Oscillatory dynamics associated with prediction during language comprehension

Lin Wang [1,2], Ole Jensen [3], Peter Hagoort [2,3]

1 Institute of Psychology, Chinese Academy of Science

2 Max Planck Institute for Psycholinguistics

3 Donders Institute for Brain, Cognition and Behaviour

Prediction in language

- Using violation paradigm, previous studies have shown that language processing involves prediction at multiple levels: semantic, syntactic, phonological, word form. (Szewczyk & Schriefers, 2013; Van Berkum, et al., 2005; DeLong, Urbach, & Kutas, 2005; Kim & Lai, 2012; Dikker, & Pylkkänen, 2013)
  - The day was breezy so the boy went outside to fly ...

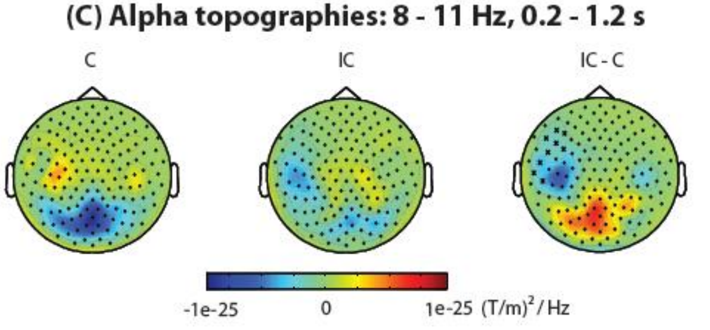
    a kite/**an** airplane.
  - She measured the flour so she could bake a ...

    cake/ceke/tont/srdt.

Oscillatory activities

- Predictive coding framework (accounted for sensory processing): beta – prediction; gamma – predictive error. (Friston, et al., 2015)
- The domain general role of alpha oscillation: (Jensen, et al., 2012; Payne & Sekuler, 2014)
  - Alpha decrease: the engagement of task-relevant areas
  - Alpha increase: functional inhibition

Incongruent vs. Congruent words: Alpha power decrease and increase in different regions (Wang, Jensen, et al., 2012)



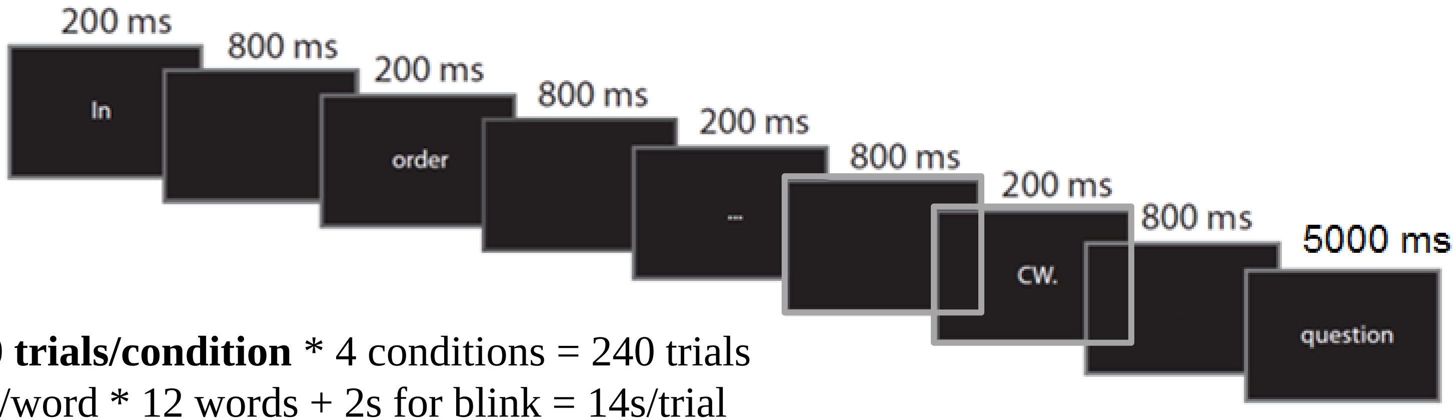
The climbers finally reached the top of the mountain/tulip.

Research questions

- What is the oscillatory signature of prediction in language comprehension?
  - Beta and alpha oscillations
  - Conceptual level vs. sensory level prediction
- How does top-down prediction generated in language context influence the integration of upcoming input?

Method

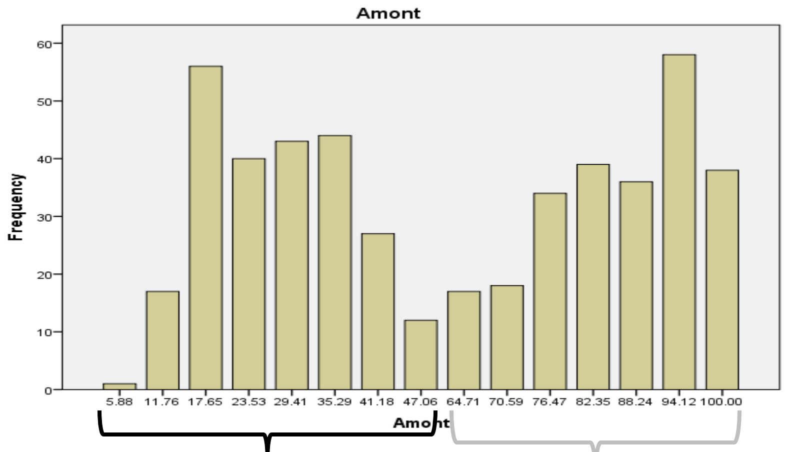
- Design: 2 Contextual constraint (HC, LC) * 2 Semantic Congruence (C, IC)
- Examples:
  - HC-C/IC: In order to see these **cells**, one uses a microscope/wheelchair.
  - LC-C/IC: In order to see these **objects**, one uses a microscope/wheelchair.
- Pretests
  - Cloze probability test (n = 34): *In order to see these cells, one uses a ...*
  - Plausibility test (n = 32)
- Procedure



60 trials/condition * 4 conditions = 240 trials
1s/word * 12 words + 2s for blink = 14s/trial
14s/trial * 240 trials = 56 mins
30 items/block * 8 blocks

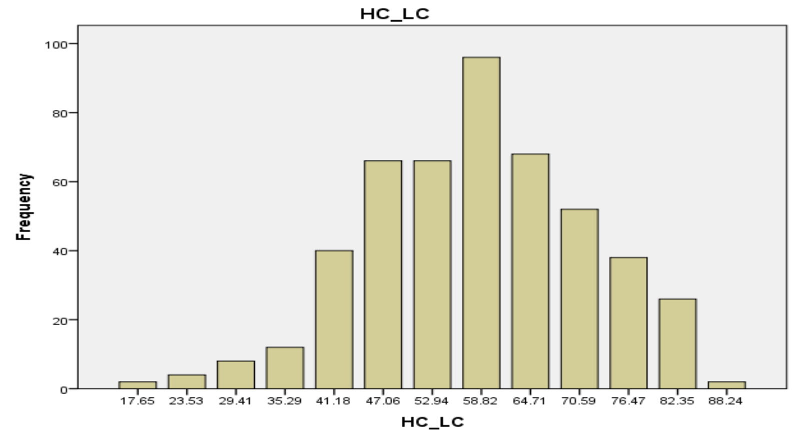
Pre-tests results

Semantic constraints: HC vs. LC



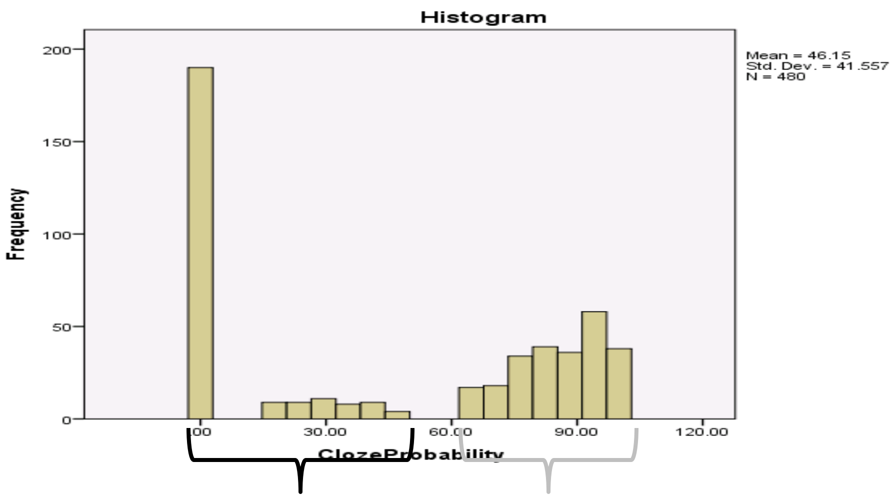
LC: 5.88-47.06 HC: 64.71-100

Semantic constraints: HC-LC



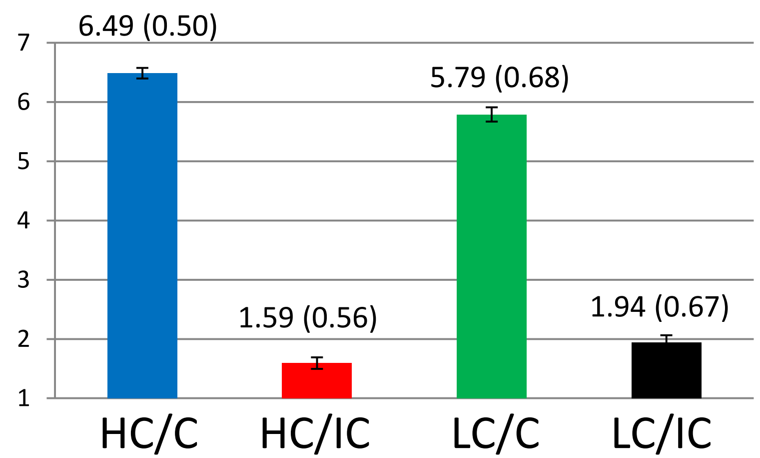
In order to see these cells, one uses a <u>glass</u>. (30%)

Cloze probability: HC vs. LC

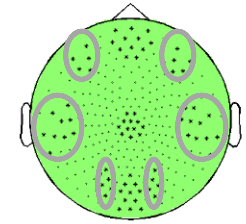


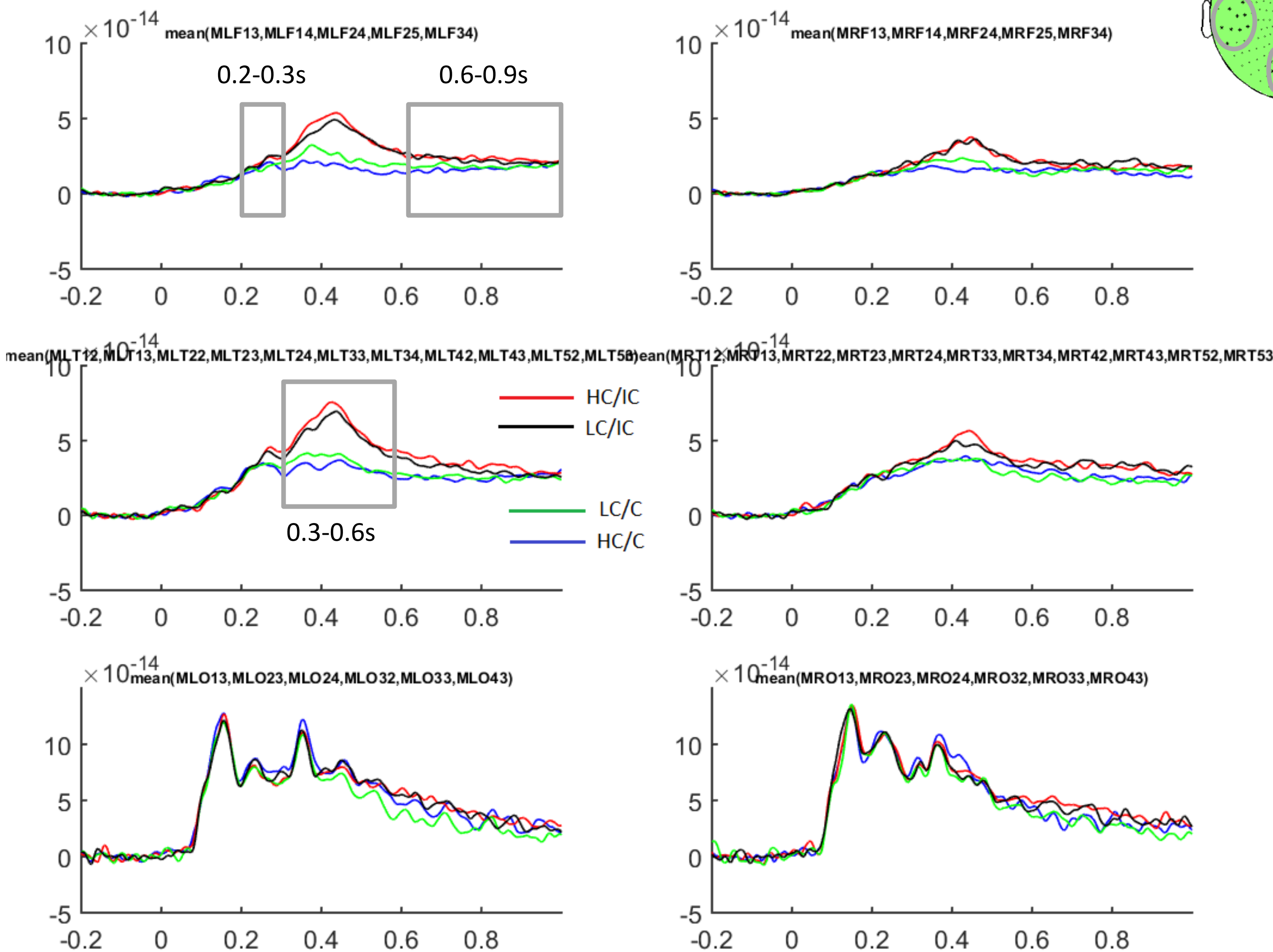
LC: 6.4 [0-47.6] HC: 85.9 [64.7-100]

