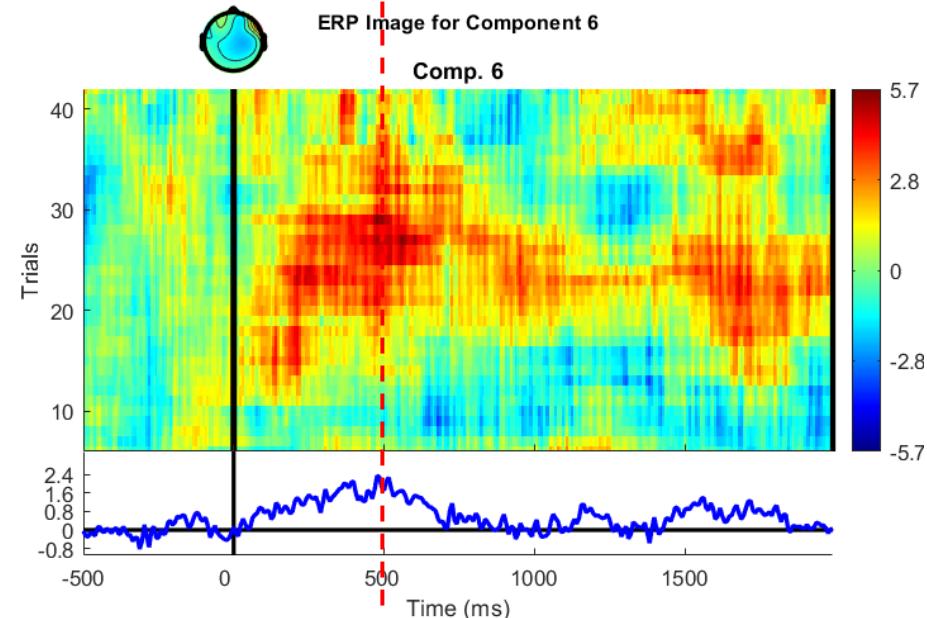
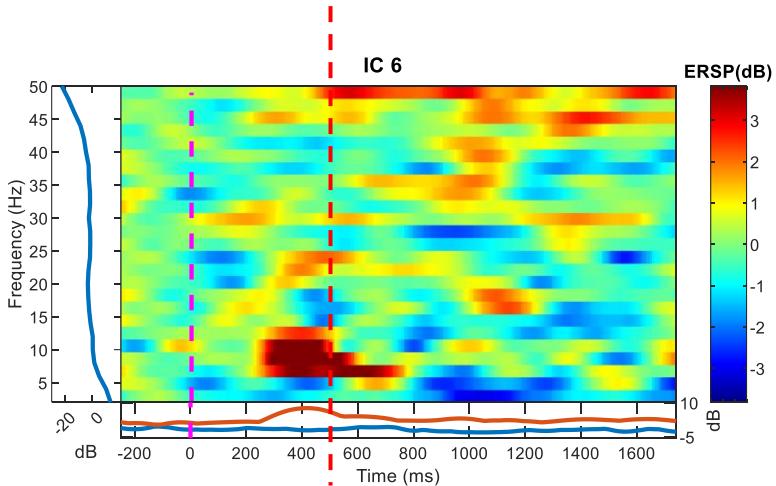
Later Stage

104_24_2

Frontal F3		
Time	+500ms	
Theta	increase	
Alpha	decrease	



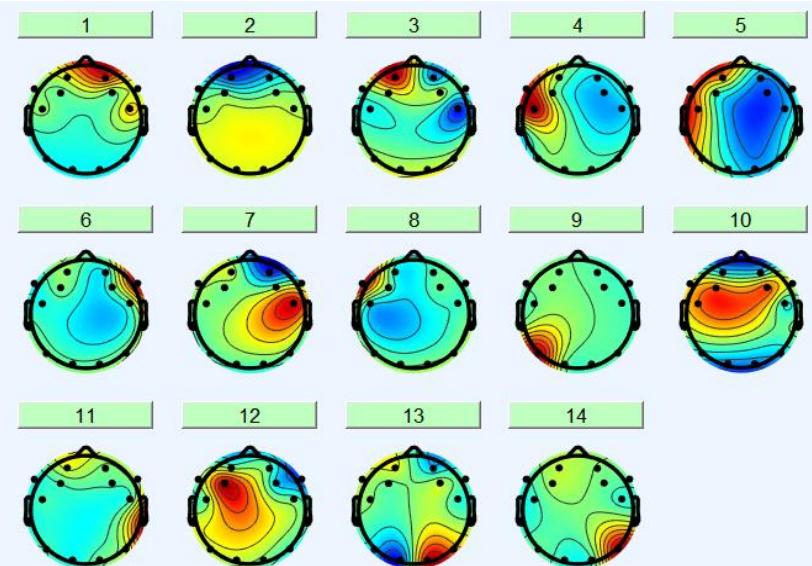
Frontal F8		
Time	+500ms	
Theta	increase	
Alpha	decrease	



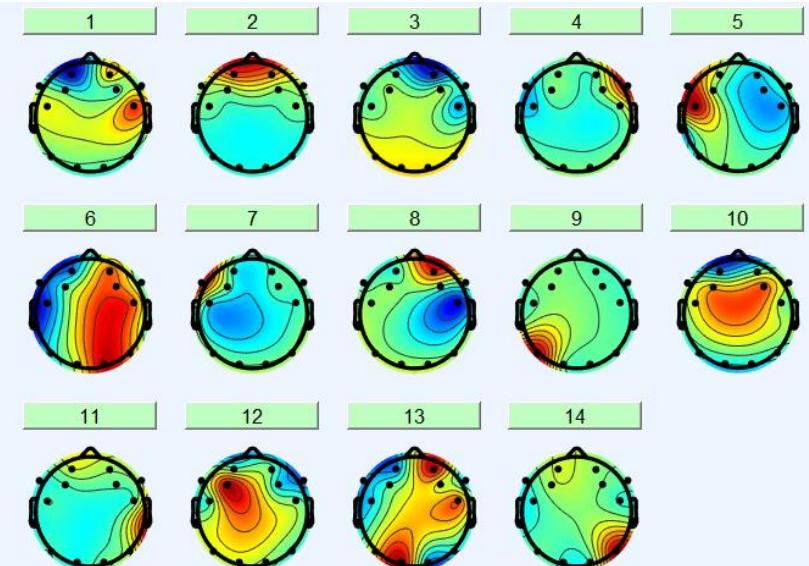
Later Stage

104_24_2

Independent Component (128Hz)



Independent Component (256Hz)



Less than 64 sampling points

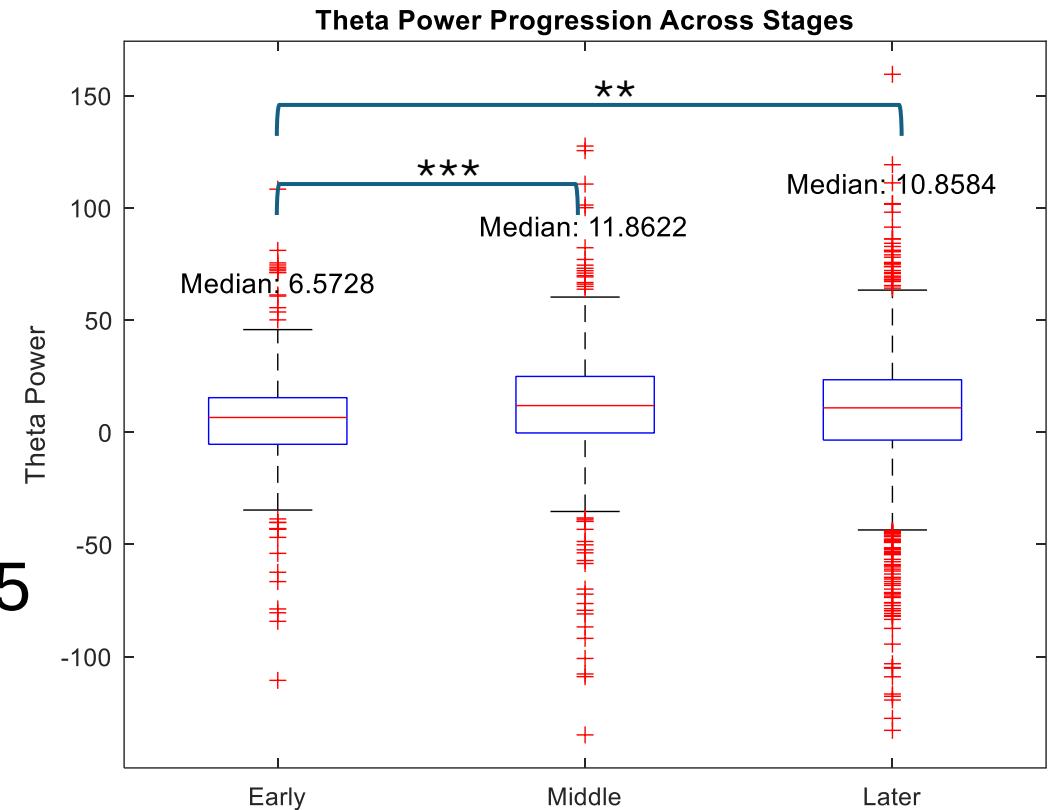
- Zero-padded region dilutes the actual signal strength
- When tracking progression over time, **relative power changes** tends to be more important
- Although zero-padding can introduce minor distortions in power quantification, it should not significantly impact the **trend** or **progression** of theta power over time, assuming the padding is applied uniformly across all sessions.

