ICON Symposium 07

Understanding high-level vision, attention and decision making by means of frequency-tagging EEG

1. **Bruno Rossion** (University of Louvain, Belgium)

2. **Jason Mattingley** (The University of Queensland, Australia)

3. **Bruno van Swinderen** (Queensland Brain Institute, Australia)

4. **Redmond O'Connell** (Trinity College Dublin, Ireland)

If you stimulate the brain periodically
(= at a fixed rate), you get:

- *a periodic response*
- *exactly at the frequency of stimulation*

Visual stimulation:

Van der Tweel, LH & Verduyn Lunel, HFE (1965). Human visual responses to sinusoidally modulated light. *Electroen. Clin. Neuro.*, 18, 587–98.

Regan, D. (1966). Some characteristics of average steady-state and transient responses evoked by modulated light. *Electroen. Clin. Neuro.*, 20, 238–248.

SOME CHARACTERISTICS OF AVERAGE STEADY-STATE AND TRANSIENT RESPONSES EVOKED BY MODULATED LIGHT

D. REGAN

Physics Department, Northern Polytechnic, London, N. 7. (Great Britain)

(Accepted for publication: August 19, 1965)

Evoked potentials are routinely extracted from large backgrounds of noise and intrinsic brain activity by utilizing the relative constancy of their time relationship with the stimuli which produce them. The masking effect of activity unrelated to the stimulus can be reduced by summation of many responses (Dawson 1954). When occipital evoked potentials are extracted, however, it is found that the relationship between stimulus and response is somewhat variable both for response amplitude and wave form, even for stimuli which produce a relatively

sity, and an analogue computer was designed to extract and measure any evoked component which maintained at every instant a constant phase relation with the stimulus train. The mean physiological intensity was held constant by maintaining a constant light flux, using an artificial pupil smaller than the eye pupil, and stabilizing the stimulated retinal area and point of entry of the light beam into the eye by good voluntary fixation. This type of stimulus was chosen for the following reasons. Firstly, it contained the repetition frequency f c/sec, with

(Some) advantages of *periodic* visual stimulation in EEG

- Objective identification of the brain response of interest

- Very high signal-to-noise ratio (SNR)

- Implicit measure of a process of interest

-Straightfoward quantification of the brain response of interest

+ EEG frequency-tagging

J. Neurol. Neurosurg. Psychiat., 1969, **32**, 479-483

Clinical investigation of lesions of the visual pathway : a new objective technique

D. REGAN AND J. R. HERON

From the Department of Communication, University of Keele, and the Department of Neurology, North Staffordshire Royal Infirmary

Regan & Heron, 1969:

"This is a preliminary report of a new method of investigating visual field defects which is objective, fairly rapid, non-traumatic, and makes comparatively small demands on the patient. We have developed a method which enables two areas of the retina to be stimulated simultaneously and weakly. The results of this are to minimize the effect of evoked potential variability, to minimize the effect of light scattered within the eye, and to improve patient cooperation. Our method gives results in both visual and quantitative forms, and can distinguish between different parts of the visual field by using different kinds of stimuli."

Regan & Heron, 1969:

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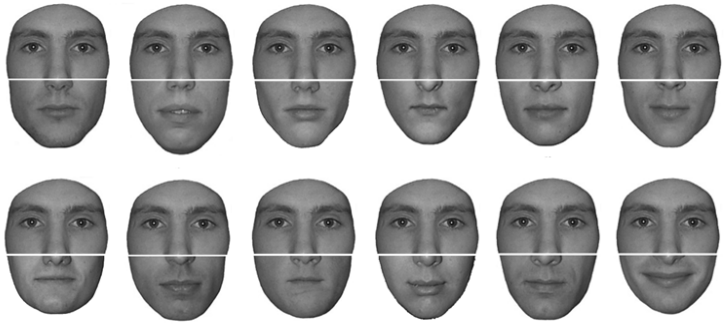
1. **Bruno Rossion** (University of Louvain, Belgium)
Objective evidence for perceptual integration by means of frequency-tagging EEG

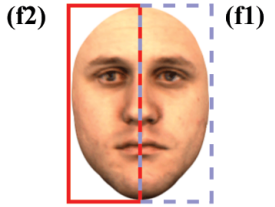
2. **Jason Mattingley** (The University of Queensland, Australia)
Using frequency tagging to measure visual perception and selective attention in health and disease

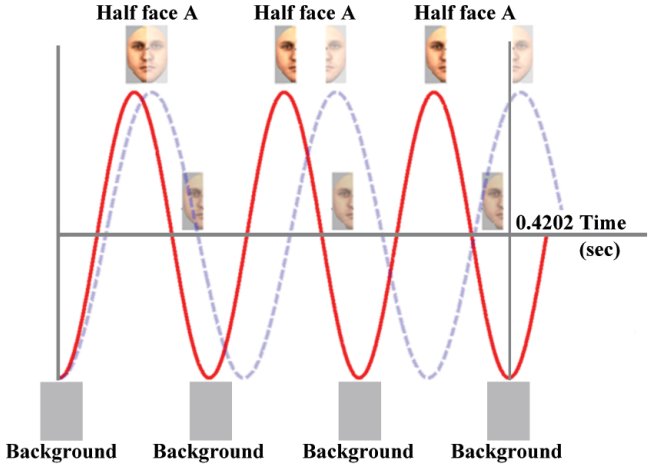
3. **Bruno van Swinderen** (Queensland Brain Institute, Australia)
Behavioural, electrophysiological, and genetic approaches to studying top-down visual attention in insects

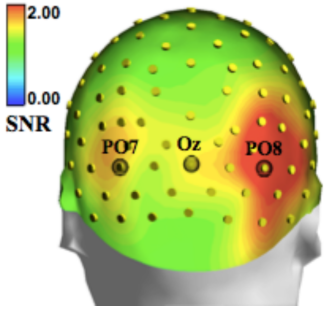
4. **Redmond O'Connell** (Trinity College Dublin, Ireland)
A window onto the basic elements of perceptual decision making in the human brain