Plausibility: four conditions



ERFs: four conditions

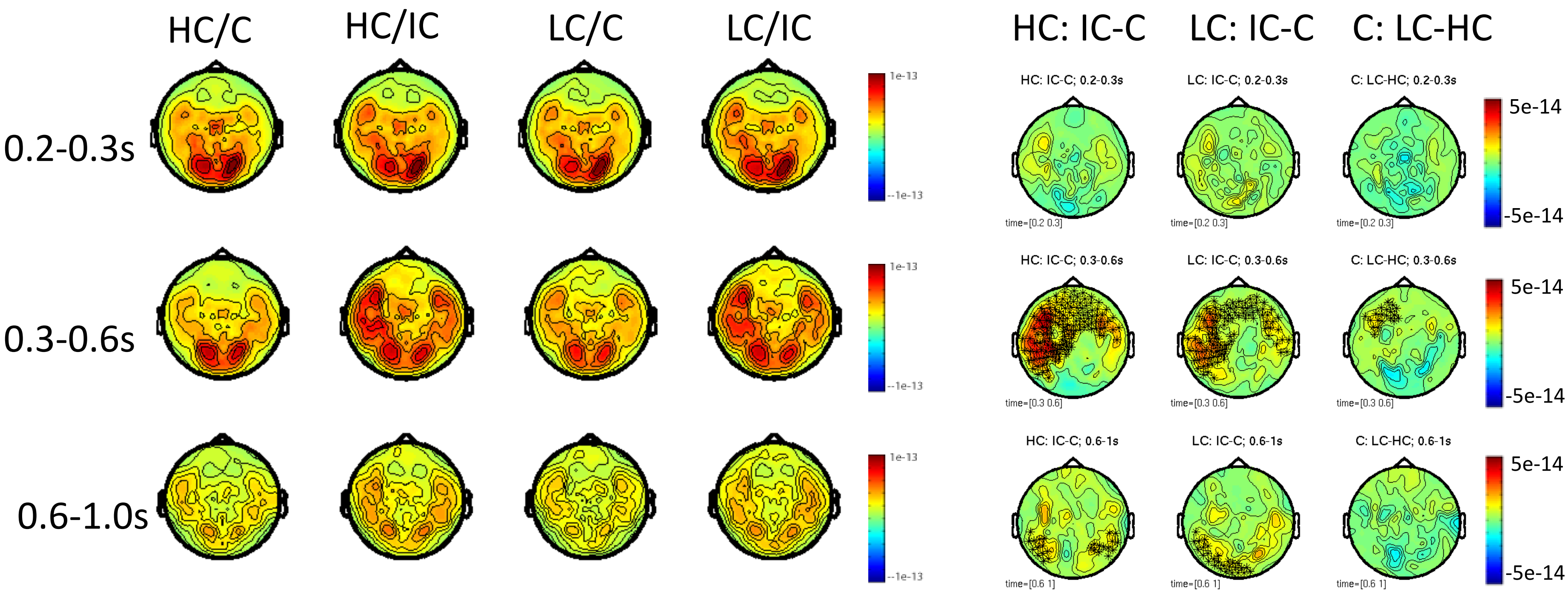




HC (C/IC): In order to see these **cells**, one uses a microscope/wheelchair.

LC (C/IC): : In order to see these **objects**, one uses a microscope/wheelchair.

ERF topographies



IC-C: classical N400 effects in both HC and LC conditions.

Interaction: HC (IC-C) vs. LC (IC-C)

300-600ms: p = .01; Stronger Congruence effect over left frontal region in the HC conditions.

200-300ms:

IC-C: p = .0899

LC-HC: p = .0679

Interaction: p = .056

300-600ms:

IC-C: p = .002

LC-HC: p = .1159 (neg)

Interaction: p = .01

32-31: p = .002

34-33: p = .002

33-31: p = .01

34-32: p = .124 (neg)

600-900ms:

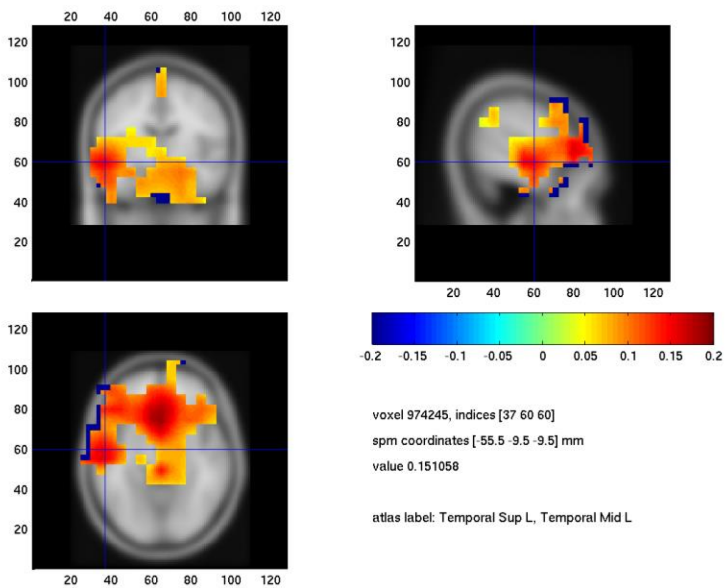
IC-C: p = .002, p = .006

LC-HC: p = .4336 (neg)

Interaction: n.s.

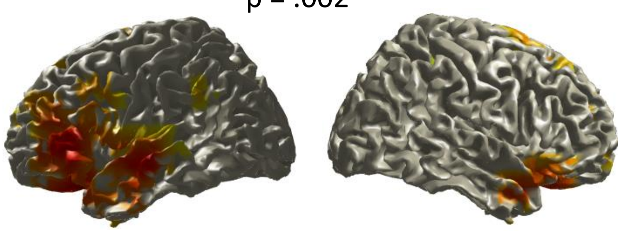
Source of the N400 effects

IC-C; 0.3 - 0.6s

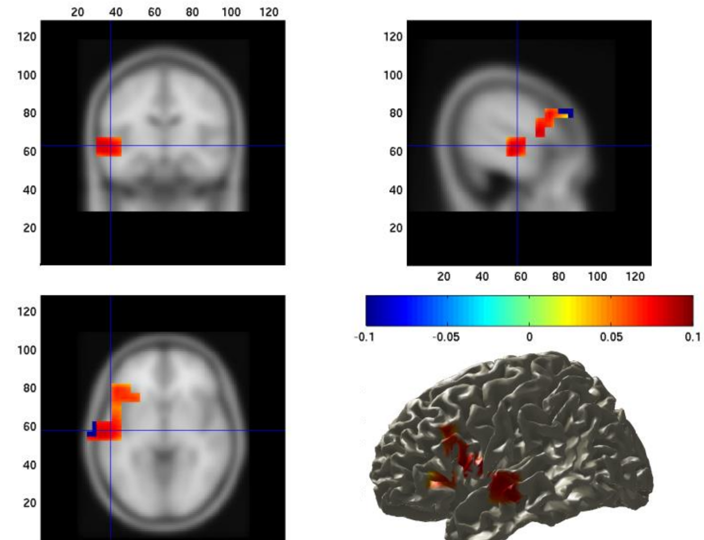


bilateral inferior frontal, superior/middle temporal, anterior cingulate

p = .002



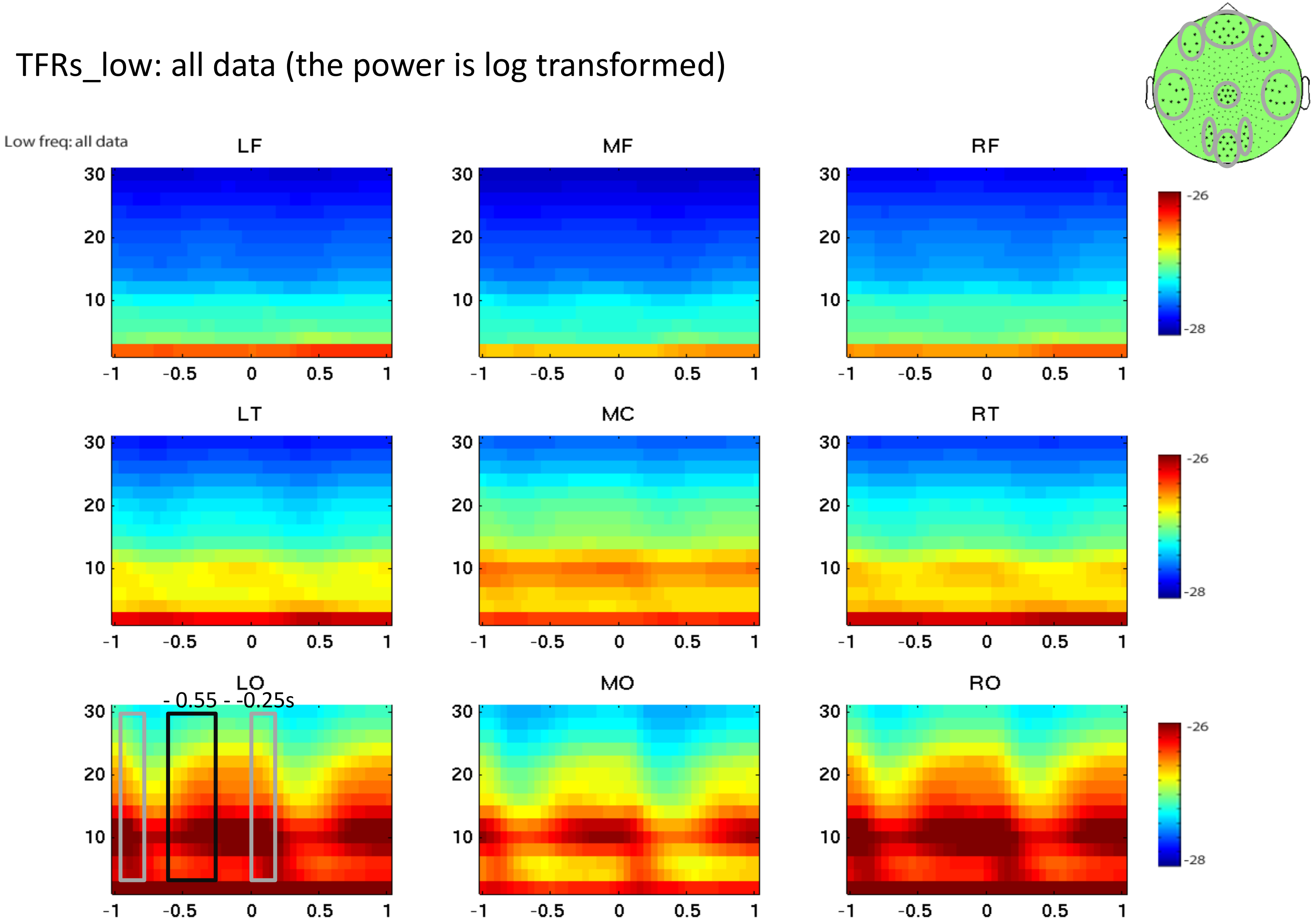
LC/C-HC/C; 0.3 - 0.6s



p = .088

Left inferior frontal and middle temporal

TFRs_low: all data (the power is log transformed)

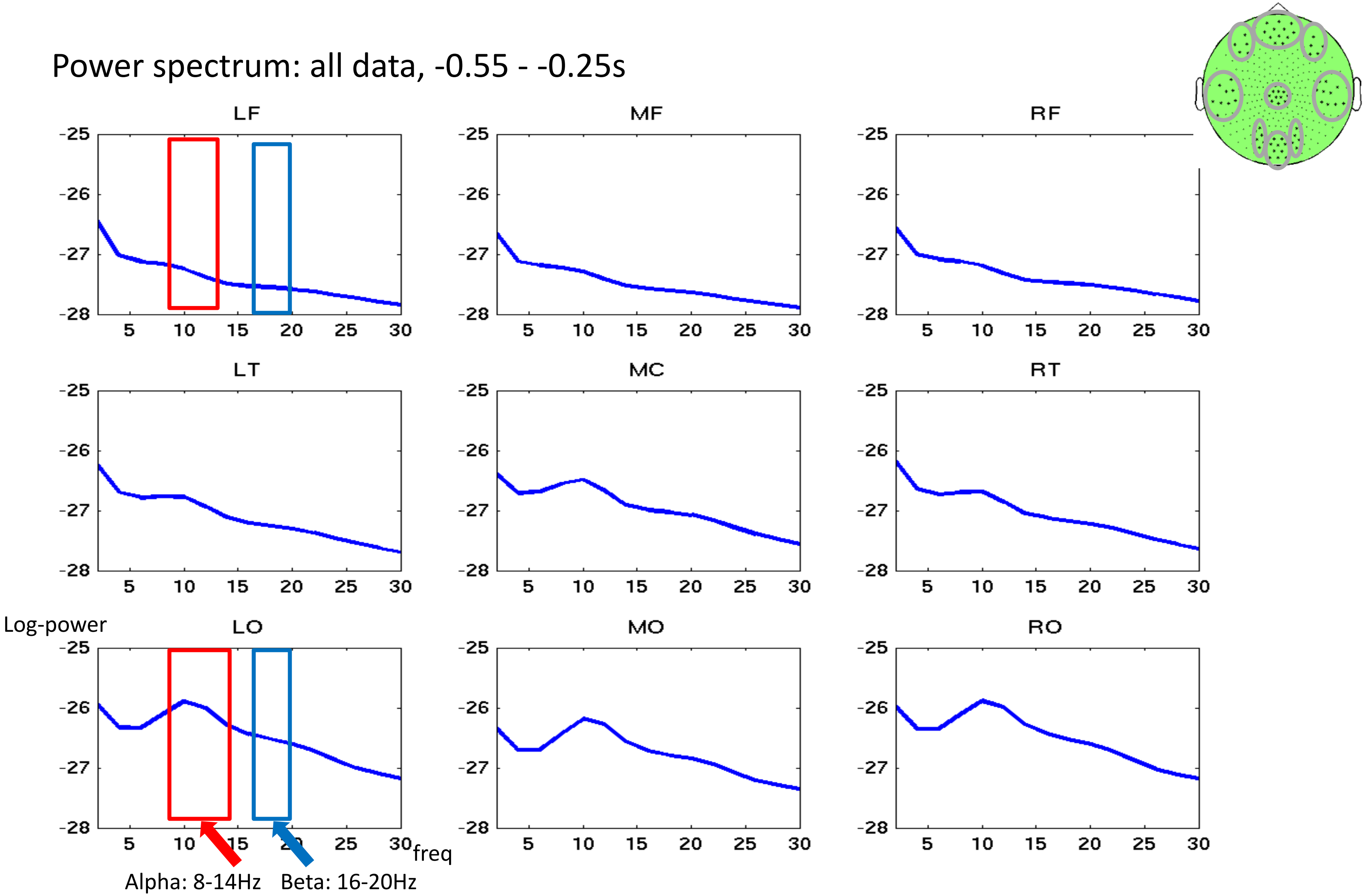


Strong induced alpha power.