P300 Latency

- Theta synchronisation occurs ahead of alpha desynchronisation

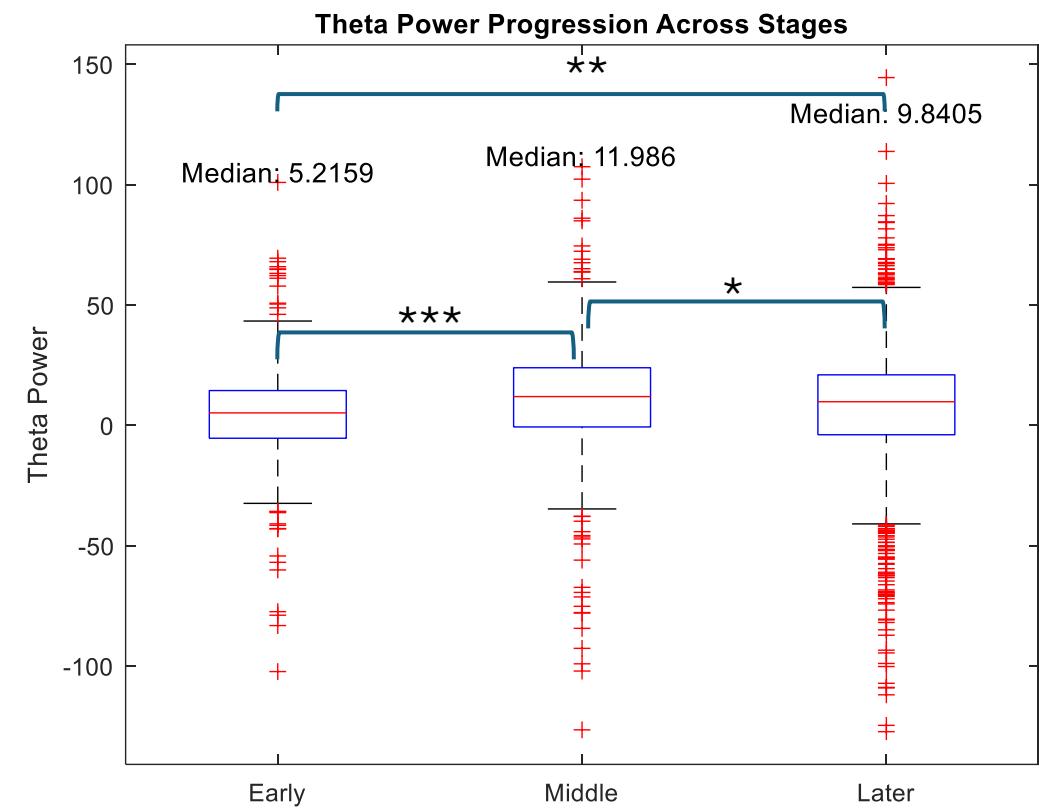
Theta (4-7Hz) power strength progression

- Baseline: [-150 0]
- P300_Latency: [-200 +200]
- Cap value: 50 μ V
- Results
- p-value (Early vs Middle): 3.1951e-05
- p-value (Middle vs Later): 0.099183
- p-value (Early vs Later): 0.0021605



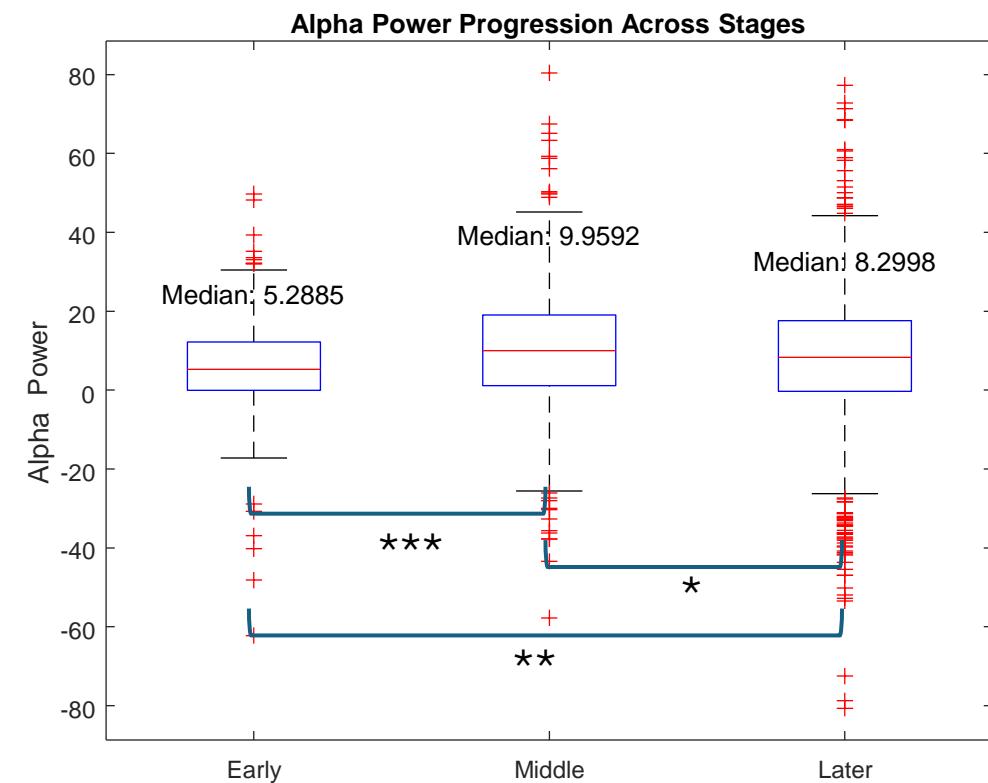
Theta (4-8Hz) power strength progression

- Baseline: [-150 0]
- P300_Latency: [-200 +200]
- Cap value: 50 μ V
- Results
- p-value (Early vs Middle): 7.5001e-06
- p-value (Middle vs Later): 0.036917
- p-value (Early vs Later): 0.0016149



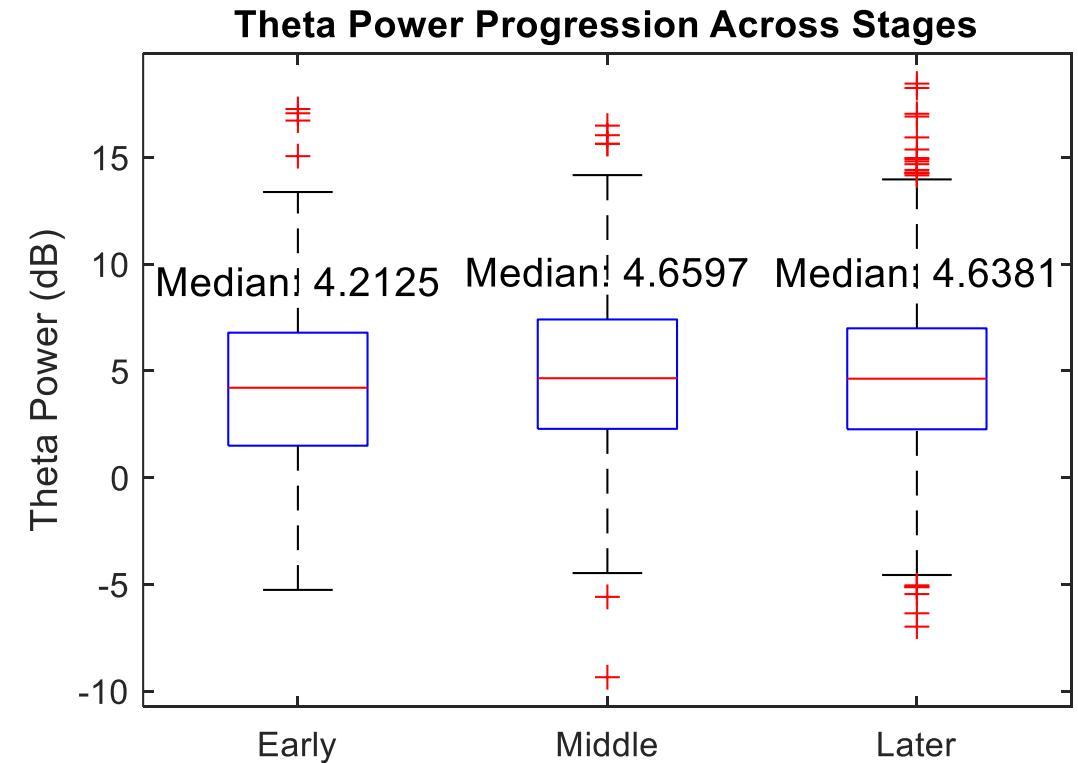
Alpha (9-14Hz) power strength progression