Objective evidence for perceptual integration by means of frequency-tagging EEG





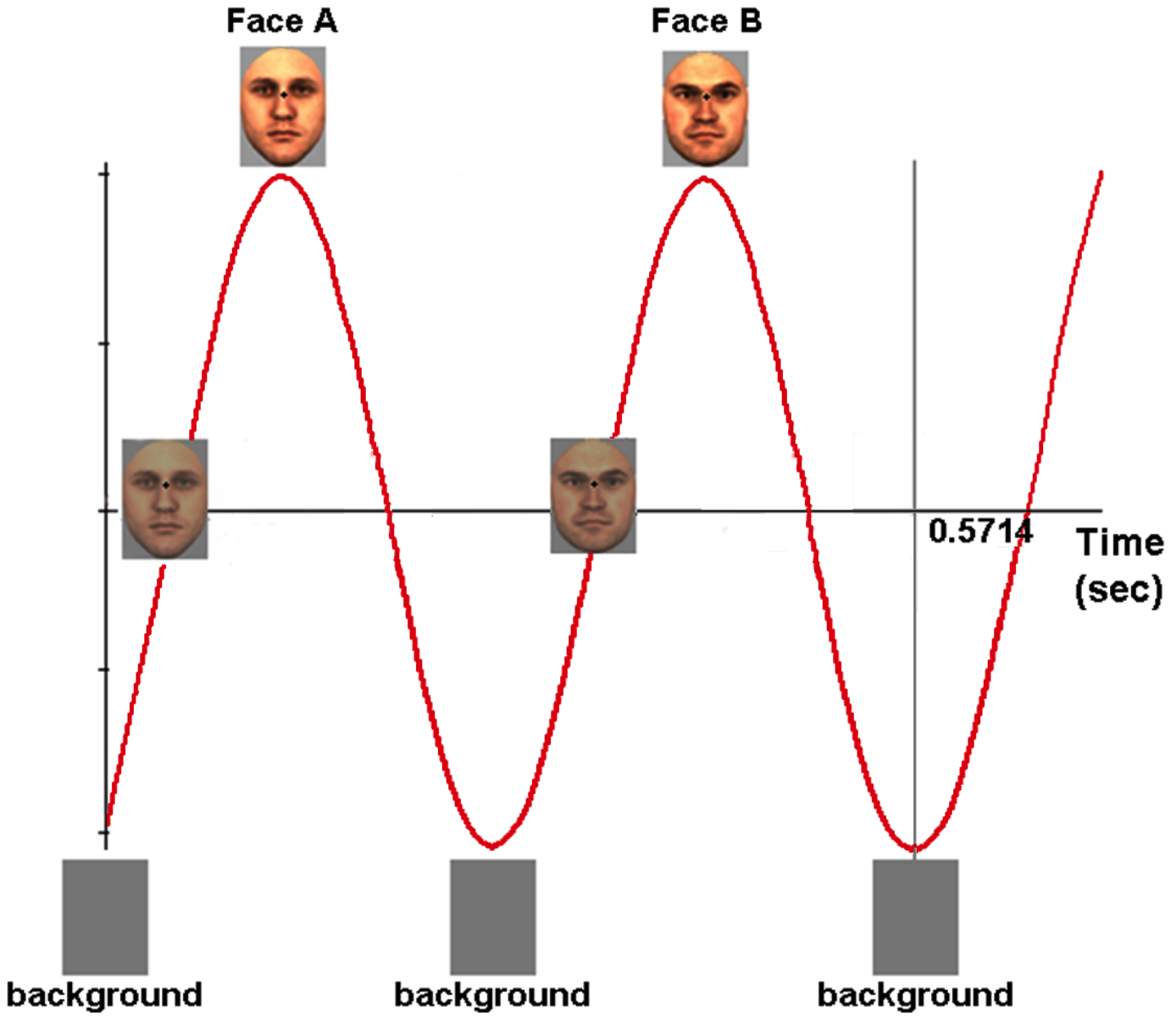




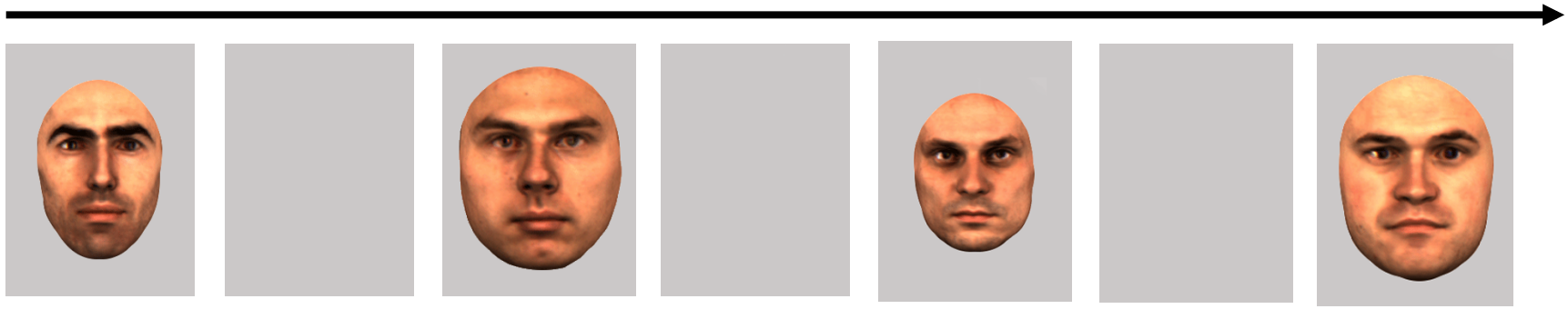
Bruno Rossion

Adriano Boremanse (University of Louvain, Belgium)
Anthony Norcia (Stanford University, USA)