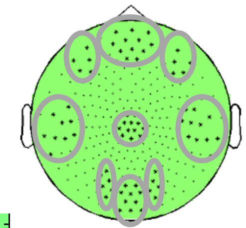
Focus on the pre-CW interval when no word was on the screen: -0.55s - -0.25s.

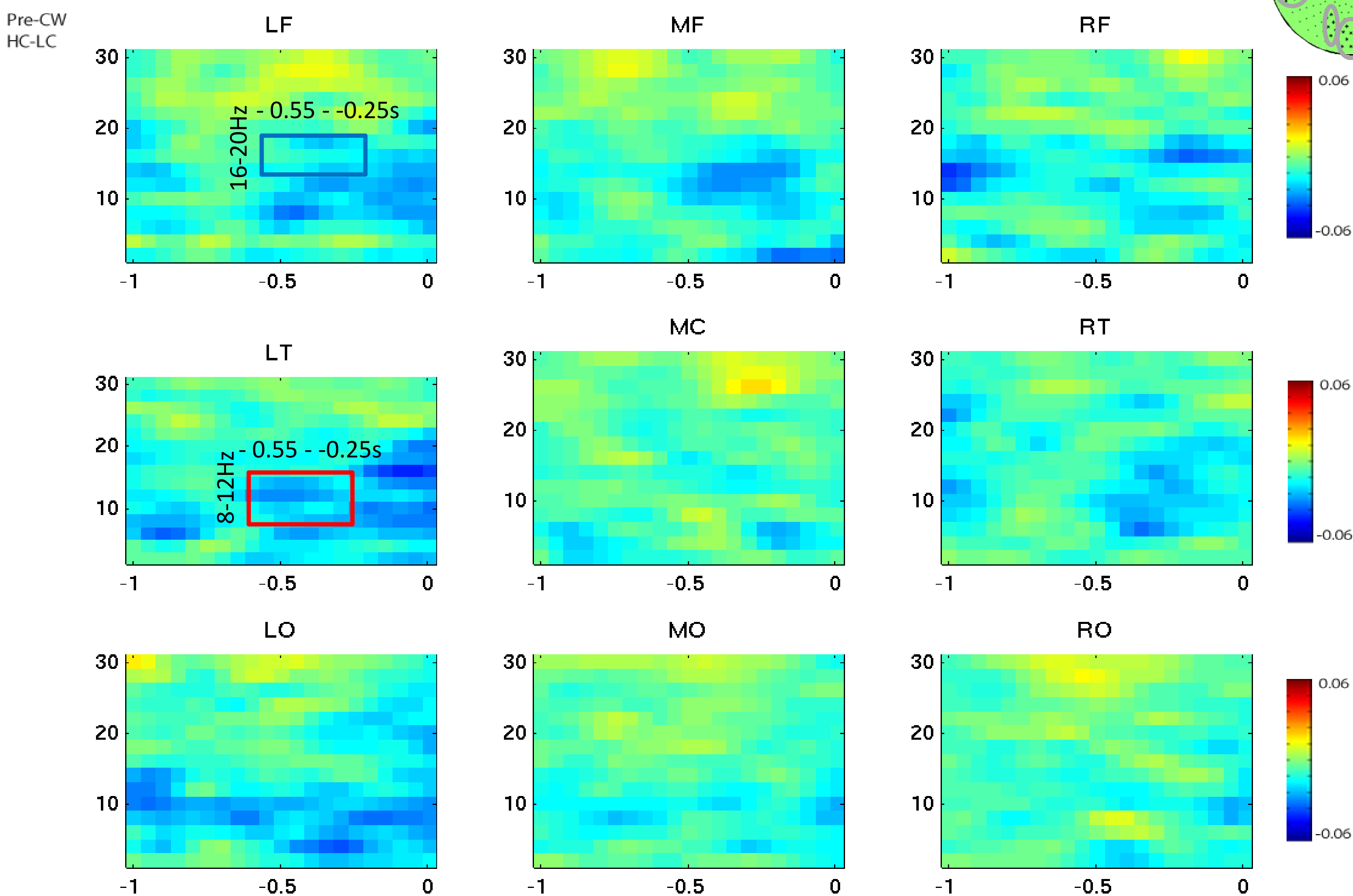
No baseline correction

Power spectrum: all data, -0.55 - -0.25s

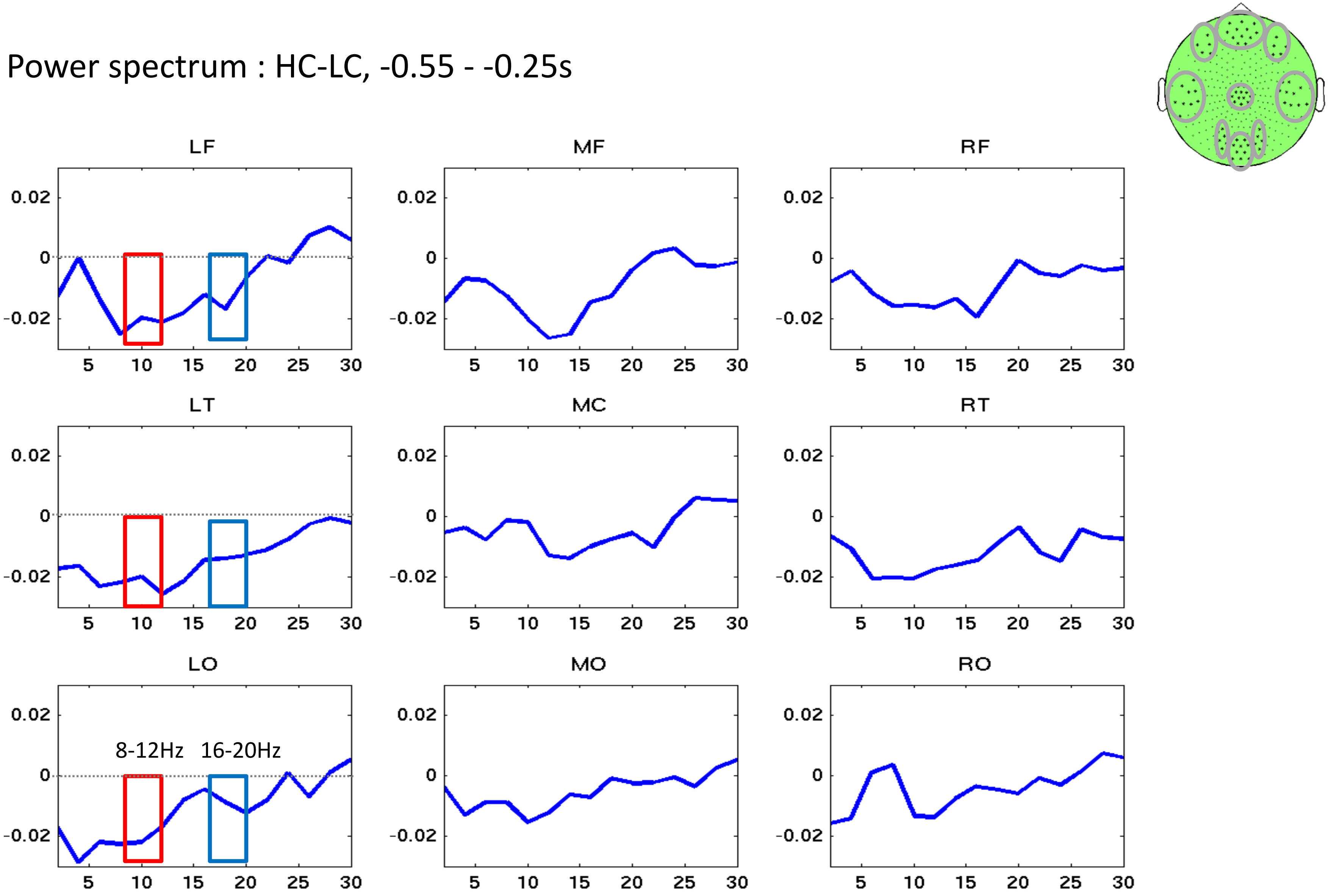


TFRs_low: pre-CW (-1 – 0s); HC-LC

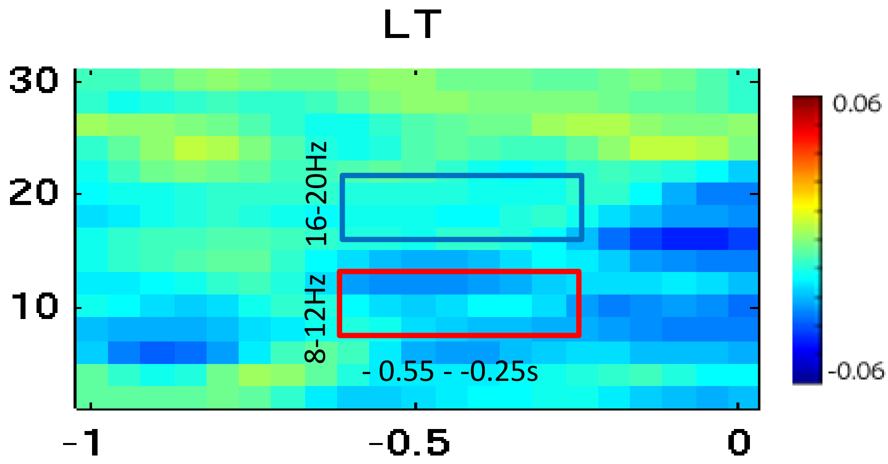


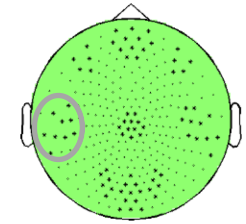


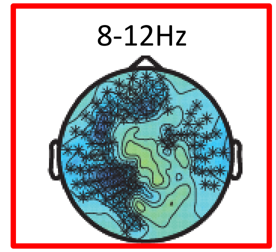
Power spectrum : HC-LC, -0.55 - -0.25s



TFRs_low: -0.55 - -0.25s, HC-LC





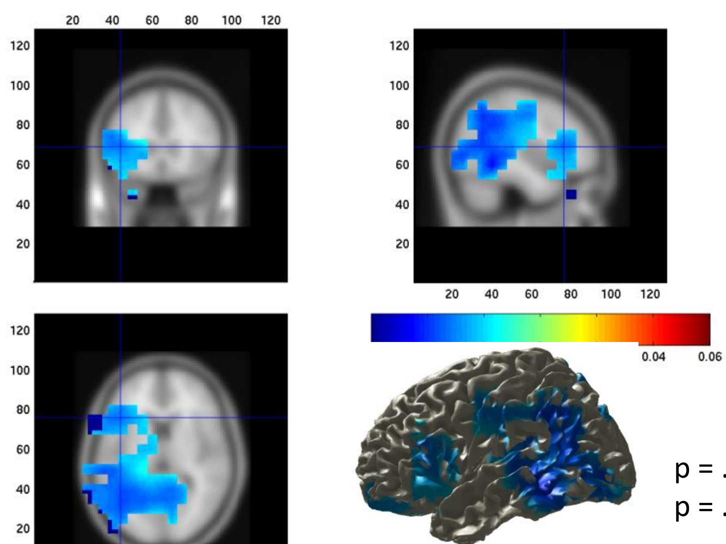


p = .002
p = .038

p = .004

Source localization:

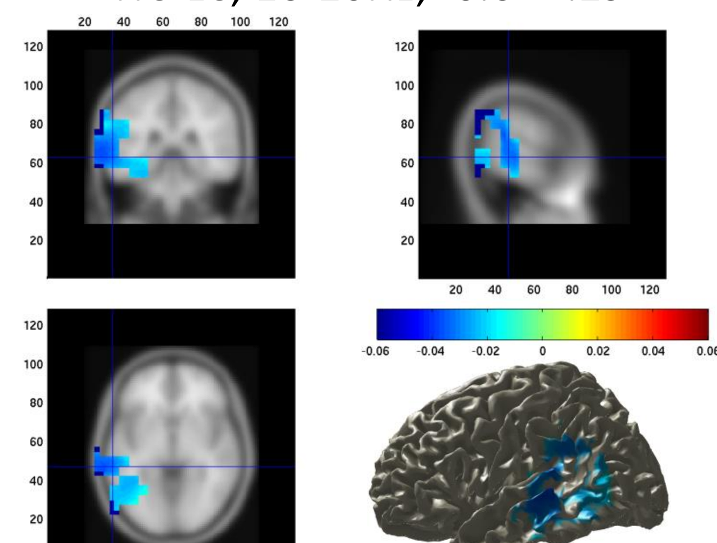
HC-LC; 8-12Hz; -0.6 - -.2s



p = .002
p = .032

Left inferior fronal, middle temporal, fusiform; Right precuneus, cerebellum

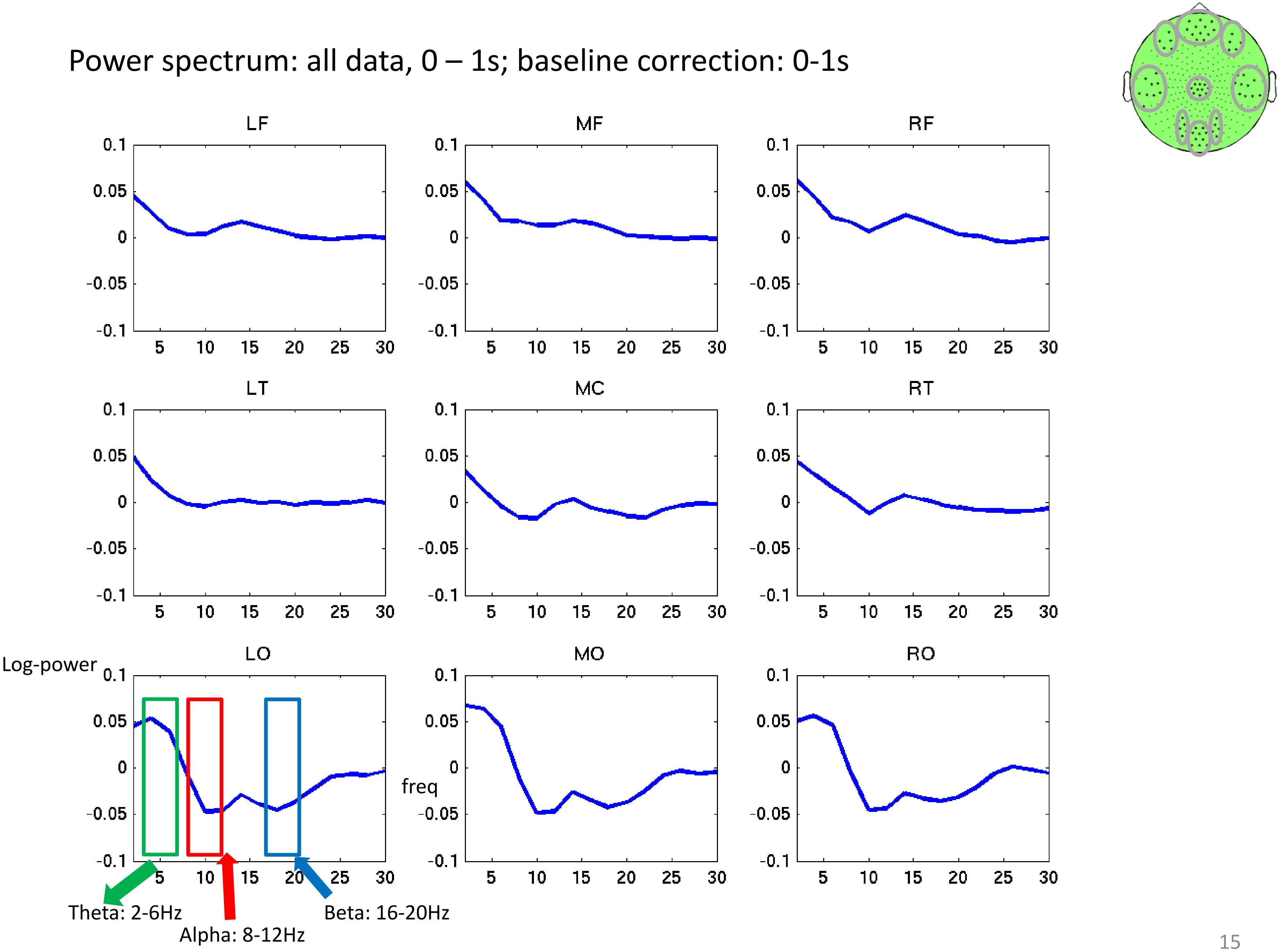
HC-LC; 16-20Hz; -0.6 - -.2s



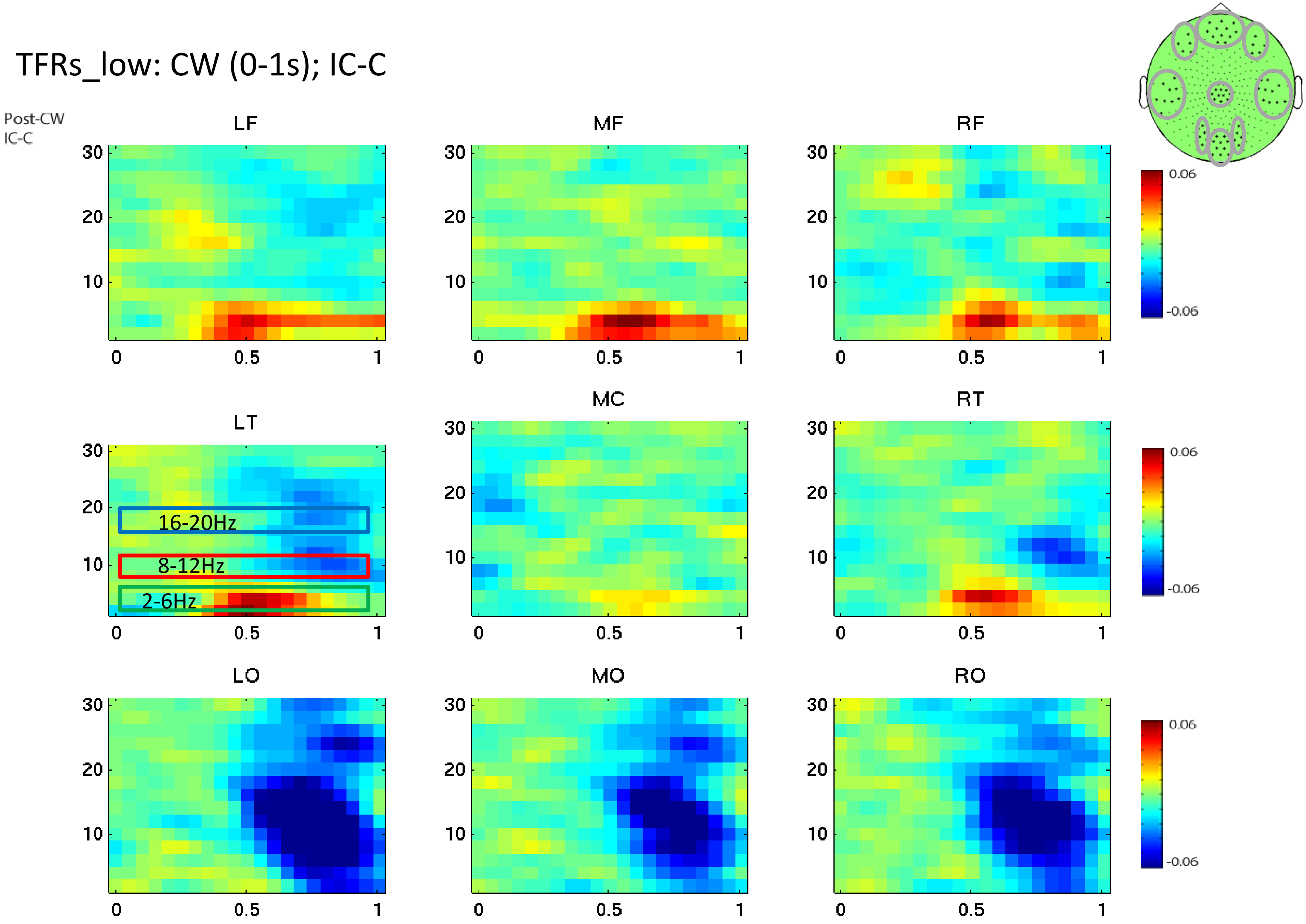
p = .012

Left middle temporal, occipital

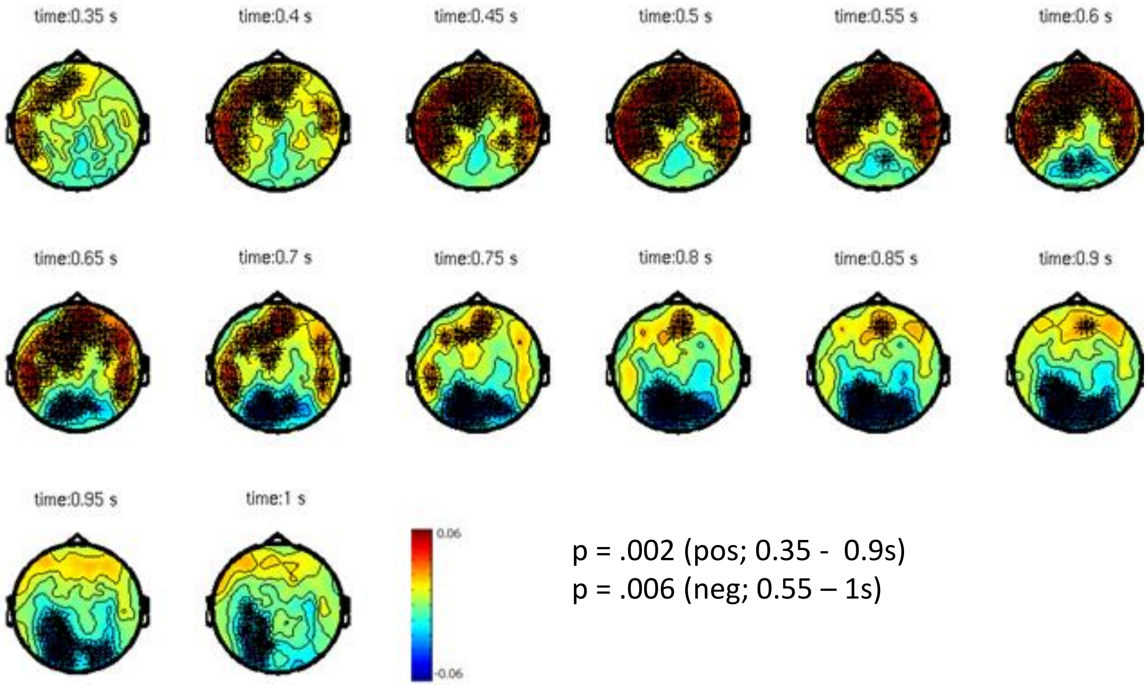
Power spectrum: all data, 0 – 1s; baseline correction: 0-1s



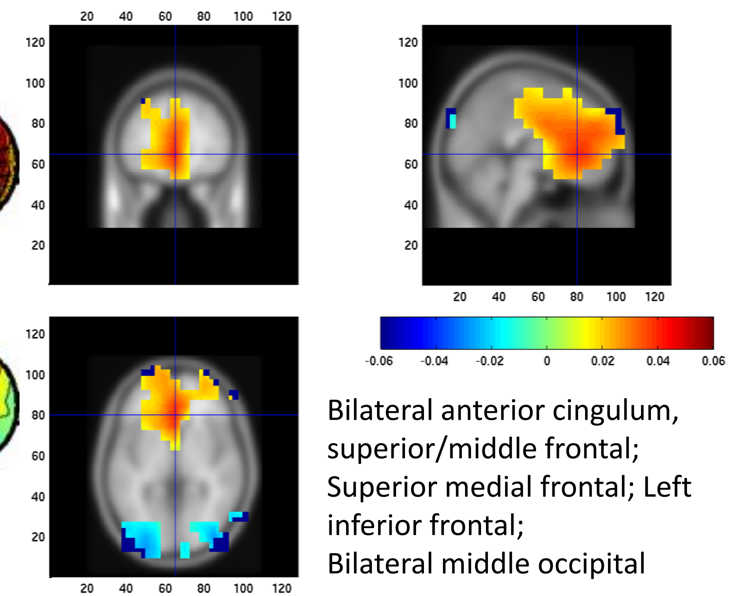
TFRs_low: CW (0-1s); IC-C



TFRs: IC-C; 2-6Hz; 0-1s

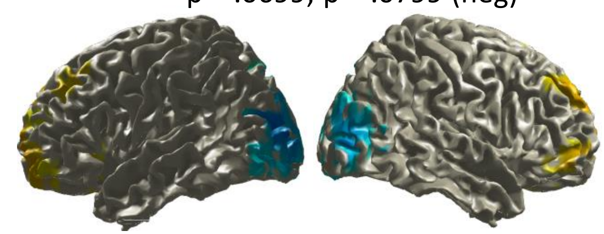


p = .002 (pos; 0.35 - 0.9s)
p = .006 (neg; 0.55 – 1s)



Bilateral anterior cingulum, superior/middle frontal; Superior medial frontal; Left inferior frontal;
Bilateral middle occipital

p = .002 (pos)
p = .0699; p = .0799 (neg)



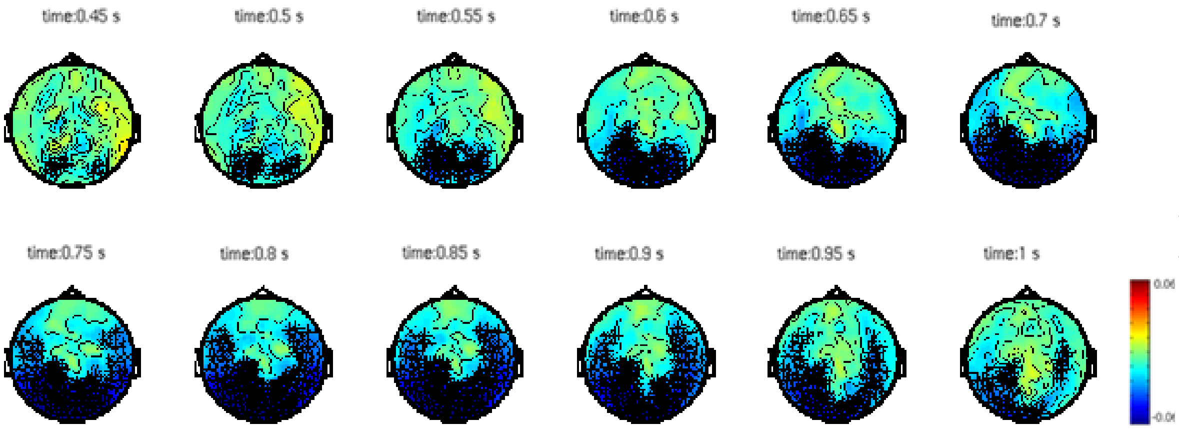
Stronger theta for IC than C:

- The time latency and localization mirror the N400 effect.

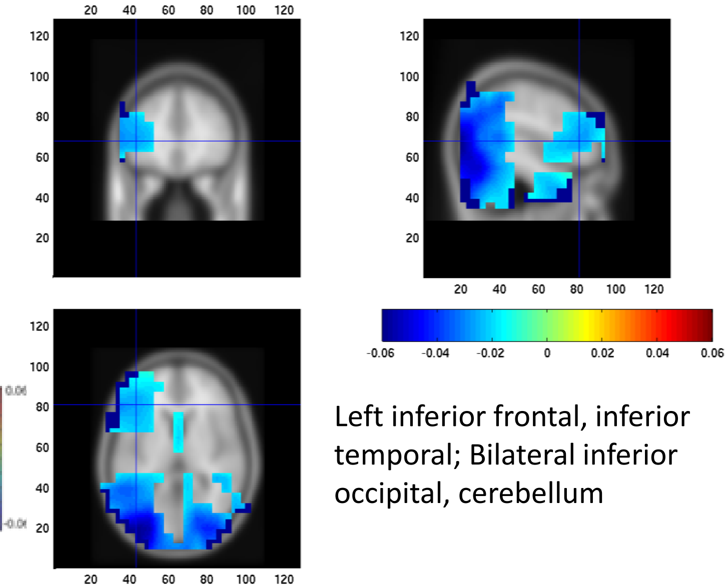
Greater effort to retrieve and integrate the IC words.