- Baseline: [-150 0]
- P300_Latency: [-200 +200]
- Cap value: 50 μ V
- Results
- p-value (Early vs Middle): 1.4664e-05
- p-value (Middle vs Later): 0.026221
- p-value (Early vs Later): 0.0030867



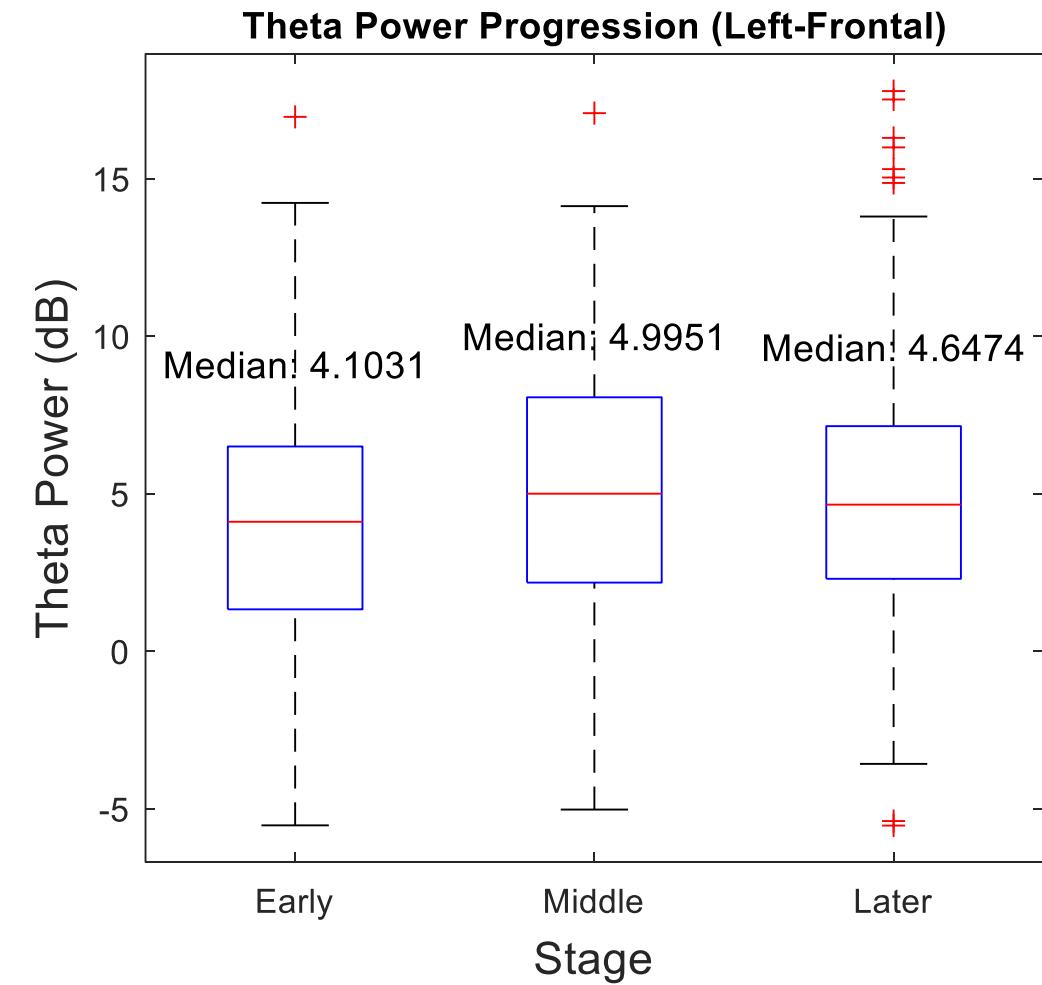
Theta (4-8Hz) Log power progression

- Baseline: [-150 0]
- P300_Latency: [-200 +200]
- Results
 - p-value (Early vs Middle): 0.080291
 - p-value (Middle vs Later): 0.72989
 - p-value (Early vs Later): 0.088033



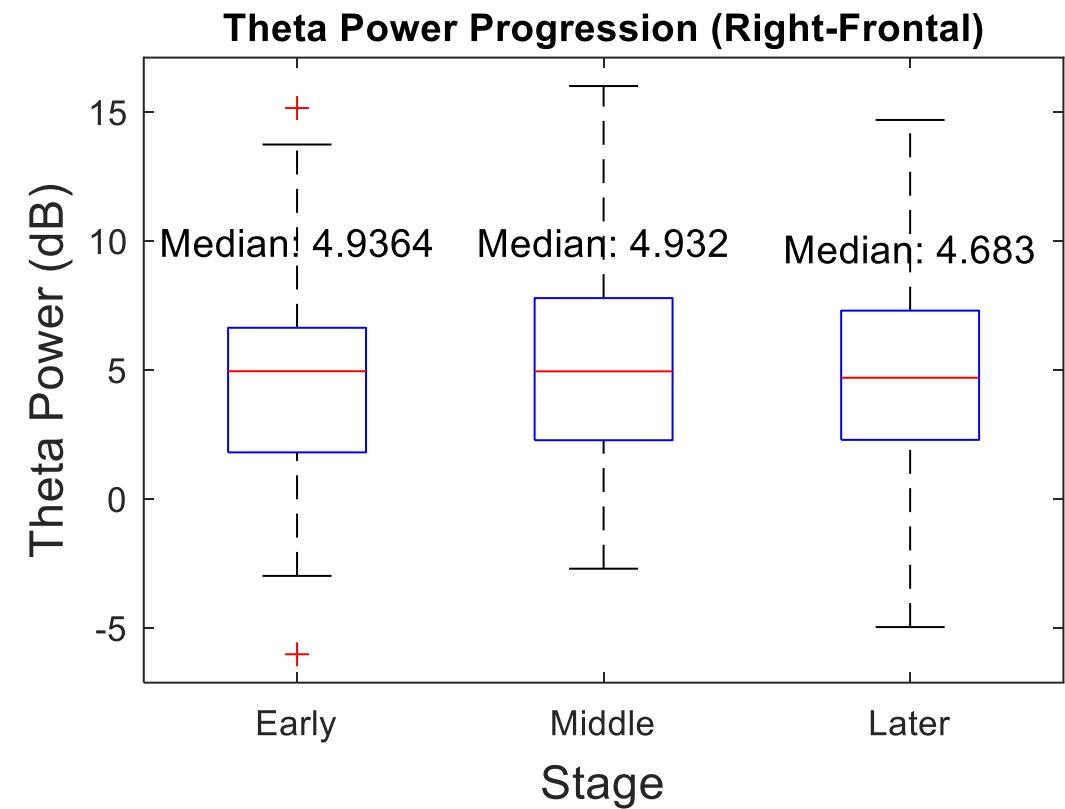
Left-Frontal Theta(4-8Hz)

- Components processed: 19
- p-value (Early vs Middle): 0.097051 (increase)
- p-value (Middle vs Later): 0.58819036 (decrease)
- p-value (Early vs Later): 0.1209802 (increase)



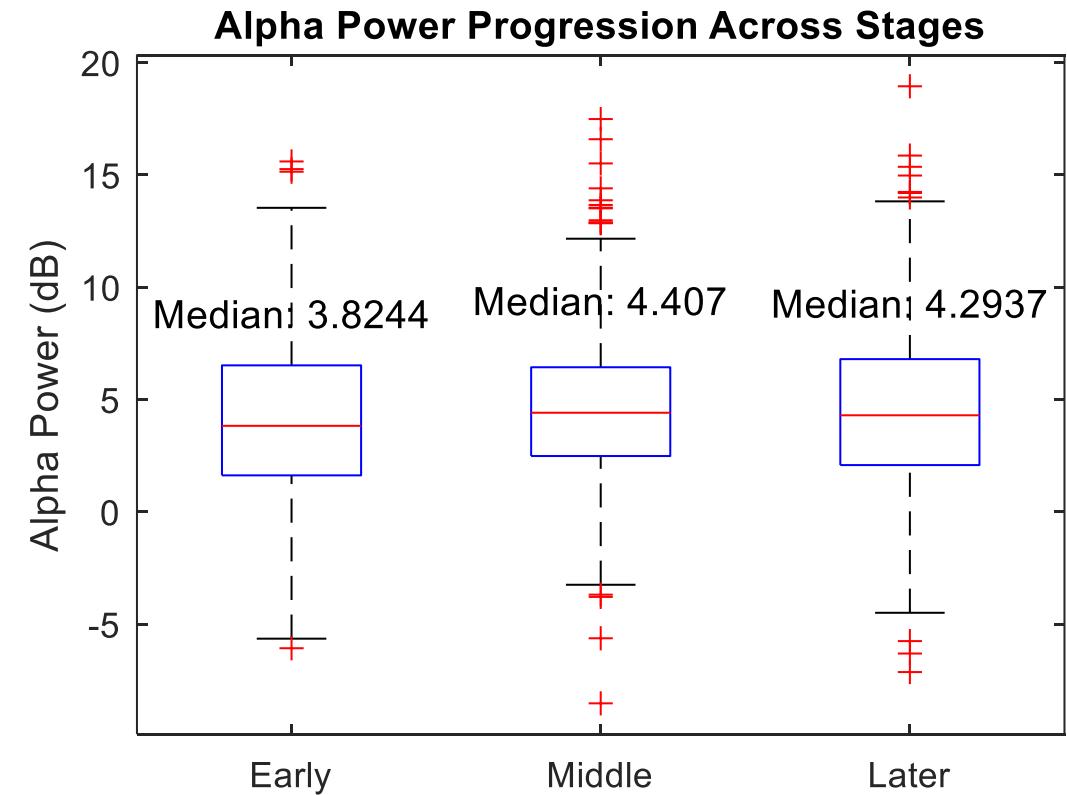
Right-Frontal Theta(4-9Hz)