3.5 Hz



Rossion & Boremanse, 2011, *JOV*



60 seconds stimulation

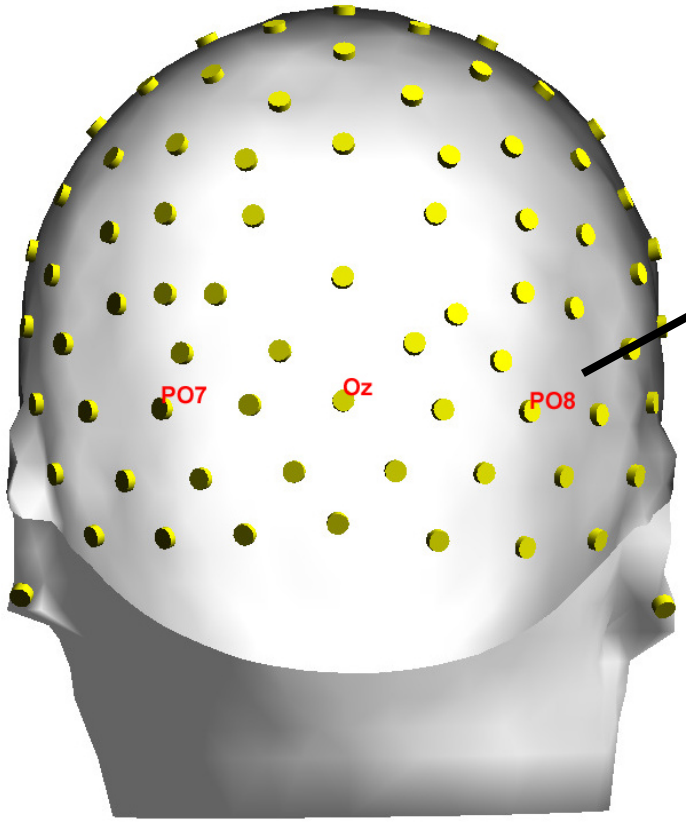
Task: detect color change (200 ms) on the fixation cross

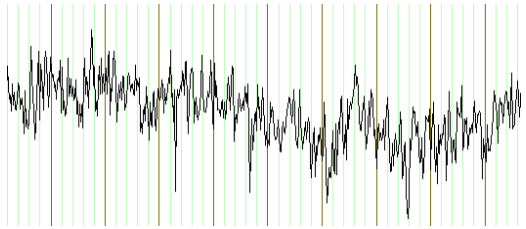
Movie of the experiment: see Rosssion & Boremanse, 2011 (J.Vision)

http://www.journalofvision.org/content/11/2/16.full.pdf

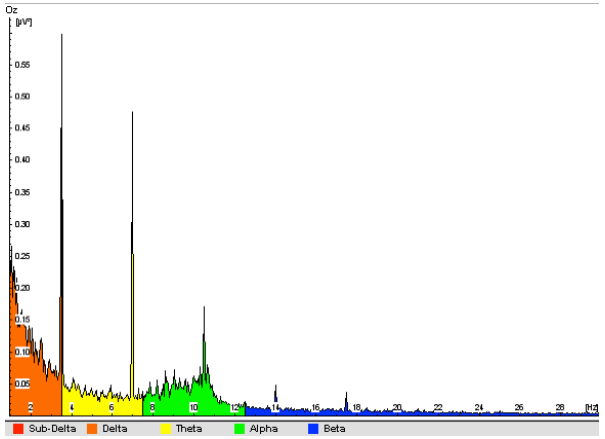
Periodic face stimulation during EEG recording (128 channels)

EEG



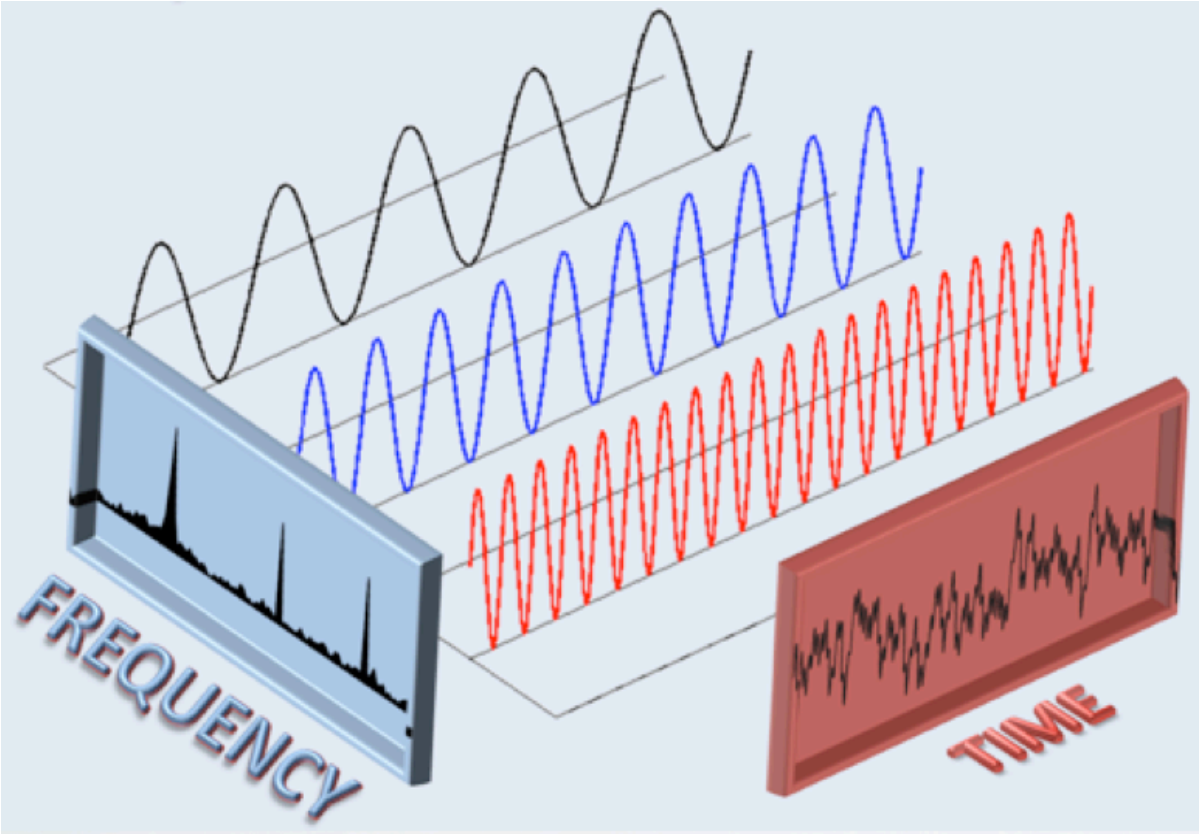


FFT



Grand averaging (12)

FFT (Fast Fourier Transform)