HC (IC-C) vs. LC (IC-C): p = .034 (0.35 – 0.6s); Stronger Congruence effect over left frontal and temporal regions in the HC conditions.

TFRs: IC-C; 8-12Hz; 0-1s

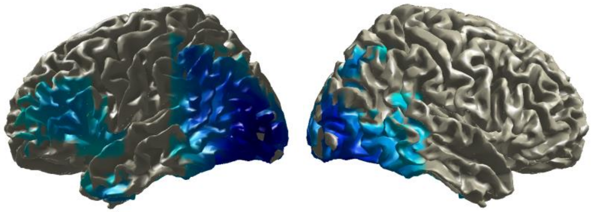


p = .002 (0.45 – 1s)



Left inferior frontal, inferior temporal; Bilateral inferior occipital, cerebellum

p = .002

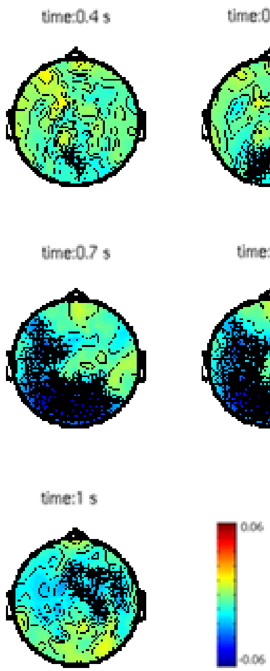


Stronger alpha suppression for IC than C:

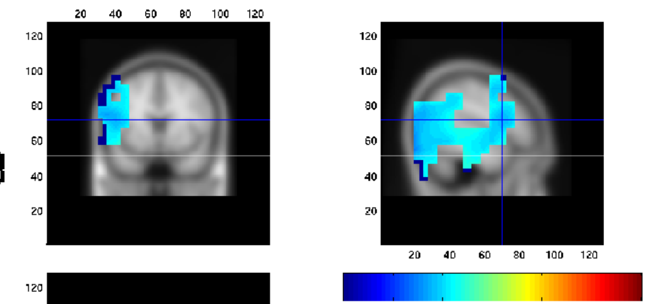
- Greater engagement of visual cortex for IC than C words even when the IC words were not on the screen:
- Iconic memory of previously presented words; double check the initial visual input.
- Alpha suppression in visual cortex in reading vs. alpha increase in visual cortex in listening.

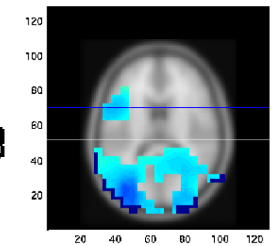
HC (IC-C) vs. LC (IC-C): p = .05 (0.25 – 0.85s); Stronger Congruence effect over left temporal and occipital regions in the HC conditions.

TFRs: IC-C; 16-20Hz; 0-1s



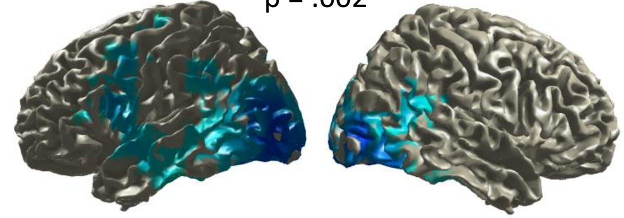
p = .002 (0.4 – 1s)





Left inferior frontal, superior/middle/inferior temporal; Bilateral middle/inferior occipital, fusiform

p = .002

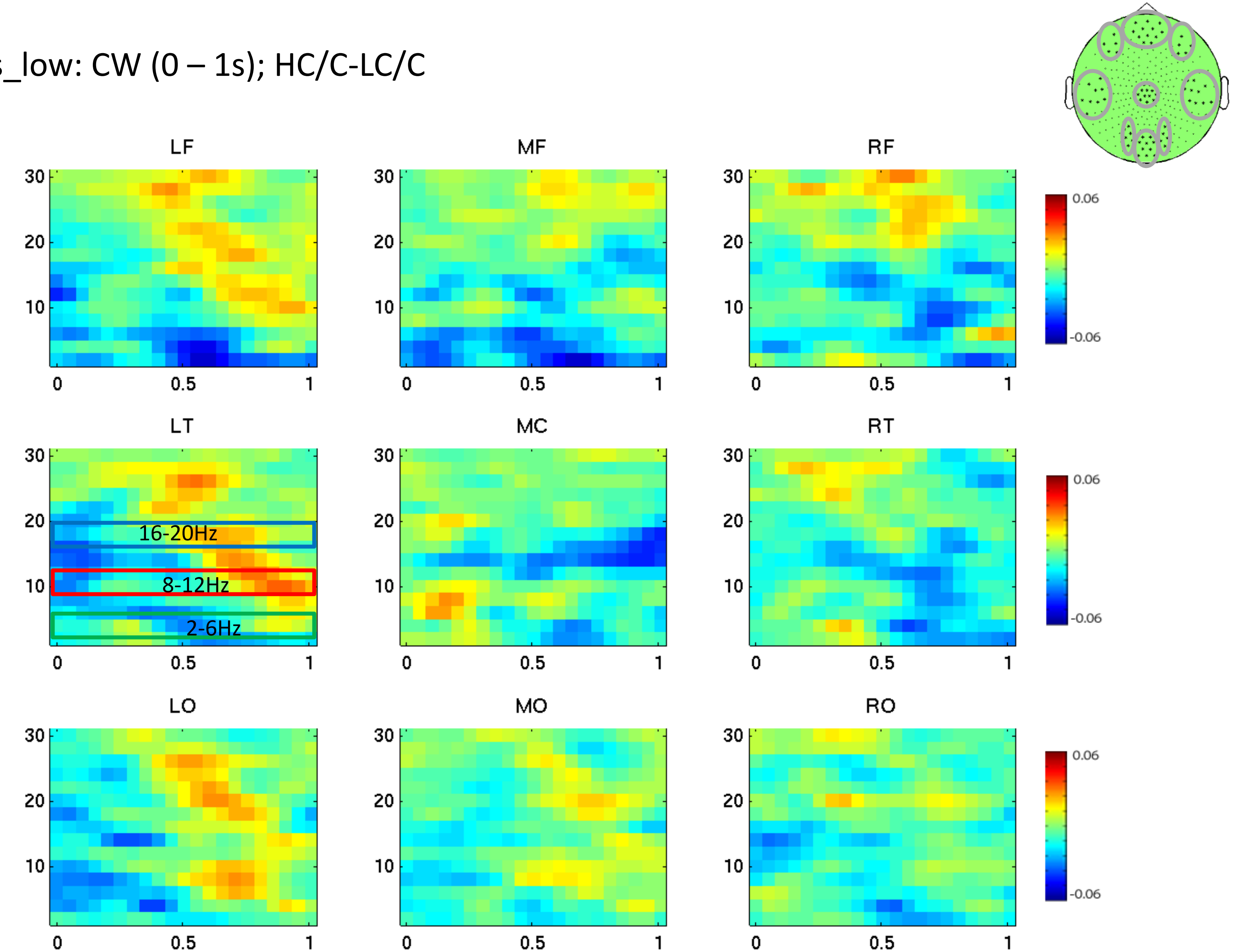


Stronger beta suppression for IC than C over LIFG:

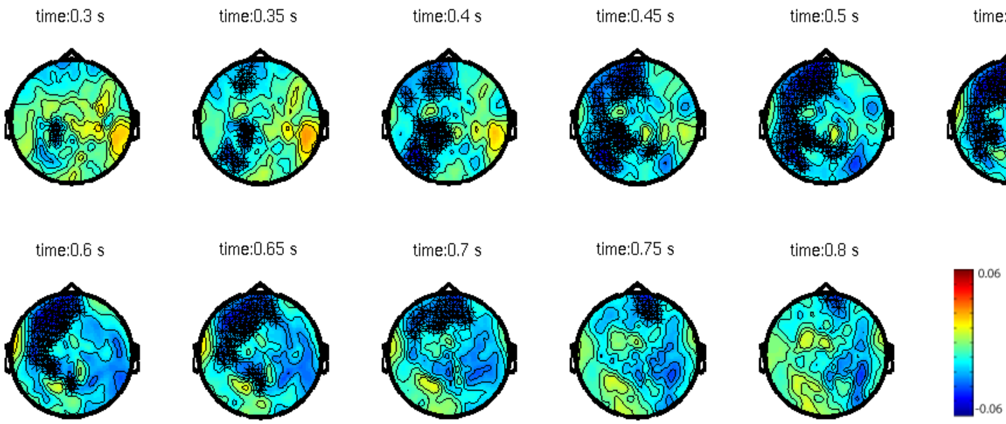
- Replicated the LIFG suppression reported in our previous study. (Wang, Jensen, et al., 2012)

HC (IC-C) vs. LC (IC-C): p = .004 (0.2 – 0.75s); Stronger Congruence effect over left frontal, temporal and occipital regions in the HC conditions.

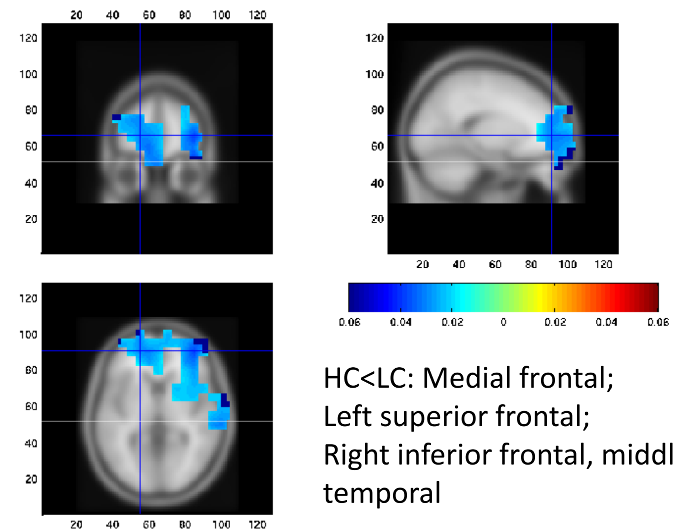
TFRs_low: CW (0 – 1s); HC/C-LC/C



TFRs: HC/C-LC/C; 2-6Hz; 0-1s

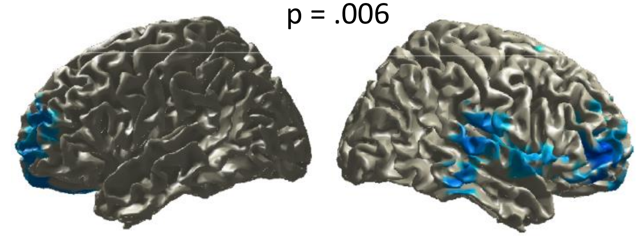


p = .004 (0.3 – 0.8s)



HC<LC: Medial frontal;
Left superior frontal;
Right inferior frontal, middle temporal

p = .006

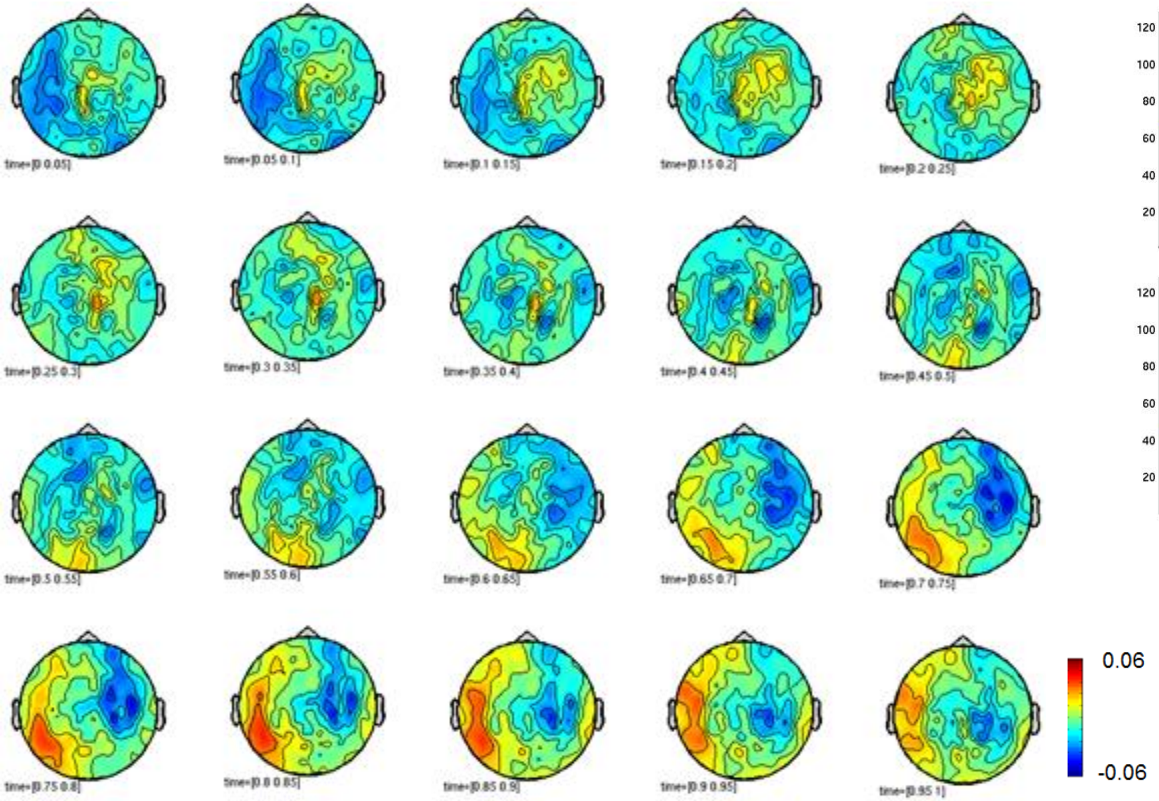


Less strong theta for HC than LC:

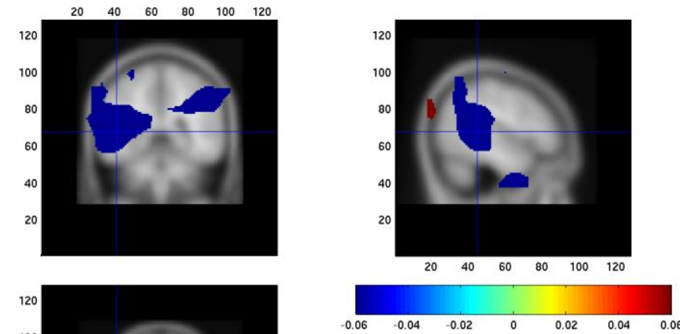
- Less effort to integrate the pre-activated HC words.