- Components processed: 15
- p-value (Early vs Middle): 0.58886 (decrease)
- p-value (Middle vs Later): 0.68453222 (decrease)
- p-value (Early vs Later): 0.81481931 (decrease)



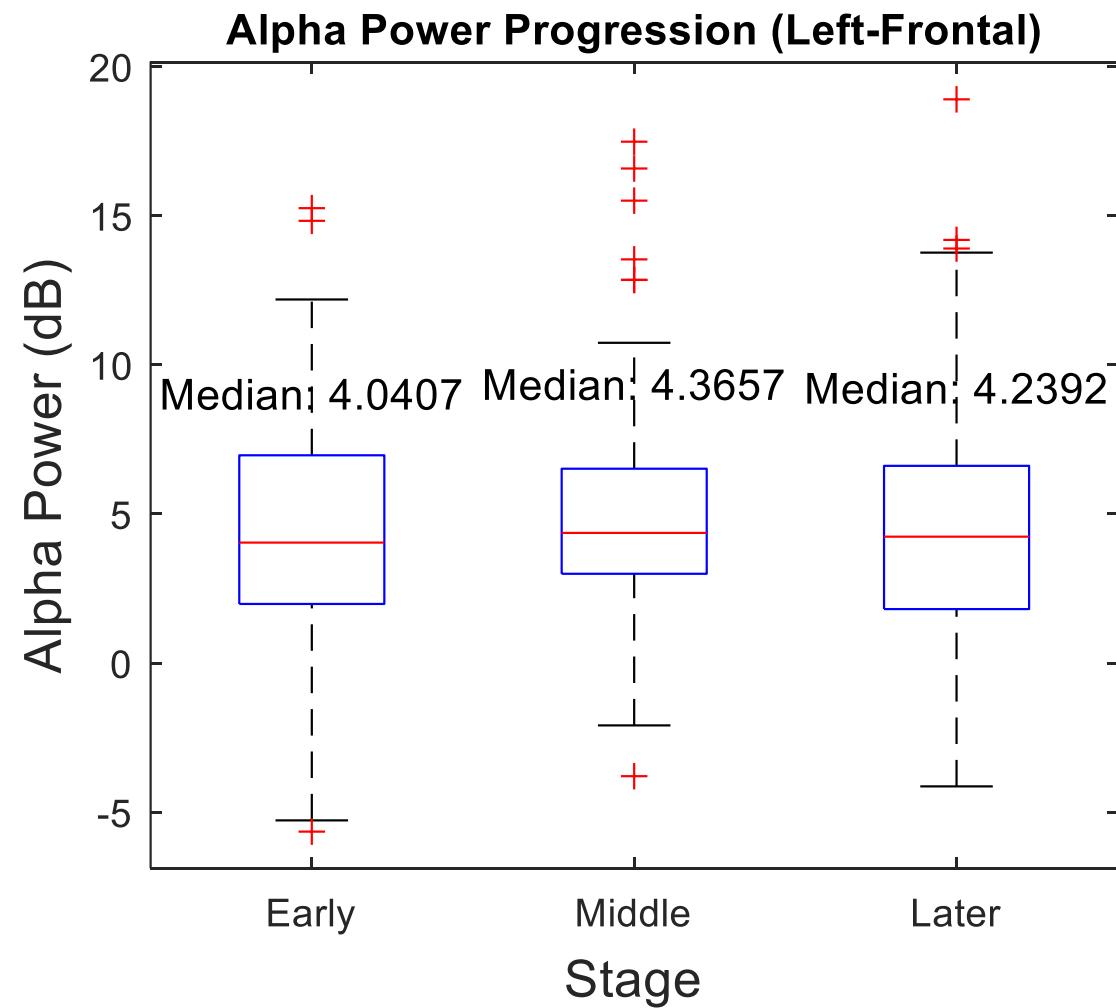
Alpha (9-14Hz) Log power progression

- Baseline: [-150 0]
- P300_Latency: [-200 +200]
- Results
- p-value (Early vs Middle): 0.072188
- p-value (Middle vs Later): 0.977
- p-value (Early vs Later): 0.052752



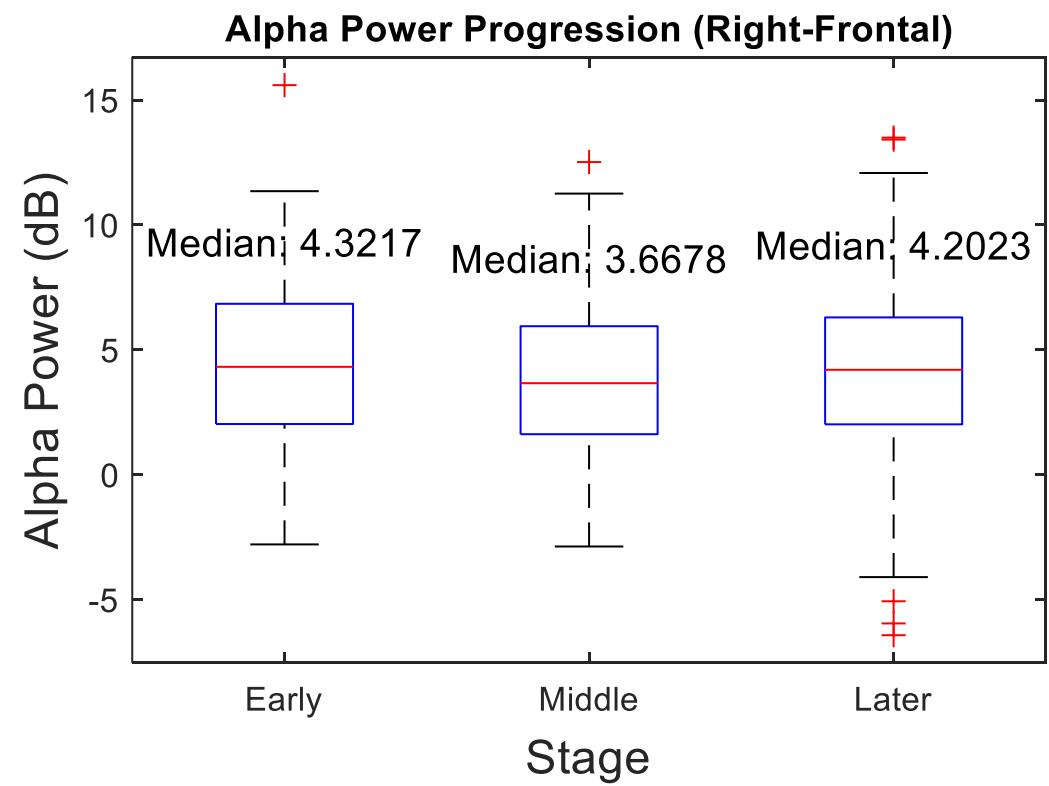
Left-Frontal Alpha(9-14Hz)

- Components processed: 19
- p-value (Early vs Middle): 0.3345 (increase)
- p-value (Middle vs Later): 0.25712181 (decrease)
- p-value (Early vs Later): 0.8730728 (increase)



Right-Frontal Alpha (9-14Hz)

- Components processed: 15
- p-value (Early vs Middle): 0.12333 (decrease)
- p-value (Middle vs Later): 0.24030264 (increase)
- p-value (Early vs Later): 0.40934969 (decrease)

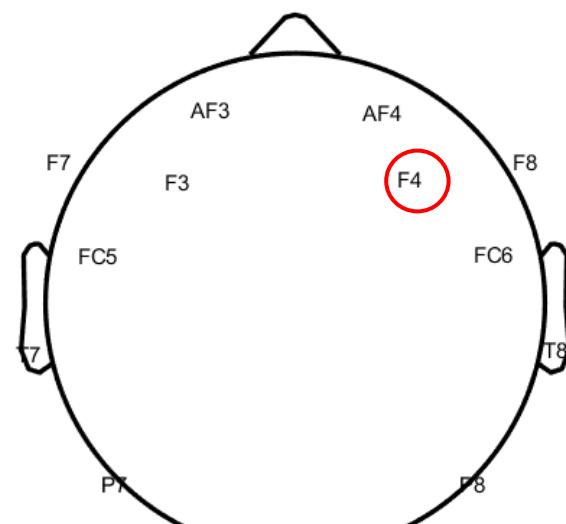


Why don't use log-transformed power:

- Baseline power is not consistent accross sessions
- Differences might be **smoothed out** by the log transformation

101_5_3 Frontal F4			104_4_1 Frontal F4			104_8_1 Frontal FC5		
Time	+450ms		Time	+600ms		Time	+400ms	
Theta	decrease		Theta	increase		Theta	increase	
Alpha	increase		Alpha	decrease		Alpha	decrease	
104_3_1 Frontal F4			104_5_2 Frontal F4			104_8_1 Parietal P8		
Time	+600ms		Time	+600ms		Time	+500ms	
Theta	increase		Theta	decrease		Theta	increase	
Alpha	decrease		Alpha	increase		Alpha	decrease	
104_3_2 Frontal F4			104_6_2 Frontal F3+F4			115_3_3 Frontal F7		
Time	+300ms		Time	+300ms		Time	+390ms	
Theta	decrease		Theta	Increase?		Theta	increase	
Alpha	increase		Alpha	Decrease		Alpha	decrease	

Subject 104 most prominent
P300 activity occurs at F4 at
early stage



$$Frequency\ resolution \Delta f = \frac{128}{32} = 4Hz$$

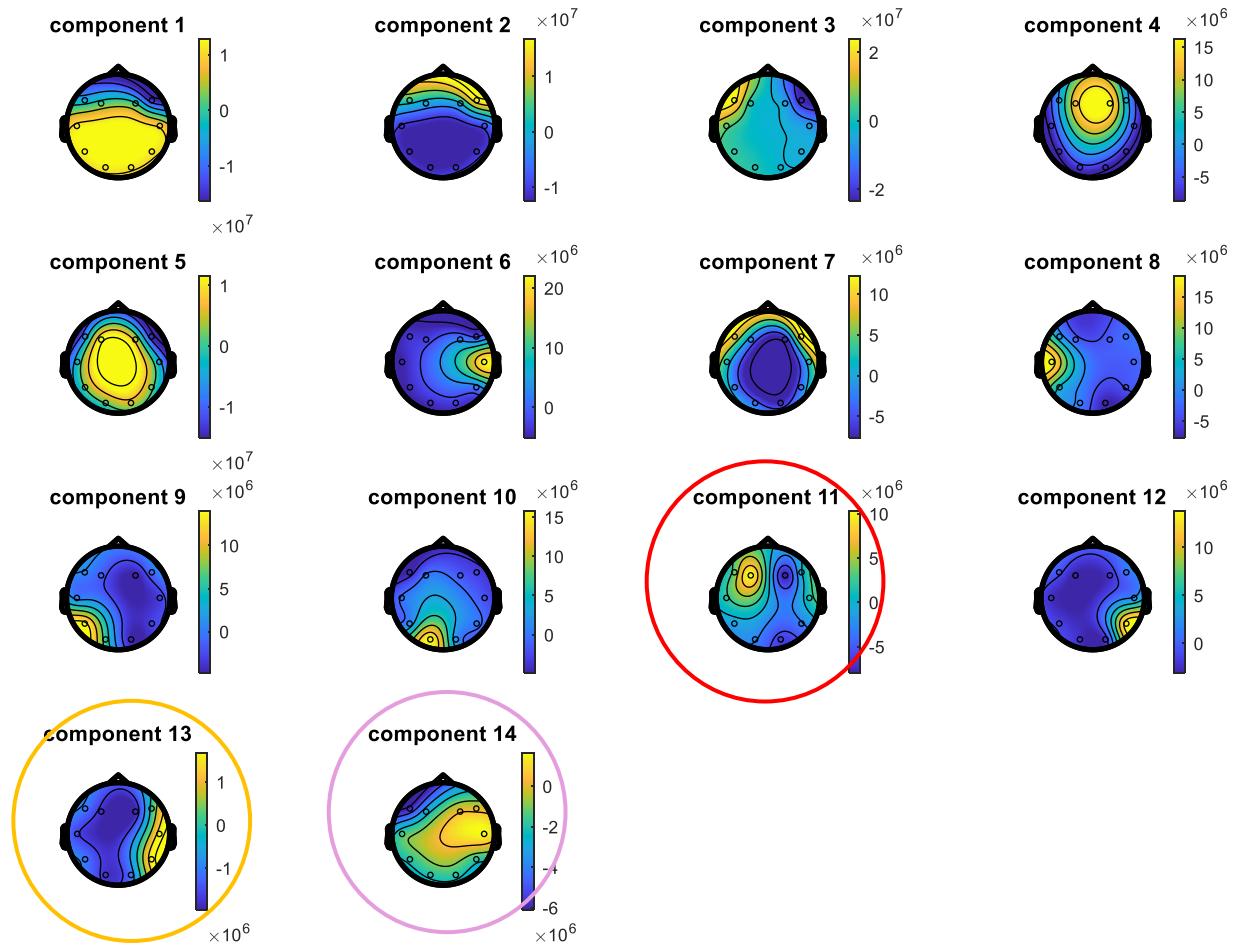
Winsize	Time Window (ms)	Temporal Resolution	Frequency Resolution
32	250 ms	High	4Hz
64	500 ms	Medium	2Hz
128	1000 ms	Lower	1Hz

So far

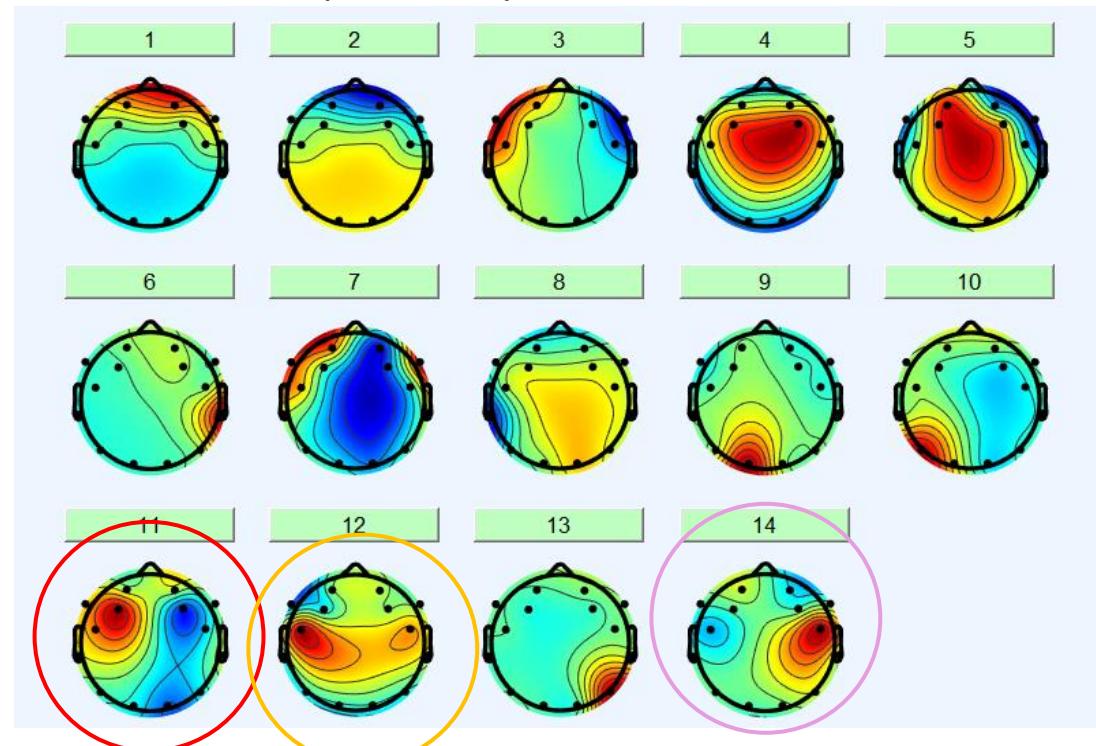
- For cleaner visualisation of ERSP:
 - Epoch [-0.5 2] to exclude reaction muscle noise after 2s
- Independent Components gives cleaner version of ERP
- Work upfront: Do not concatenate the recordings for now. If the recordings are all from the early stage, concatenate the components with the most prominent ERP in the same region (e.g., frontal). (confirm this with Dr Lakany)

Source check (101_1_2)