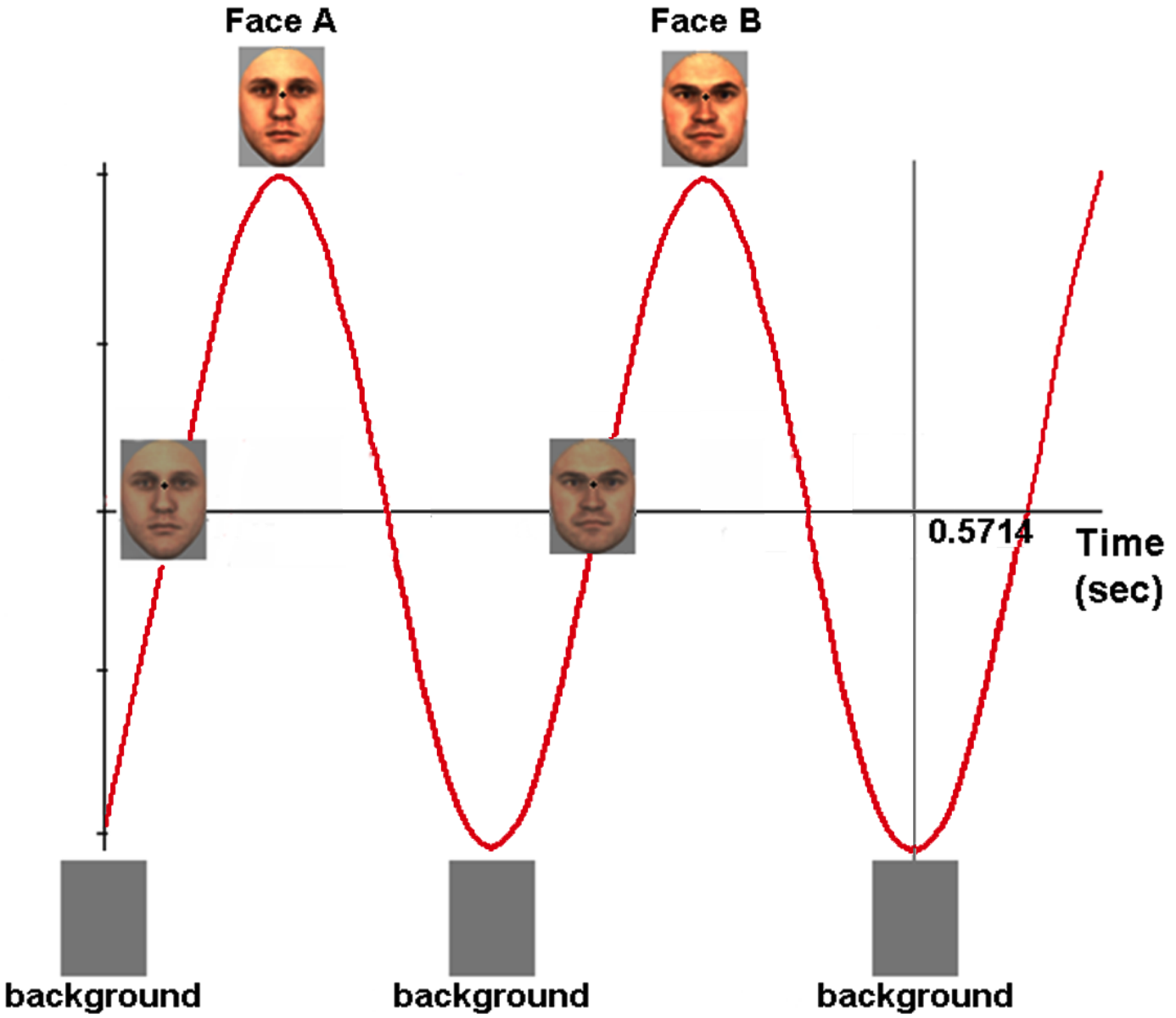


Time-domain signal

FFT

Frequency-domain signal

3.5 Hz

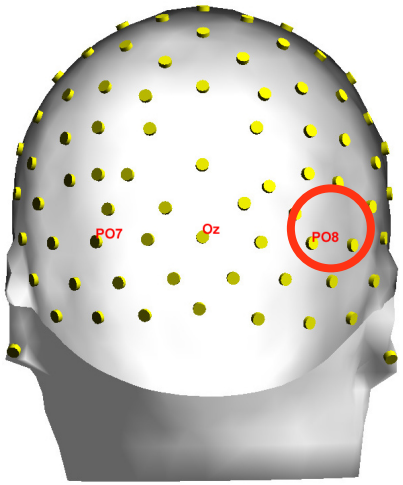