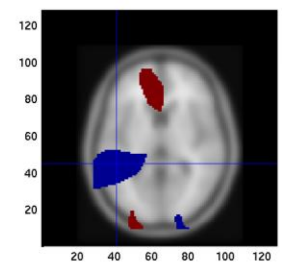
TFRs: HC/C-LC/C; 8-12Hz; 0-1s

Mask with 50% maximum



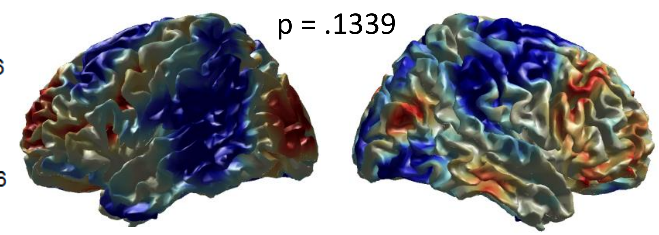
p = .1558 (neg)





HC>LC:
Superior medial frontal, Left anterior cingulum, occipital
HC<LC:
Left superior/middle temporal; Right supramarginal, postcentral

p = .1339



Stronger alpha suppression for HC than LC:

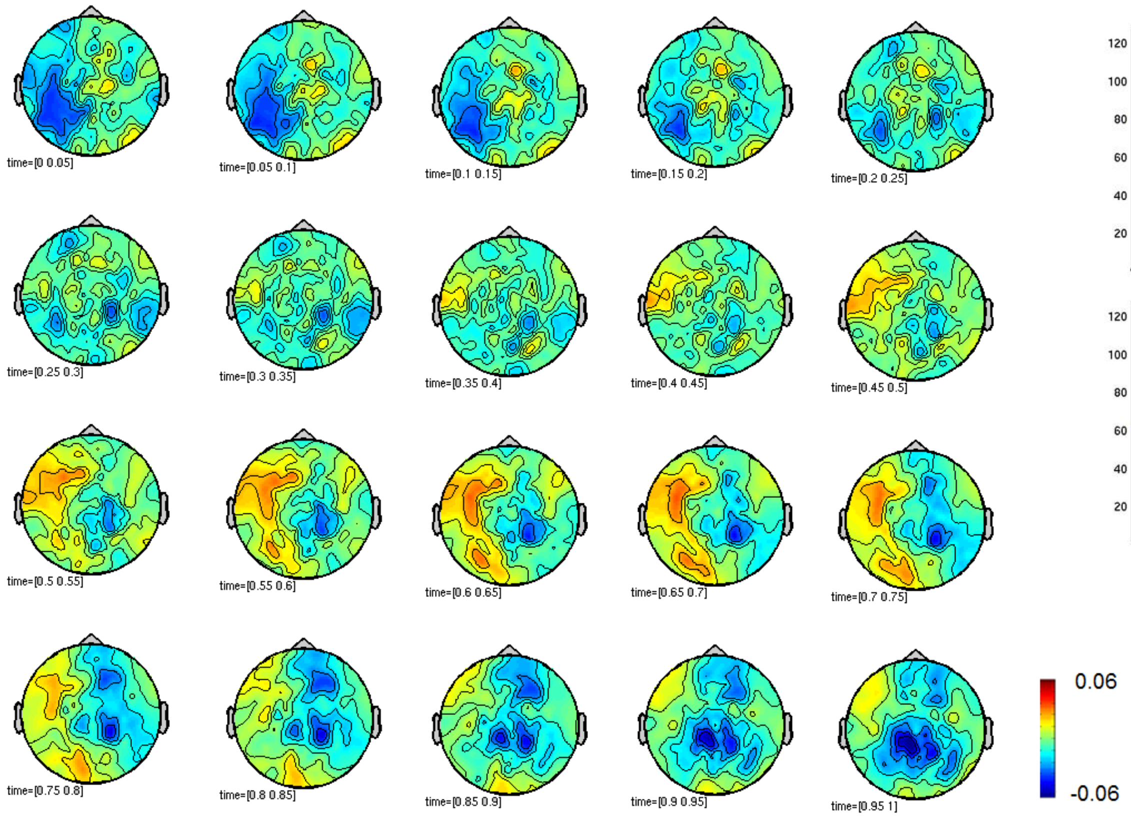
- Early time window: The brain might be still in a prediction state
- Late time window: Motor preparation after completing semantic integration.

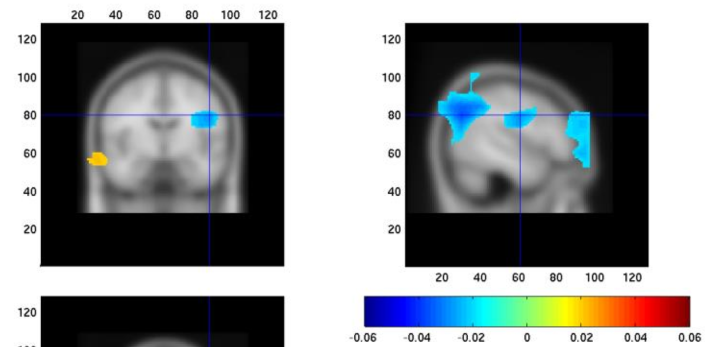
Stronger alpha power for HC than LC over left occipital region:

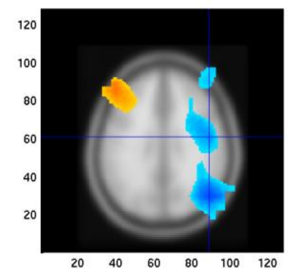
- The visual cortex was shut down because the HC words matched with the pre-activated words.

TFRs: HC/C-LC/C; 16-20Hz; 0-1s

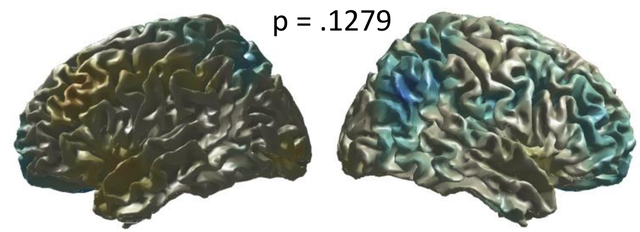
Mask with 50% maximum







HC>LC: Left middle frontal, superior temporal
HC<LC: Right inferior frontal, postcentral, middle occipital; Bilateral superior parietal

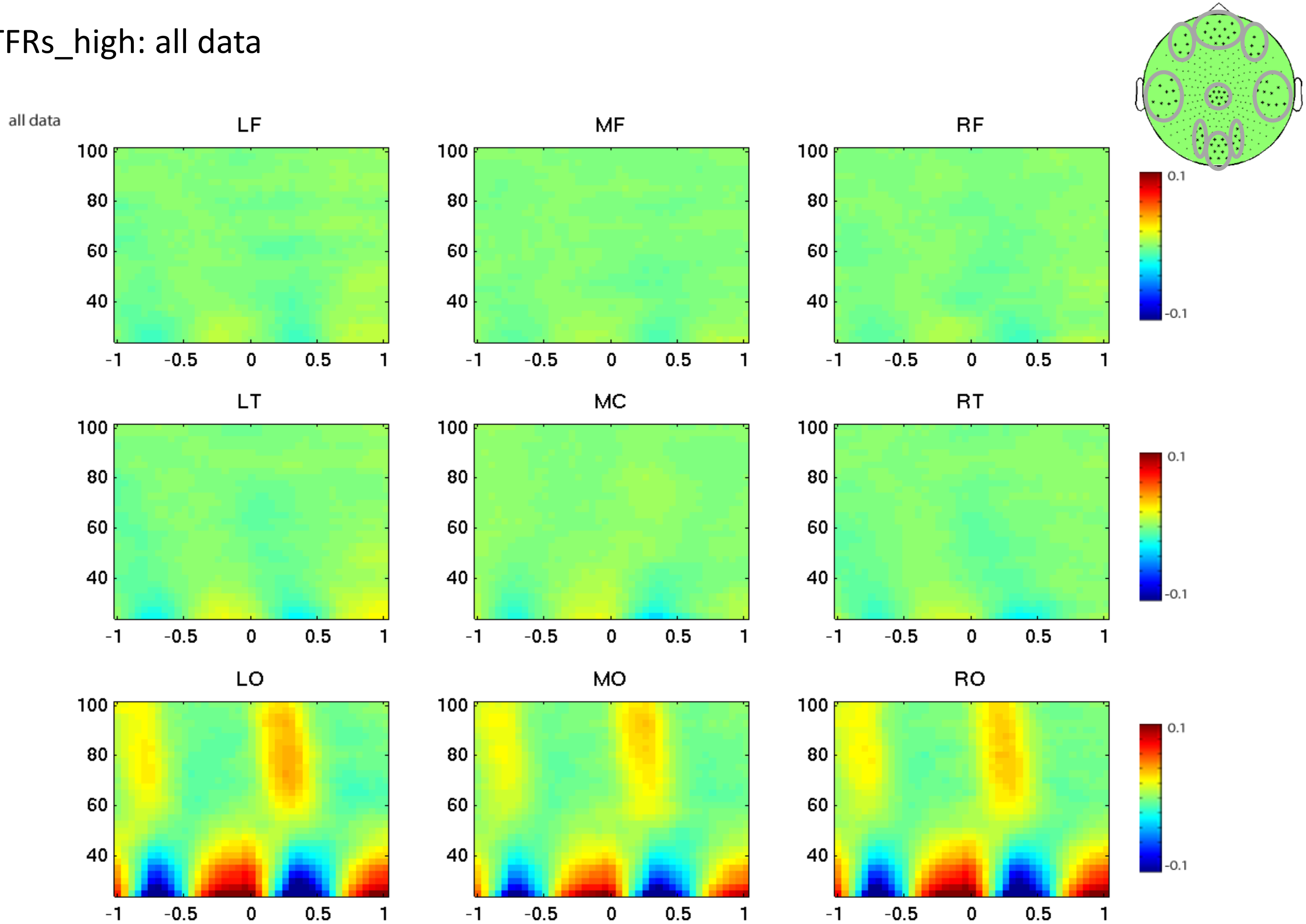


p = .074 (neg)
p = .080 (neg)

Stronger beta suppression for HC than LC:
- Early time window: More attentive in the HC condition.
- Late time window: Motor preparation after completing semantic integration.

Stronger beta power for HC than LC over left frontal and temporal regions:
- The highly predicted HC words are easier to be integrated.

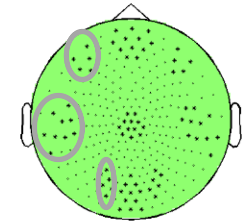
TFRs_high: all data



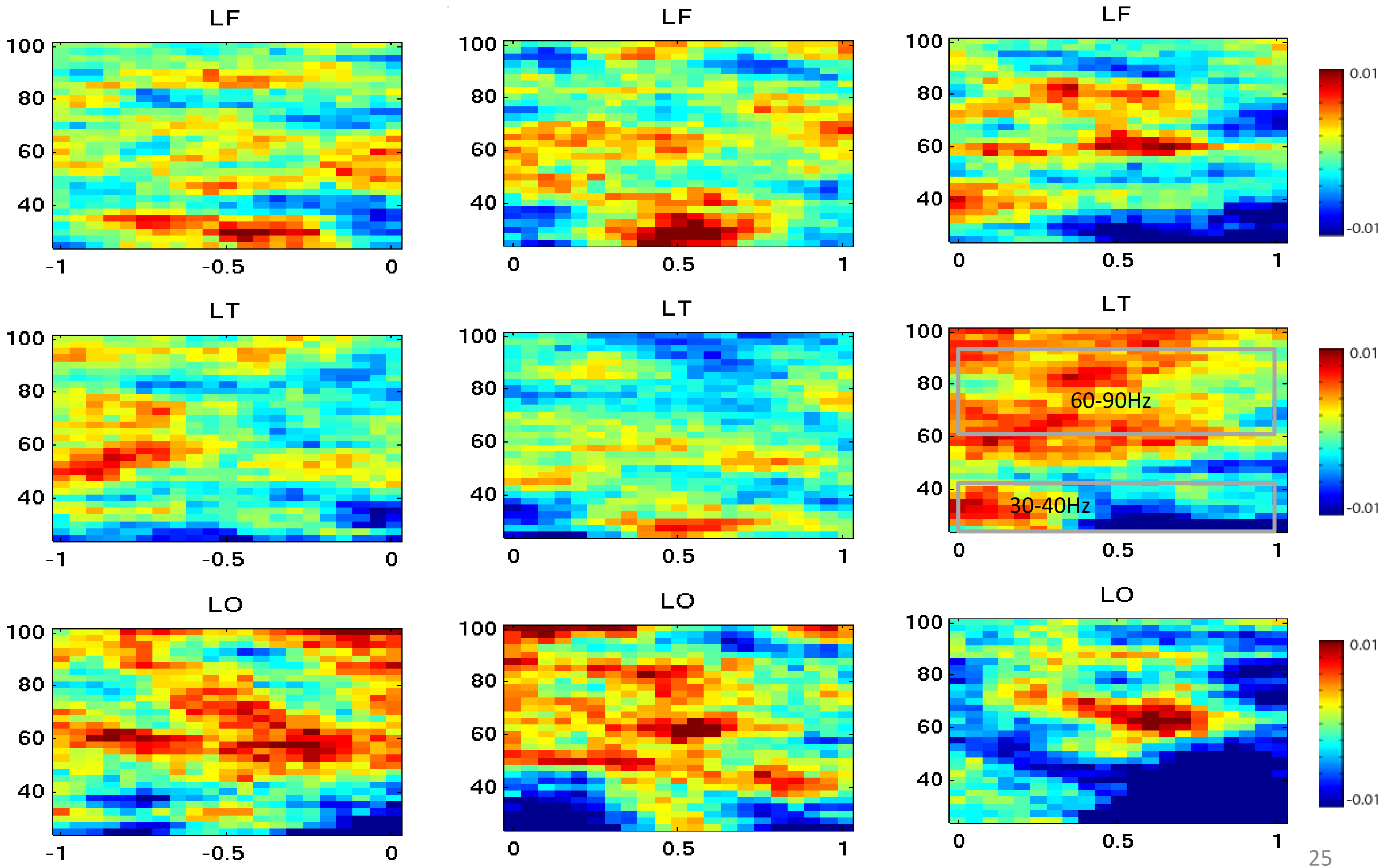
Strong induced gamma power.