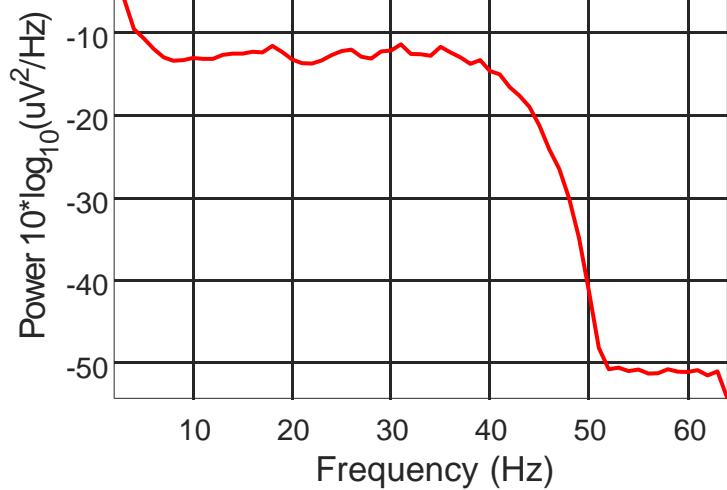
(101_1_2) ICs from Fieldtrip



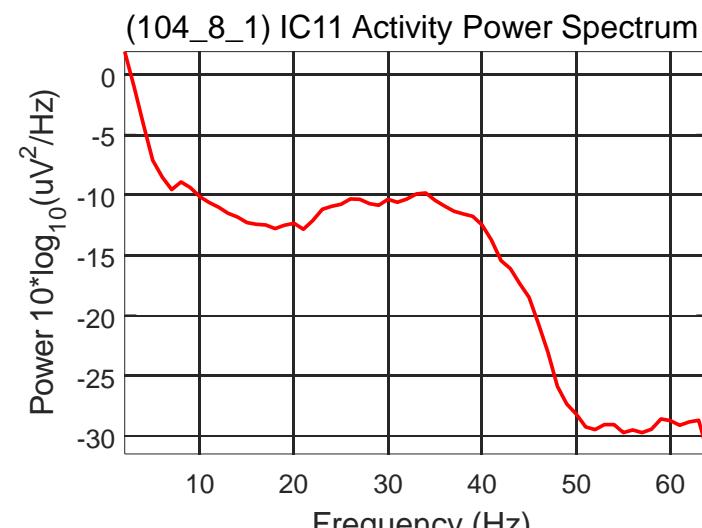
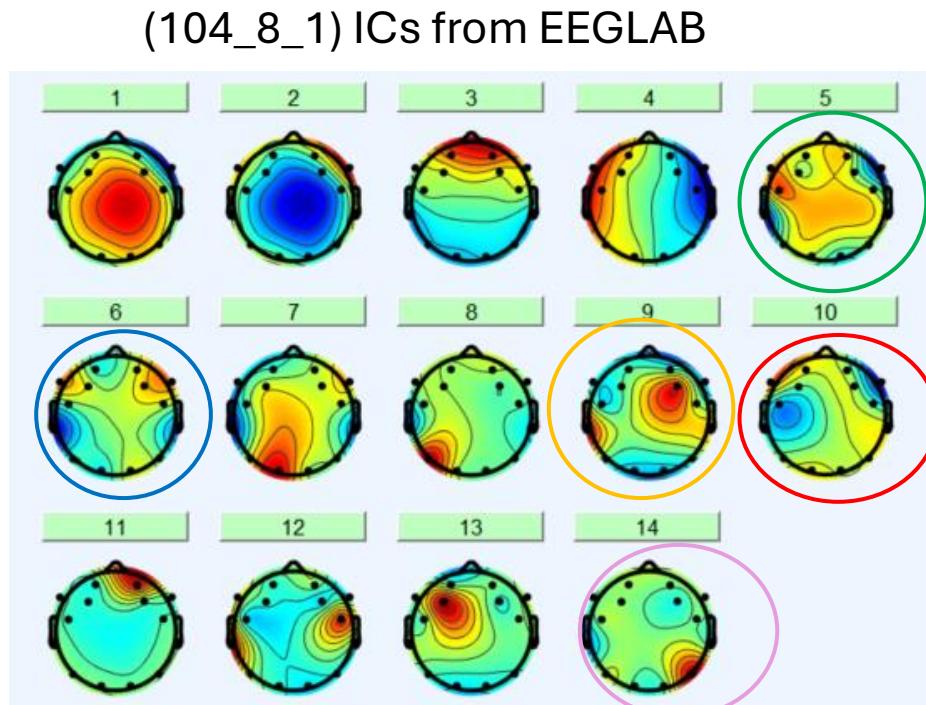
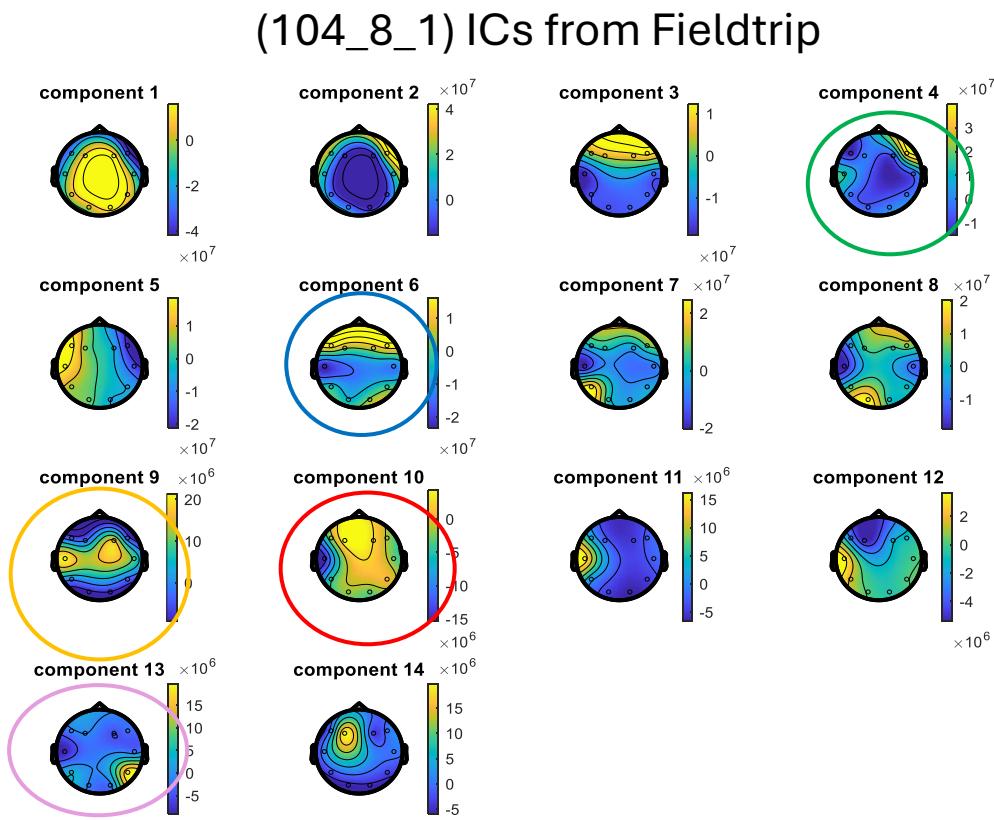
(101_1_2) ICs from EEGLAB