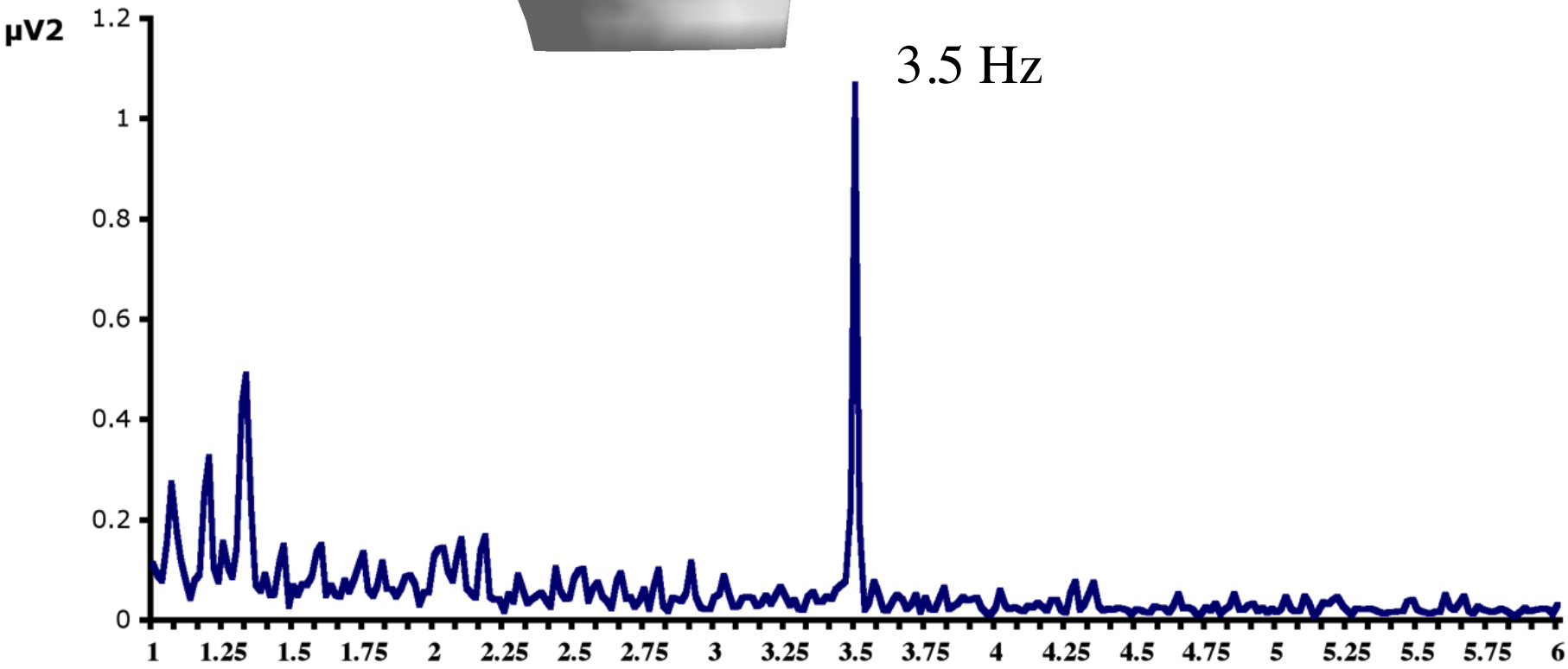
Rossion & Boremanse, 2011

Result

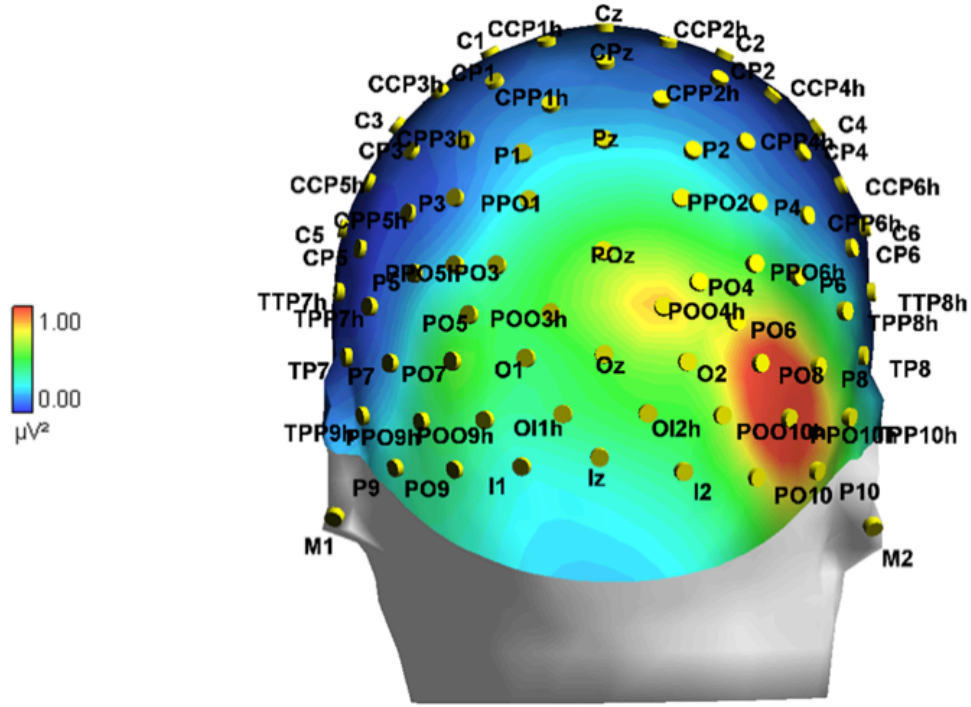
Frequency Resolution of 1/60s = 0.017 Hz