Baseline correction:
-0.75 - -0.25s

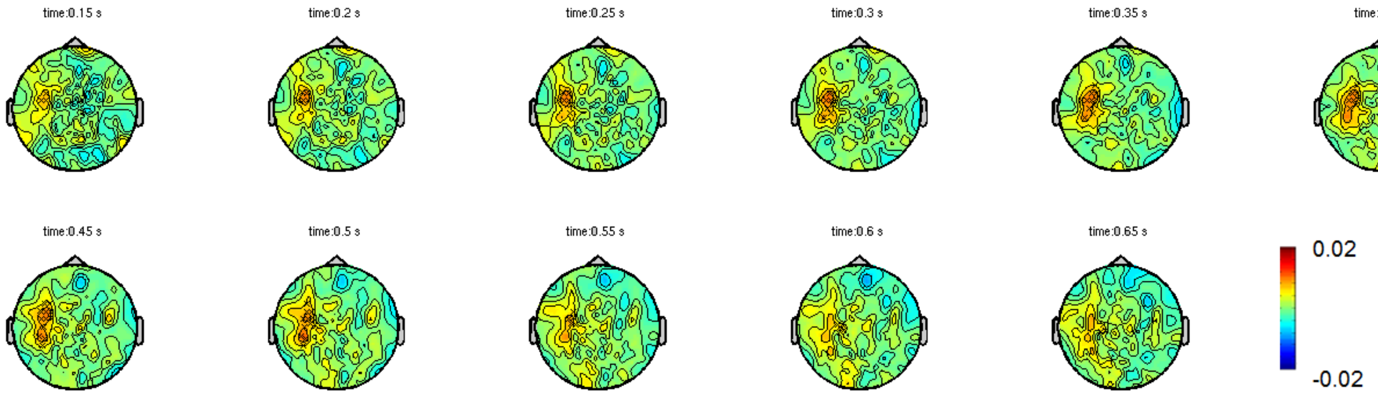
TFRs_high: contrasts



pre-CW (-1 – 0s); HC-LC | CW (0 – 1s); HC-LC | CW (0 – 1s); IC-C



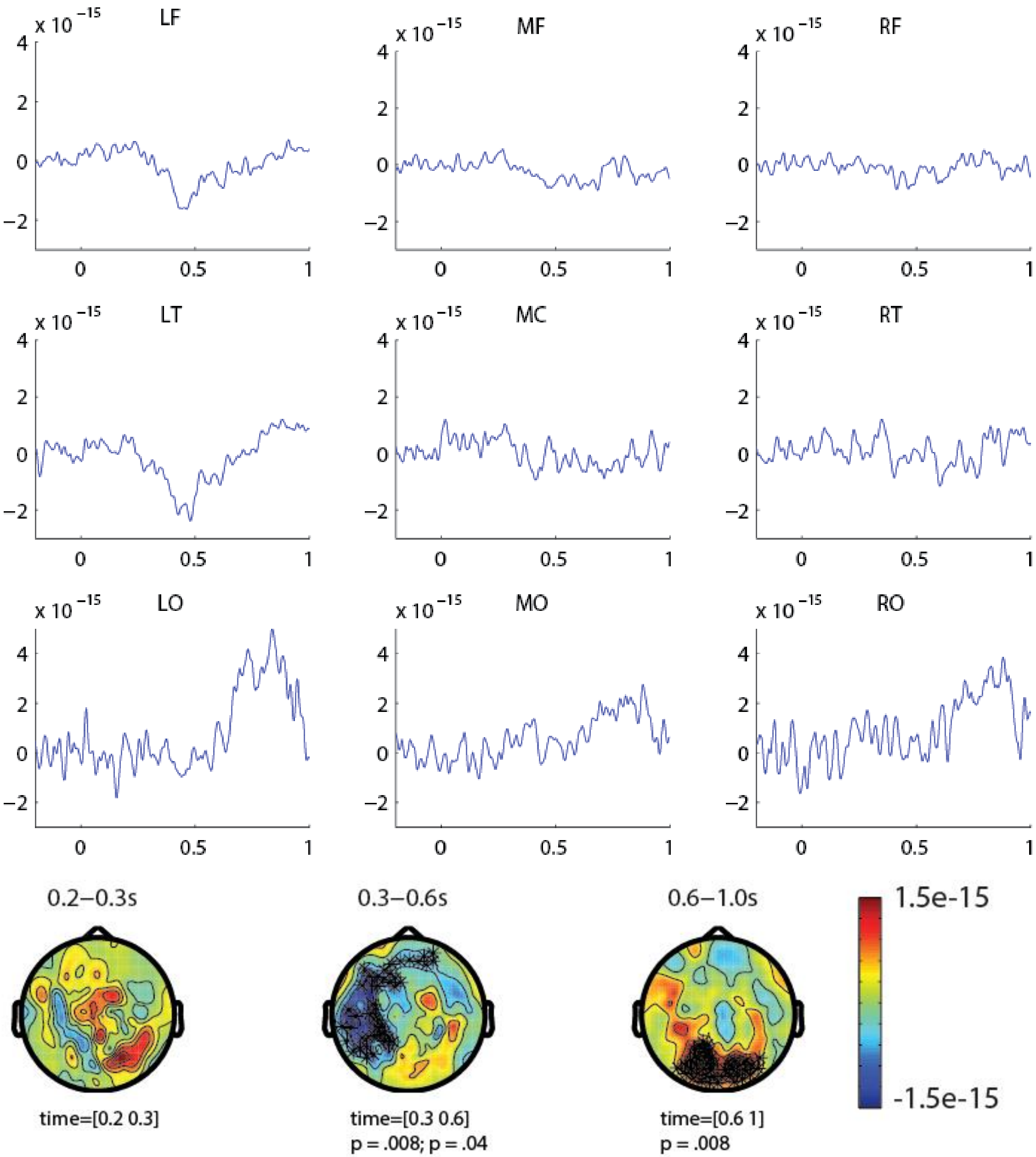
TFRs_high: CW (60-90Hz); IC-C



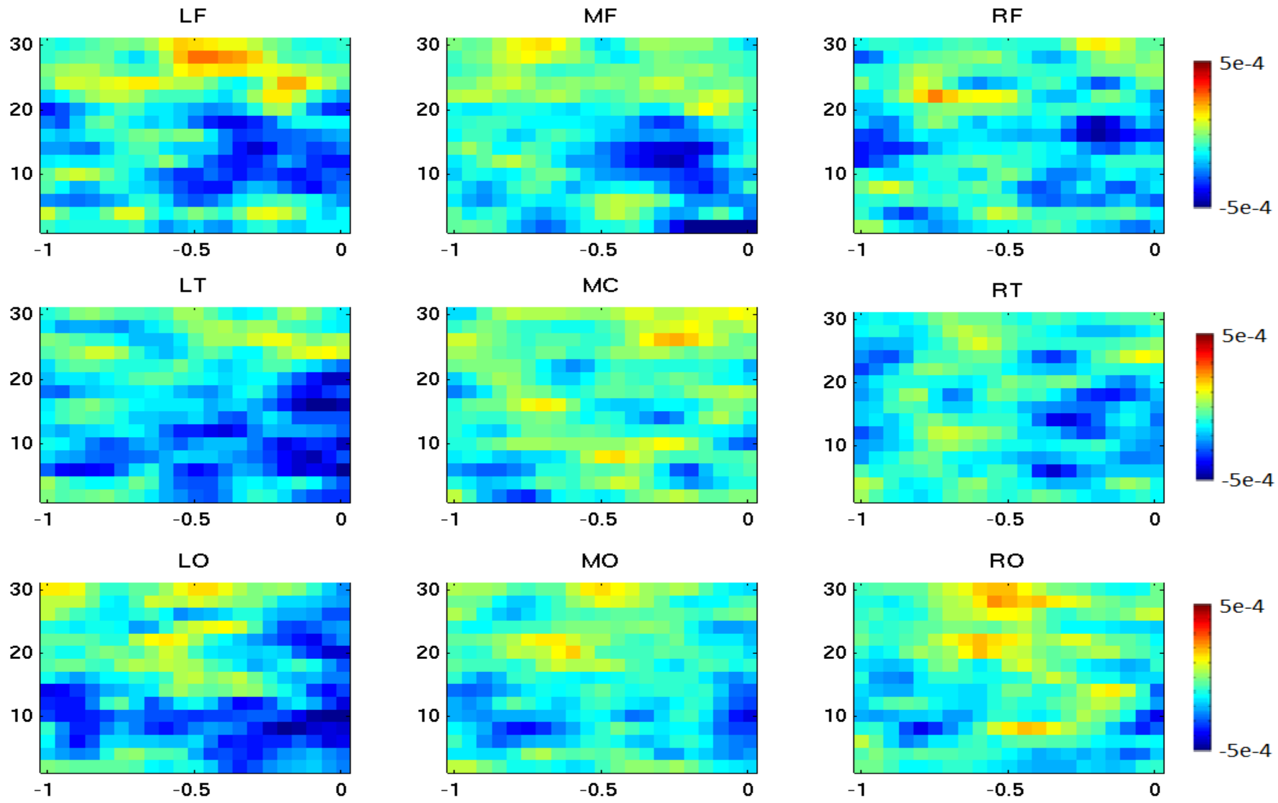
p = .023 (0.15 – 0.65s)

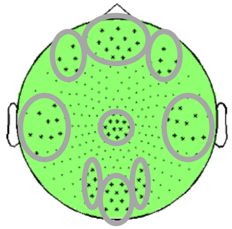
HC (IC-C) vs. LC (IC-C): p = .8791 (no interaction)