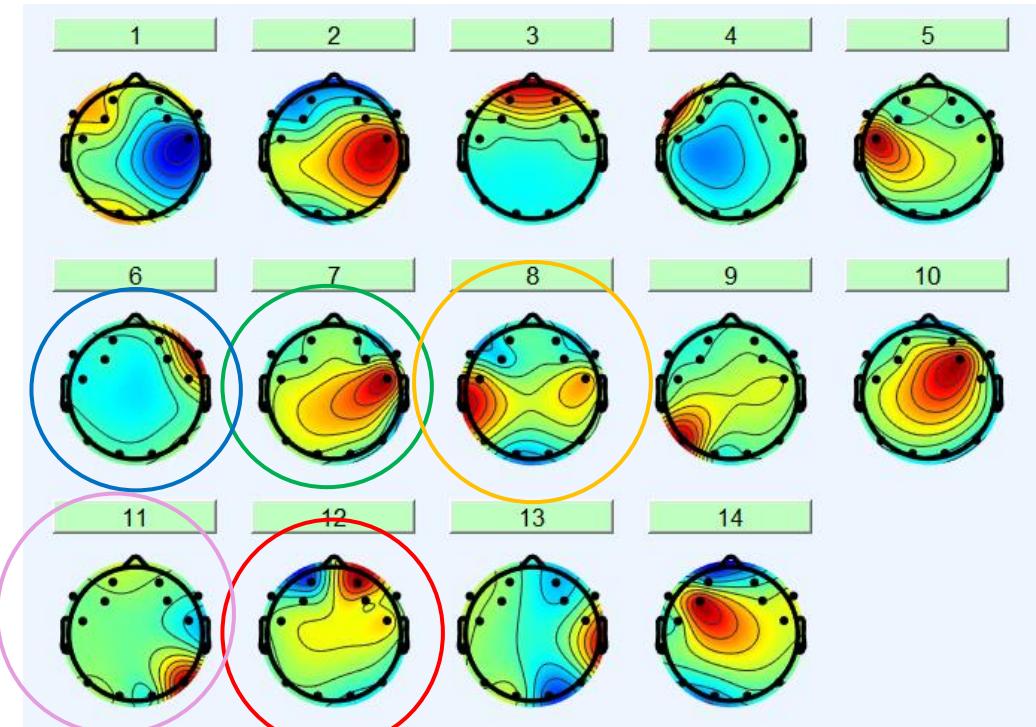
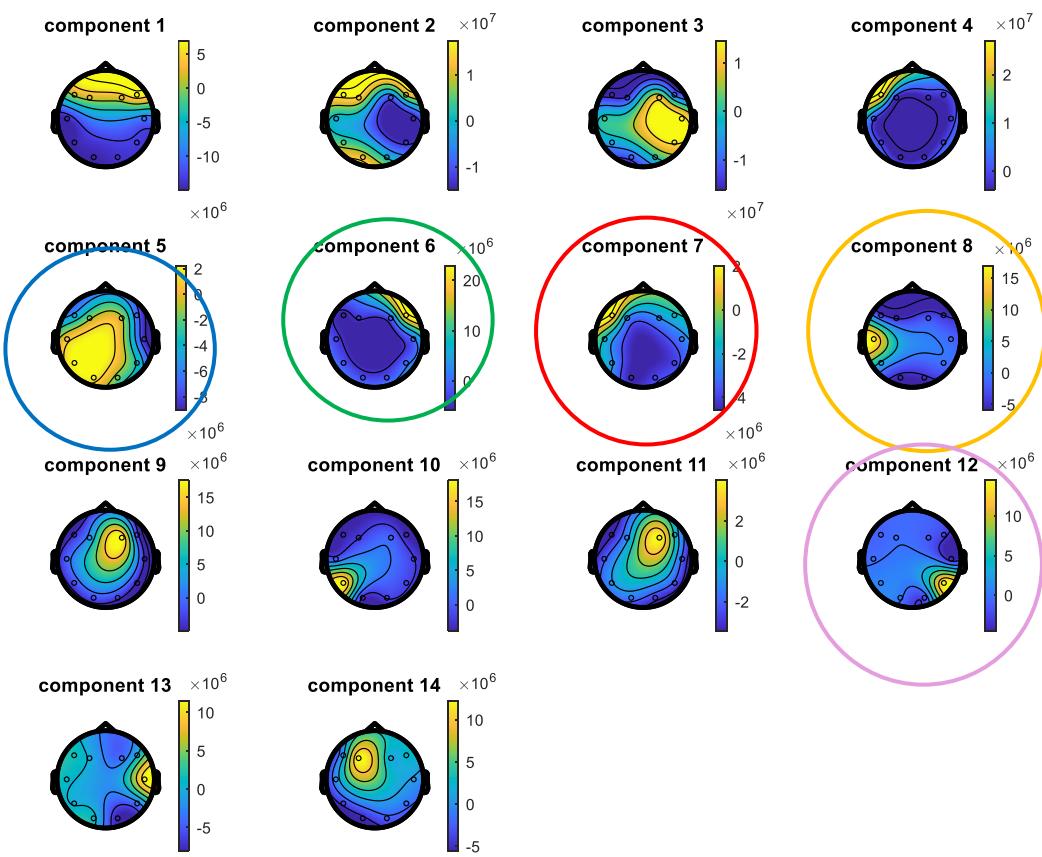
(101_1_2) IC12 Activity Power Spectrum



Source check (104_8_1)



Source check (103_15_2)



Sign flip contributes to source difference (polarity)

$$X = A \cdot S$$

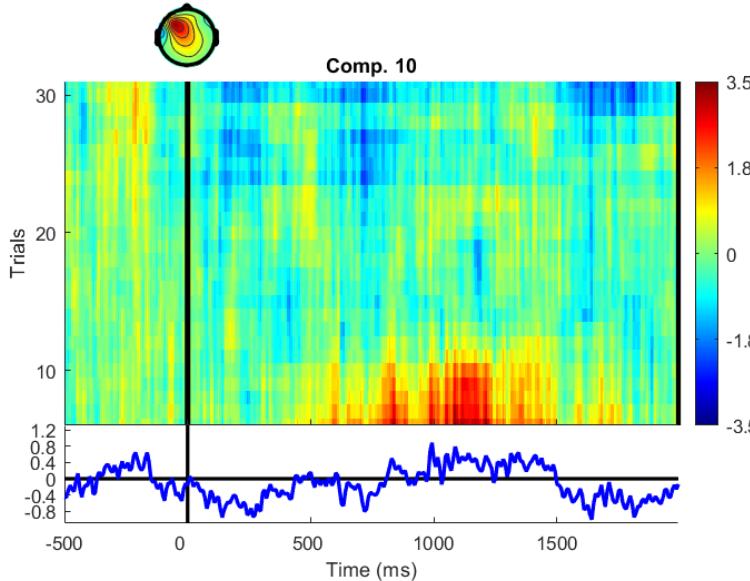
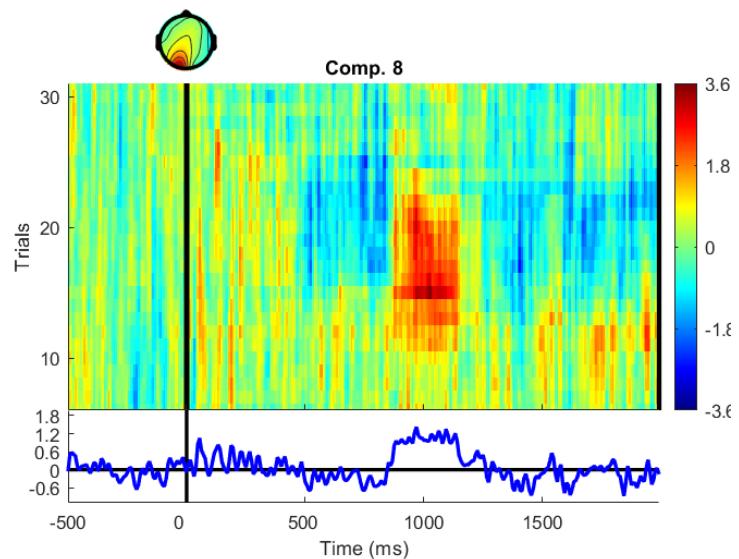
- Where:
 - A is the mixing matrix (spatial distribution)
 - S is the source matrix (time courses)
- **Multiplying both** a source component and its corresponding column in the mixing matrix by **-1** does not change the observed data matrix X, ICA is blind to the sign. Mathematically:

$$X = (-A) \cdot (-S)$$

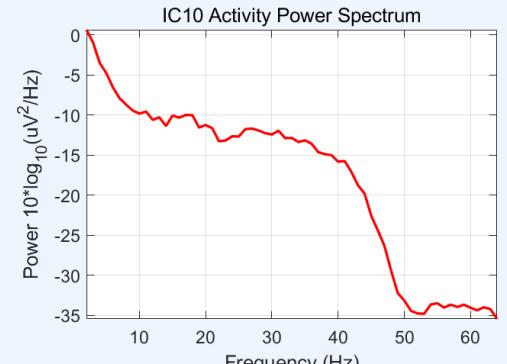
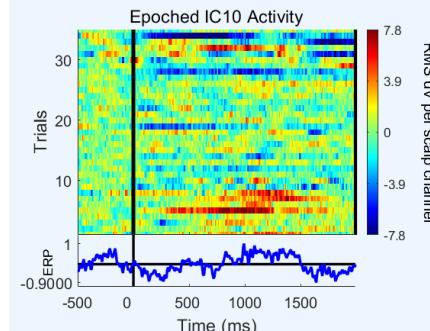
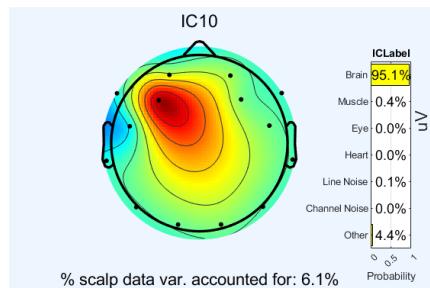
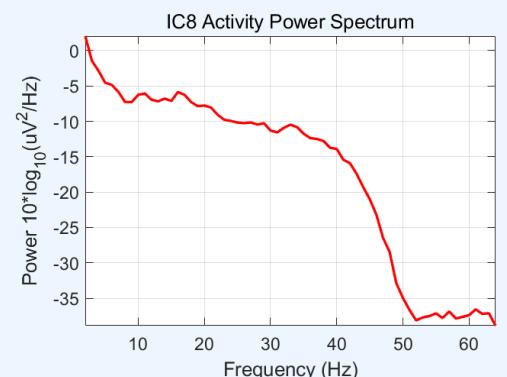
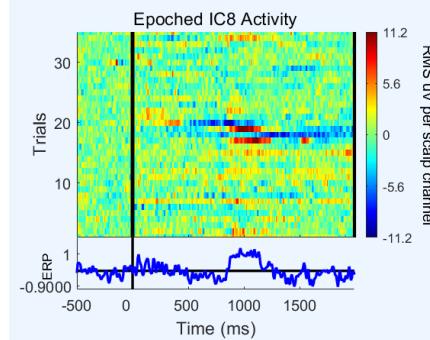
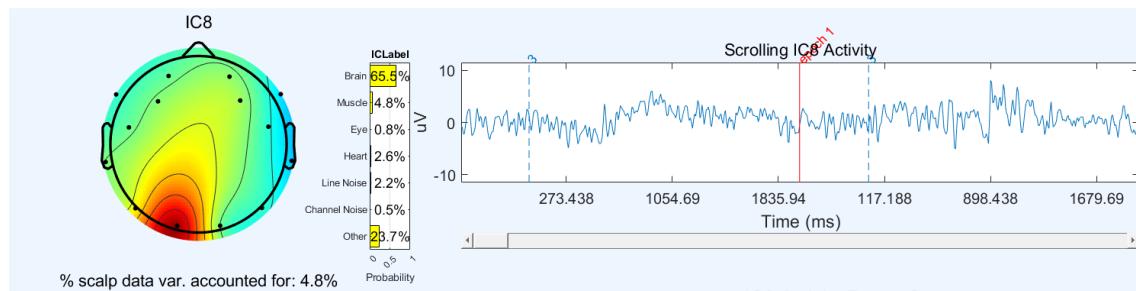
Sign Ambiguity in ICA and Source Localization