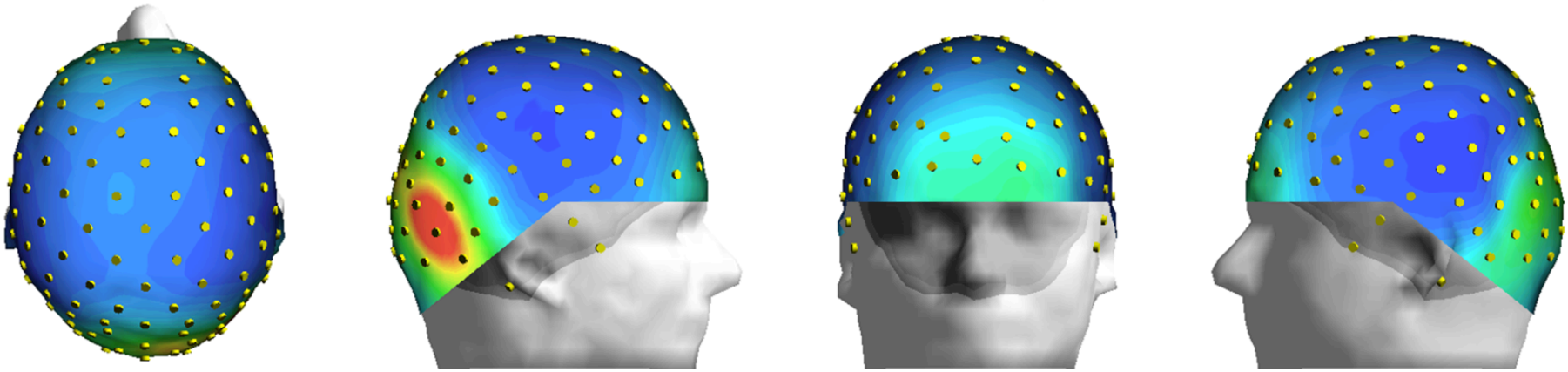
PO8





EEG Power: 1-6 Hz



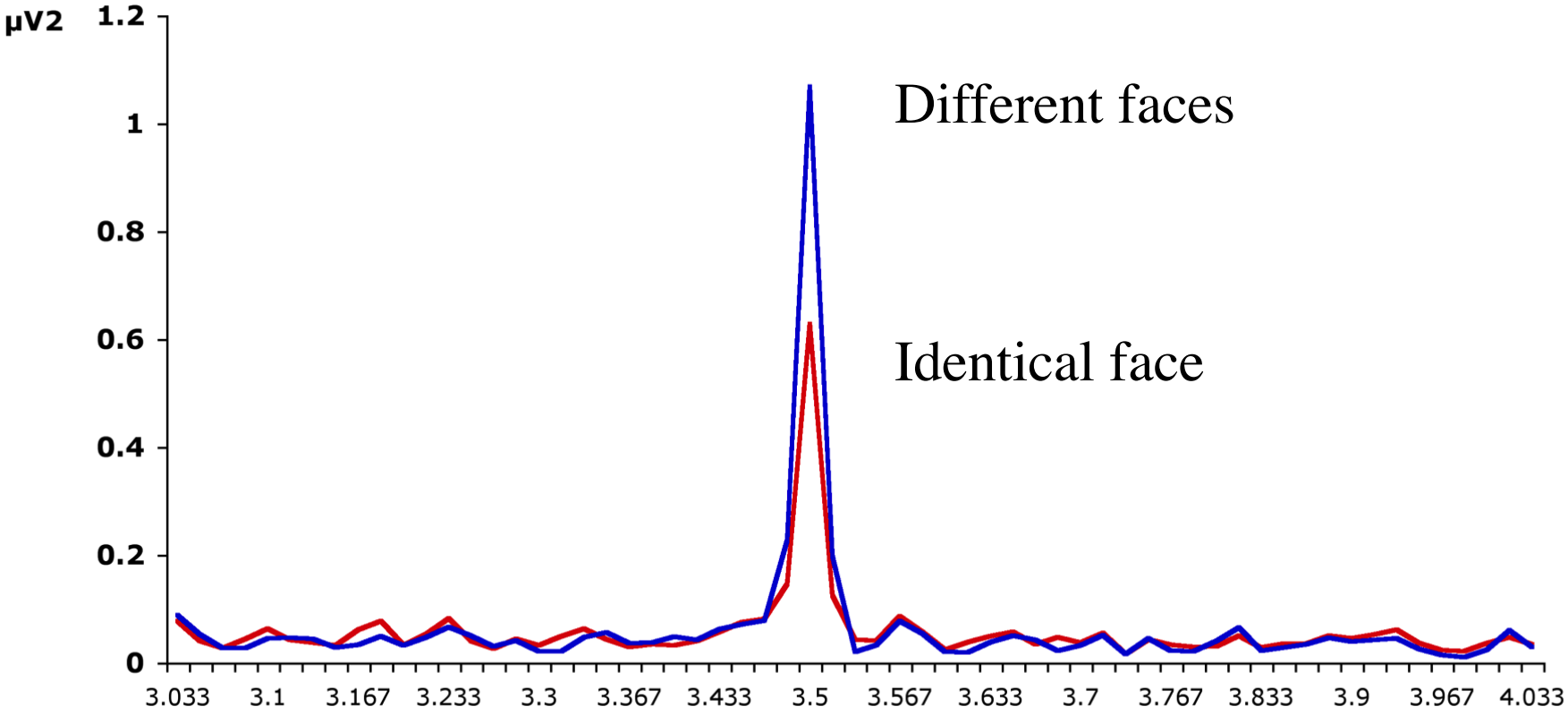


Rossion & Boremanse, 2011

2 conditions: different faces *vs*. same face

60 seconds stimulation

PO8