Regression beta values: CW (0 – 1s); ERF vs. PL rating

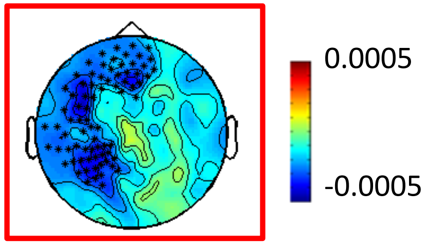


Regression beta values: pre-CW (-1 – 0s); TFR vs. semantic constraint rating



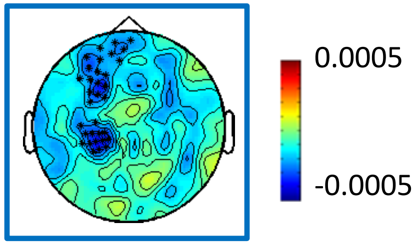


-0.55 – -0.25s, 8-12Hz



p = .002

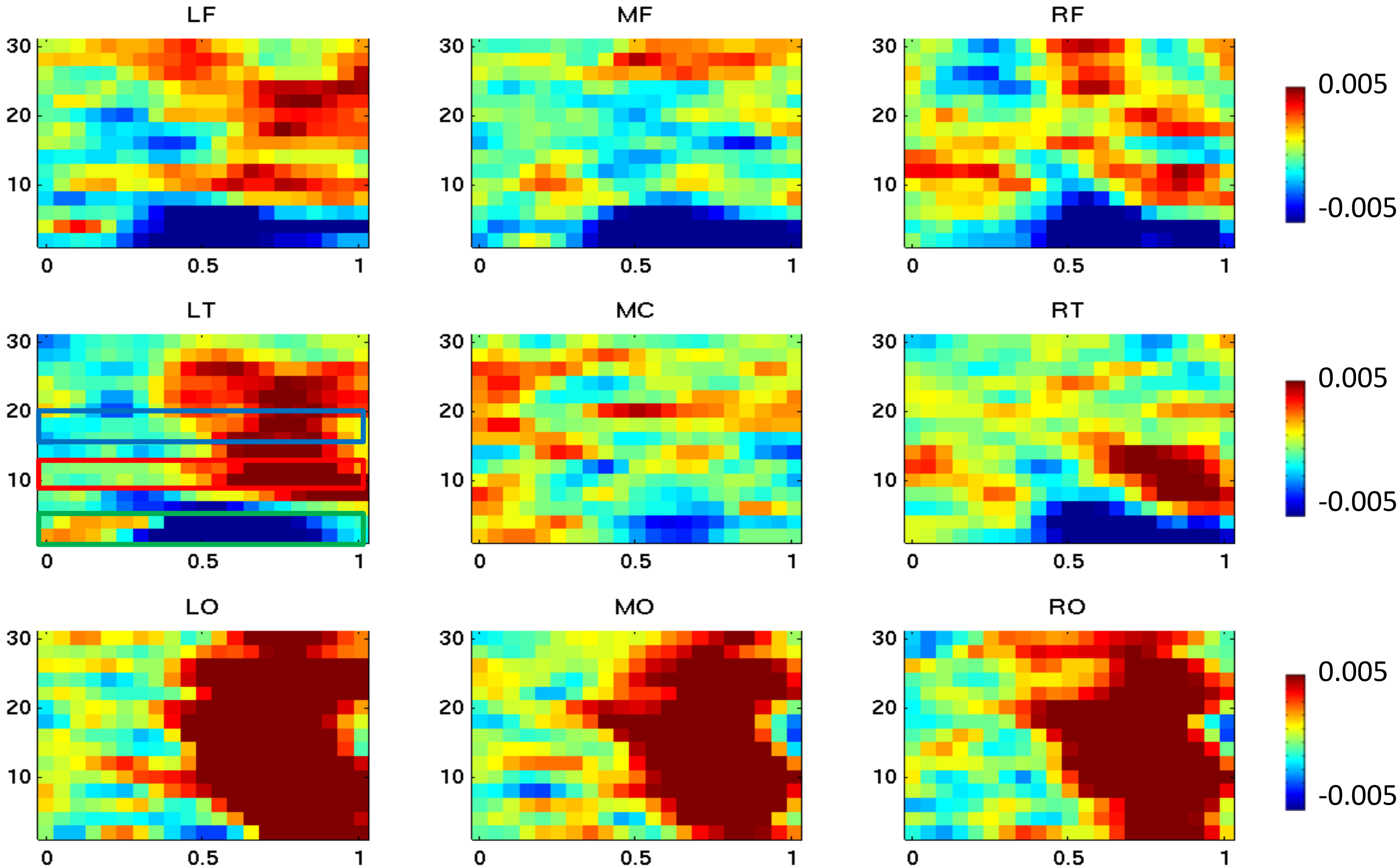
-0.55 – -0.25s, 16-20Hz

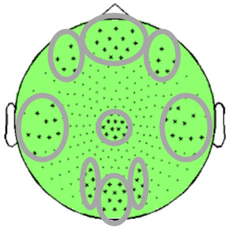


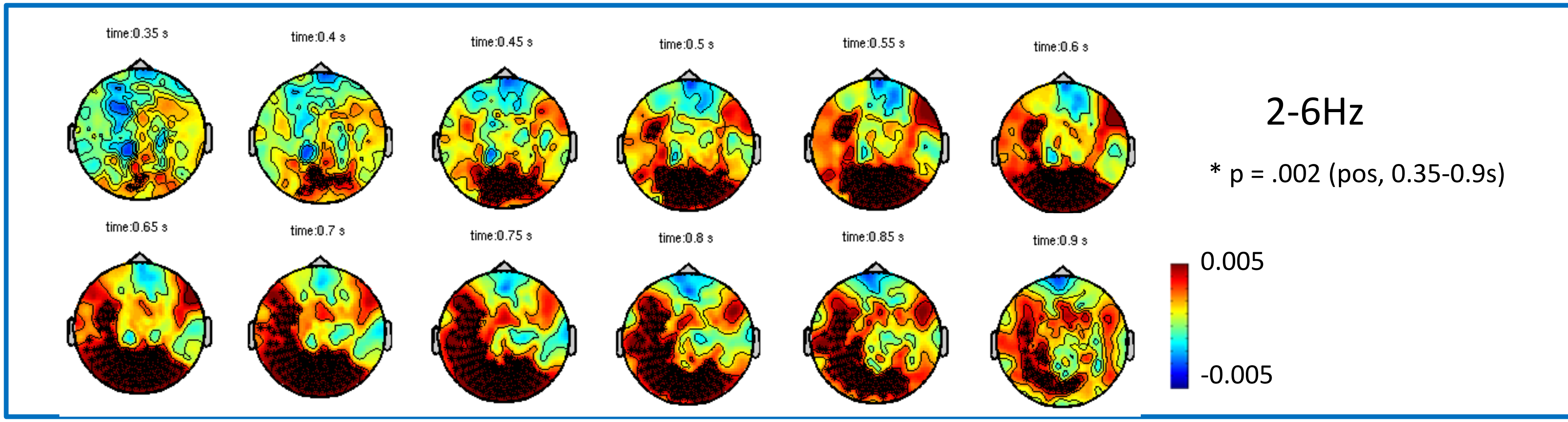
p = .024; p = .003

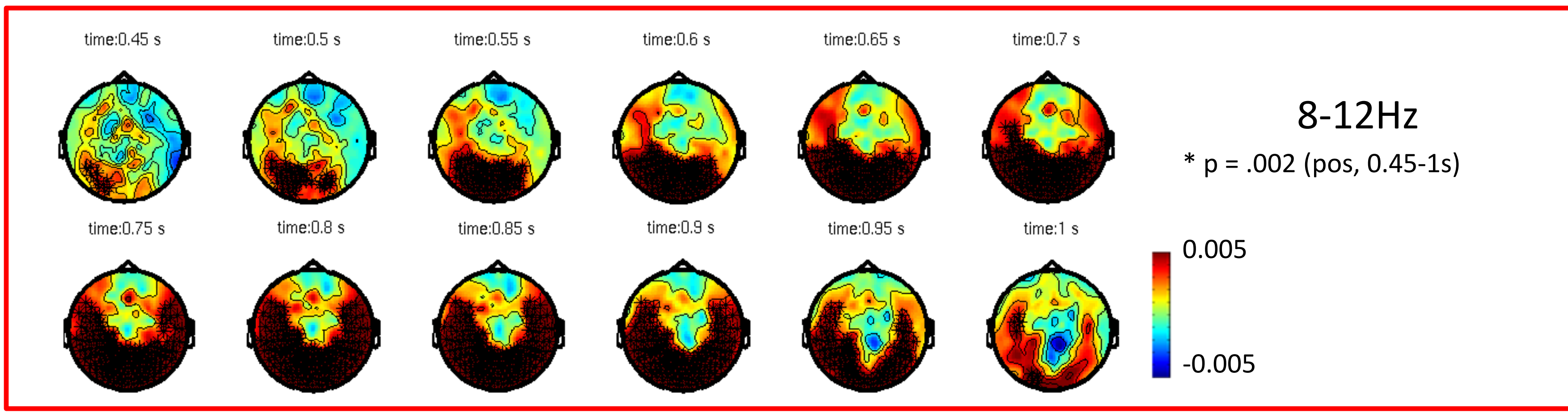
The regression results are consistent with the results of the HC-LC contrast.

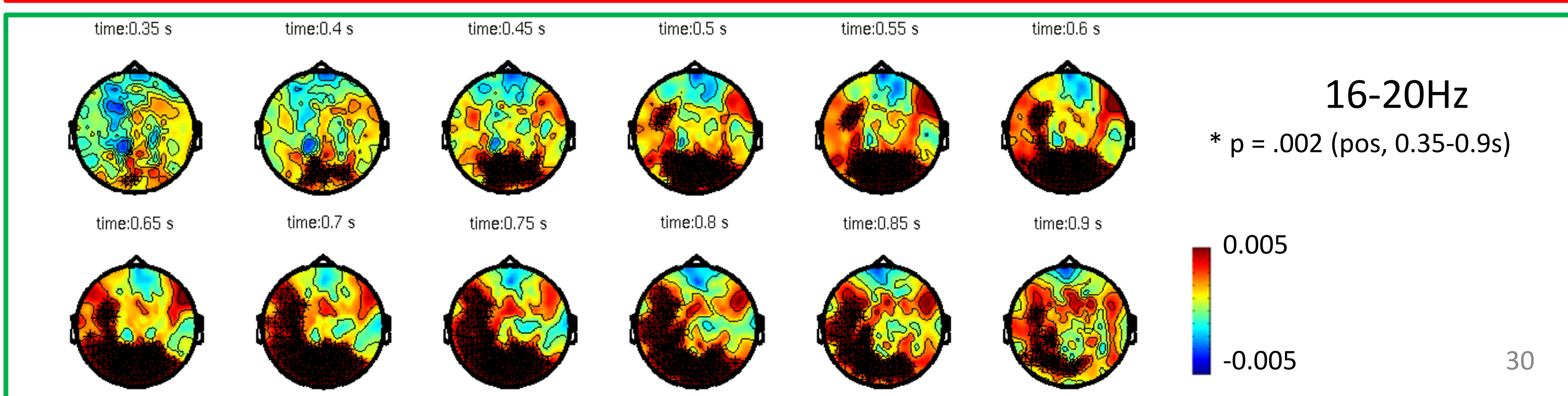
Regression beta values: CW (0 – 1s); TFR vs. PL rating



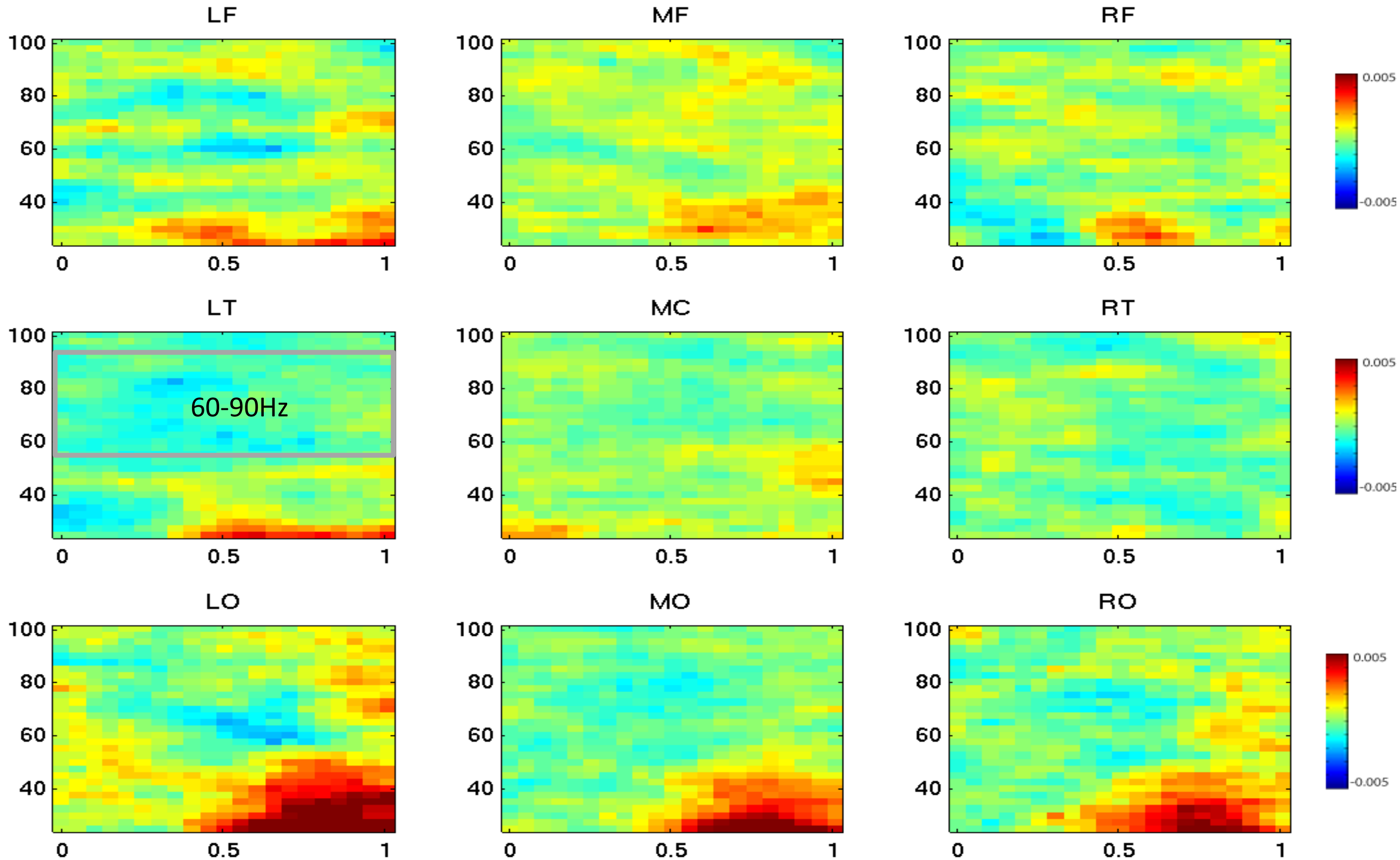



time:0.35 s
time:0.4 s
time:0.45 s
time:0.5 s
time:0.55 s
time:0.6 s
time:0.65 s
time:0.7 s
time:0.75 s
time:0.8 s
time:0.85 s
time:0.9 s
2-6Hz
* p = .002 (pos, 0.35-0.9s)
0.005
-0.005


time:0.45 s
time:0.5 s
time:0.55 s
time:0.6 s
time:0.65 s
time:0.7 s
time:0.75 s
time:0.8 s
time:0.85 s
time:0.9 s
time:0.95 s
time:1 s
8-12Hz
* p = .002 (pos, 0.45-1s)
0.005
-0.005

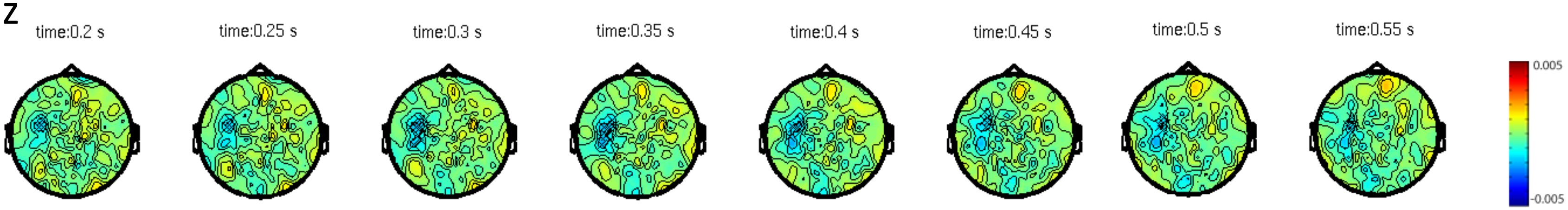

time:0.35 s
time:0.4 s
time:0.45 s
time:0.5 s
time:0.55 s
time:0.6 s
time:0.65 s
time:0.7 s
time:0.75 s
time:0.8 s
time:0.85 s
time:0.9 s
16-20Hz
* p = .002 (pos, 0.35-0.9s)
0.005
-0.005

Regression beta values: CW (0 – 1s); TFR vs. PL rating



60-90Hz

x p = .07



60-90Hz: Prediction error

Summary

1. Both **alpha and beta** power suppressions relate to the **prediction/engagement of task relevant regions**.
2. Both **semantic and sensory regions** are pre-activated during language prediction.
3. **Visual cortex** was engaged for processing unexpected stimuli even when no stimuli was presented.

To do

1. Phase resetting of alpha/beta and gamma oscillations
2. Alpha phase synchronization between LIFG and MTG regions
3. Cross frequency coupling (alpha-gamma)
4. Correlations between pre-CW and post-CW effects