- **Sign Ambiguity:** A common reason for differences in source localization (e.g., T7 vs. T8) is sign ambiguity in ICA.
- **Algorithm Behaviour:** ICA frequently outputs components with different signs across runs or software packages. The algorithm focuses only on statistical independence.
- **Independence Not Affected:** The sign of an ICA component does not affect the statistical independence or accuracy of source separation.
- **Impact on Topoplot:** the topographical map appear different by shifting positive or negative contributions at electrodes.

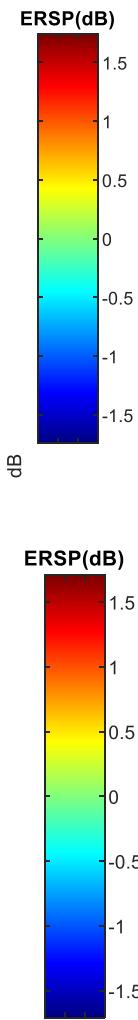
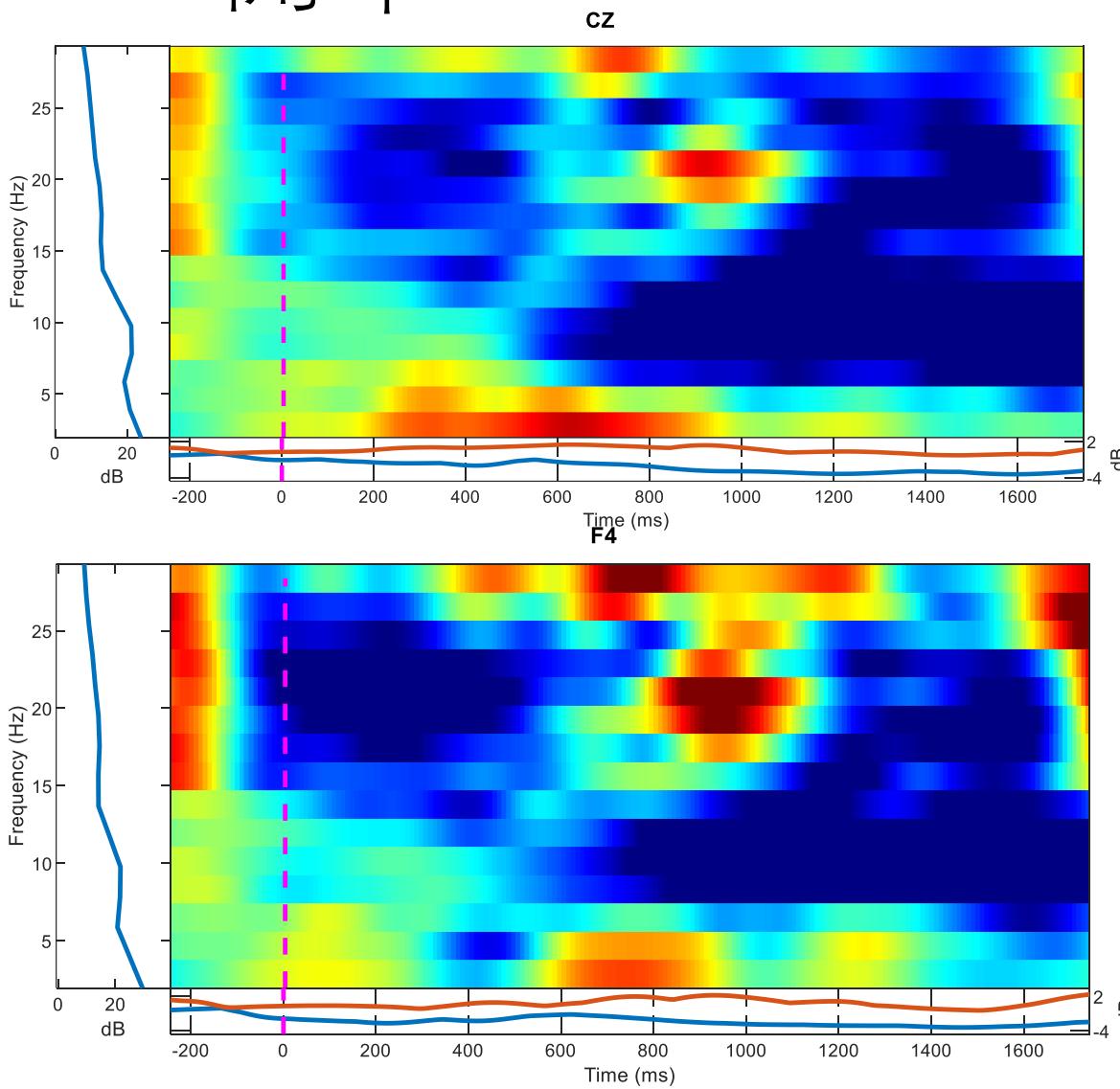
101_3_1 Noise?



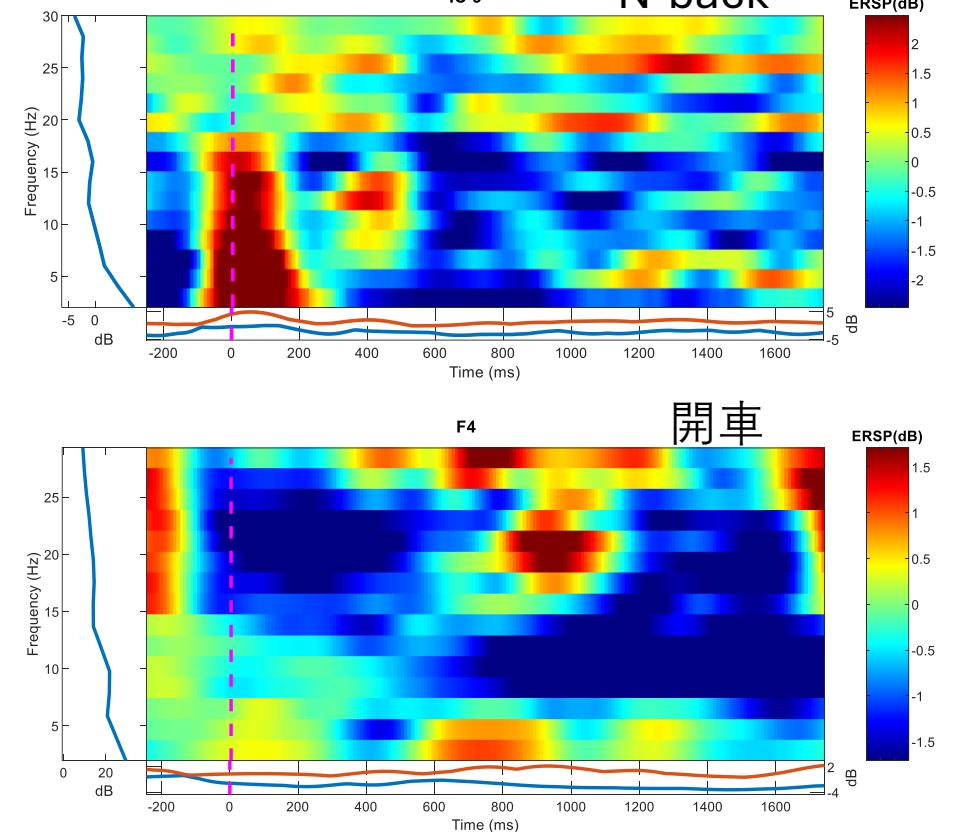
Positivity at 1000ms??



開車



101_5_3 com9 Source在F4
IC 9 N-back



ERSP(dB)