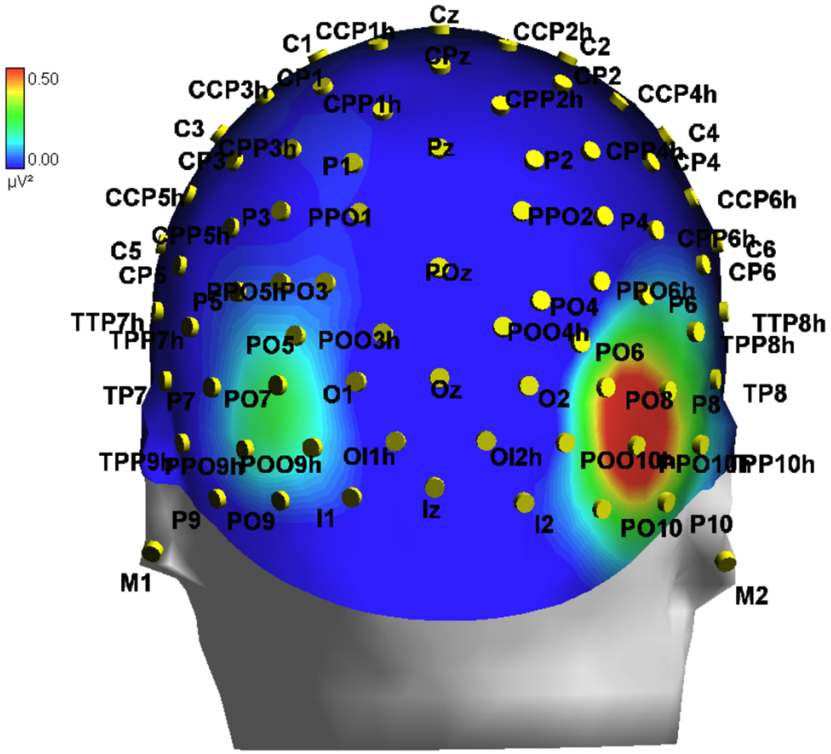


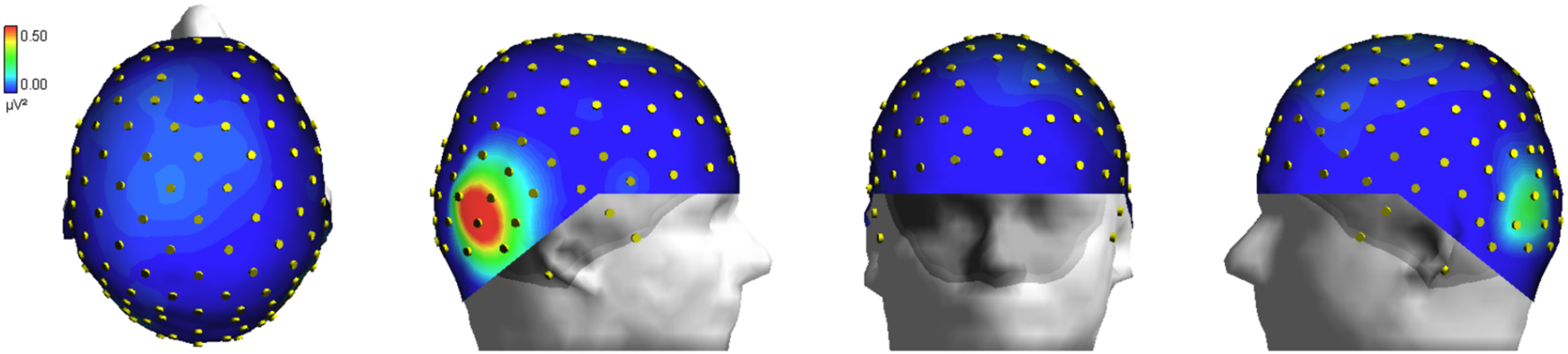
EEG Power:
3-4 Hz

Rossion & Boremanse, 2011

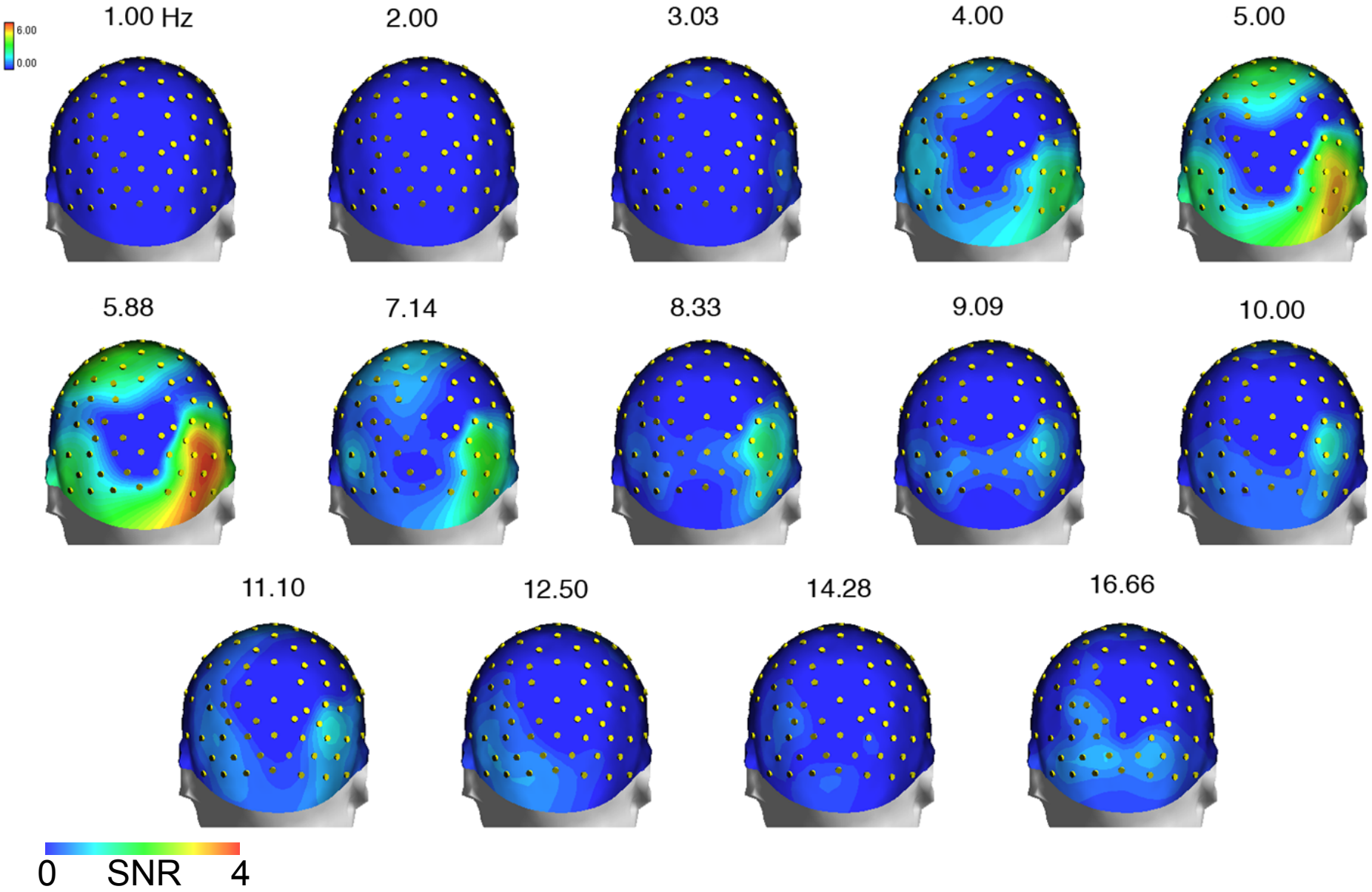
Subtraction

EEG Power (3.5 Hz)
Different - Same



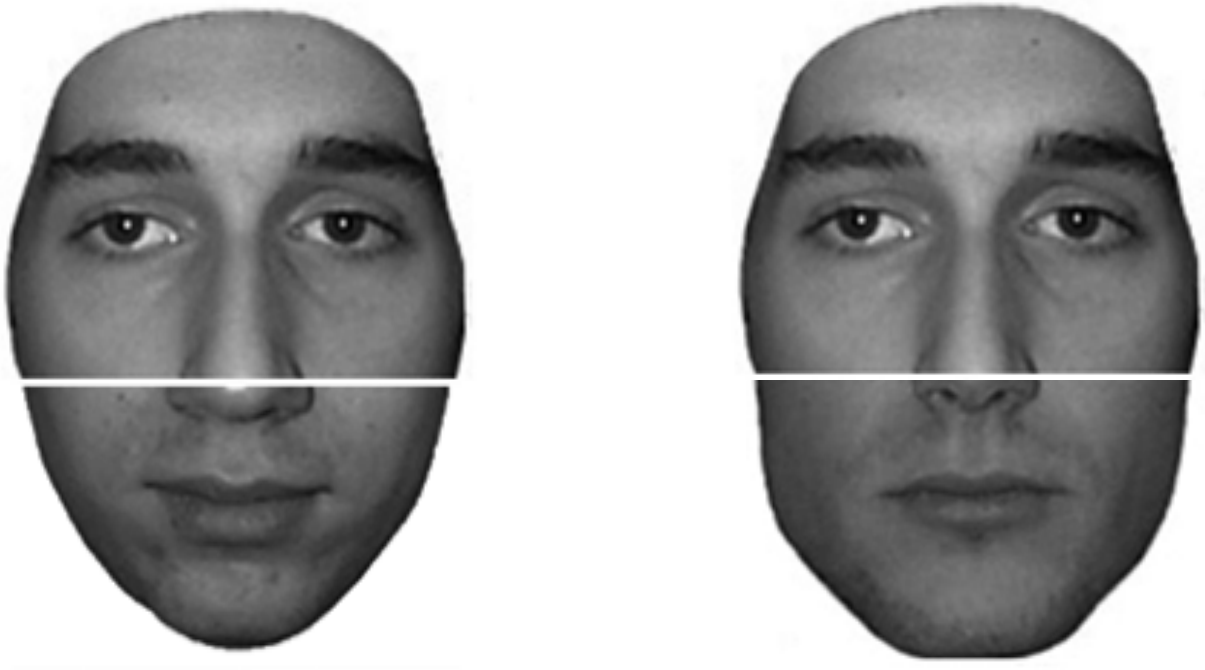


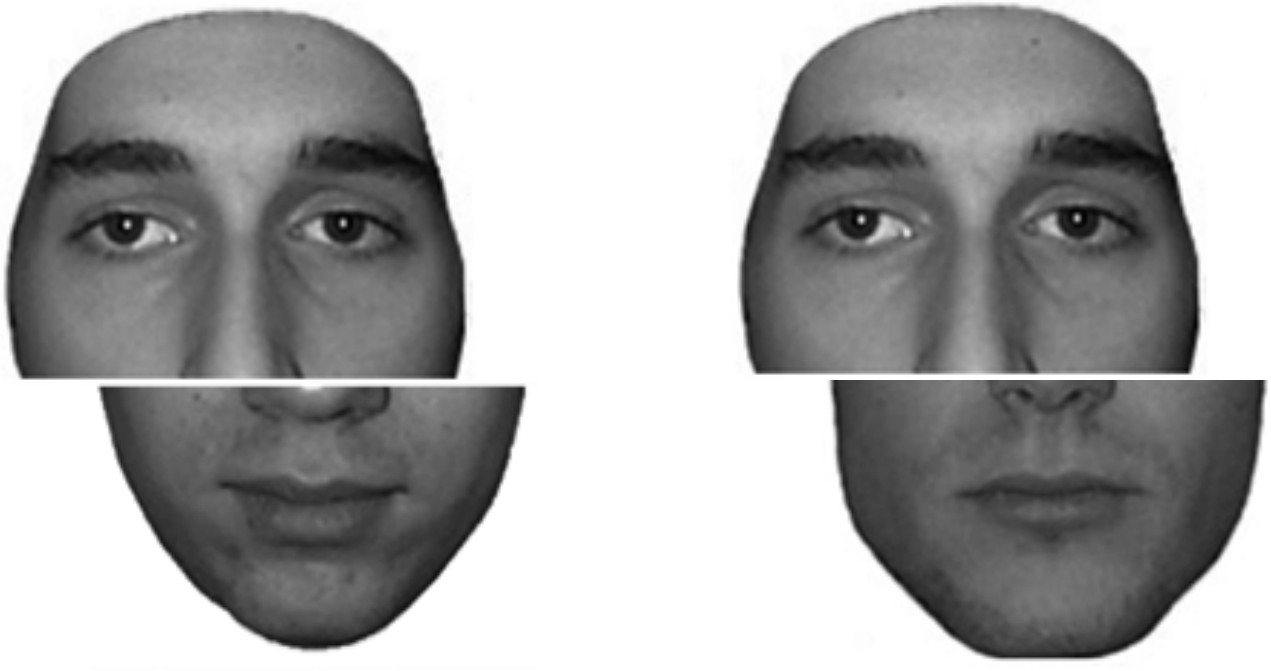
Subtraction: different - identical faces

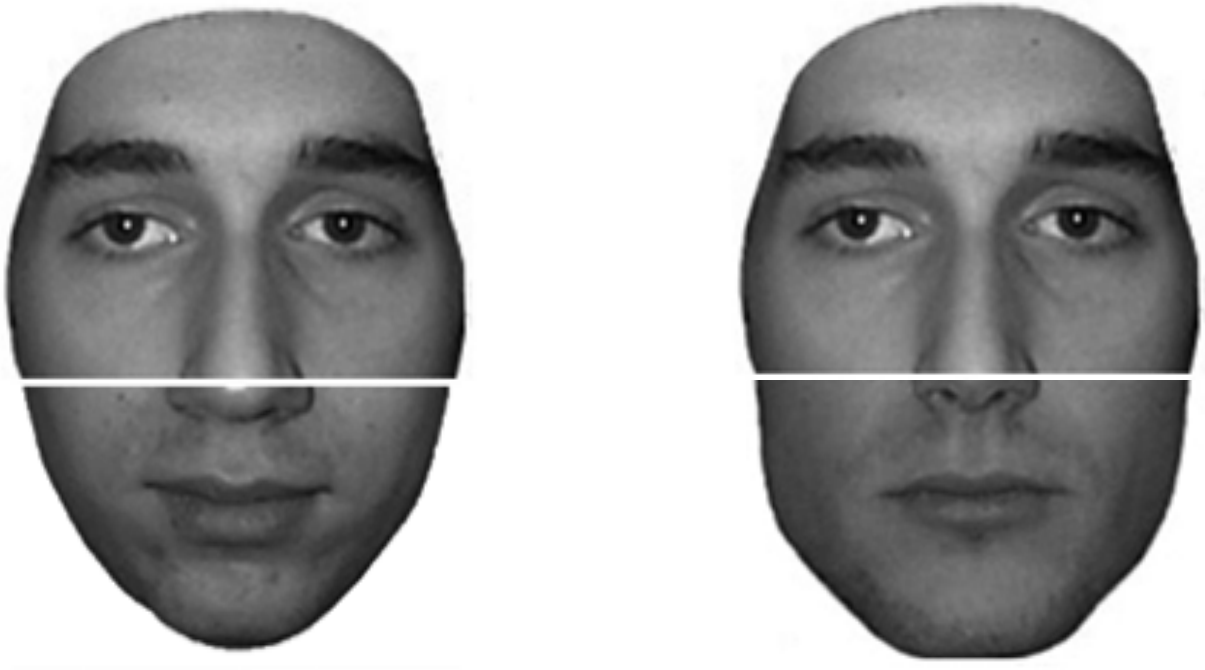


Alonso-Prieto et al., 2013

Perceptual integration?





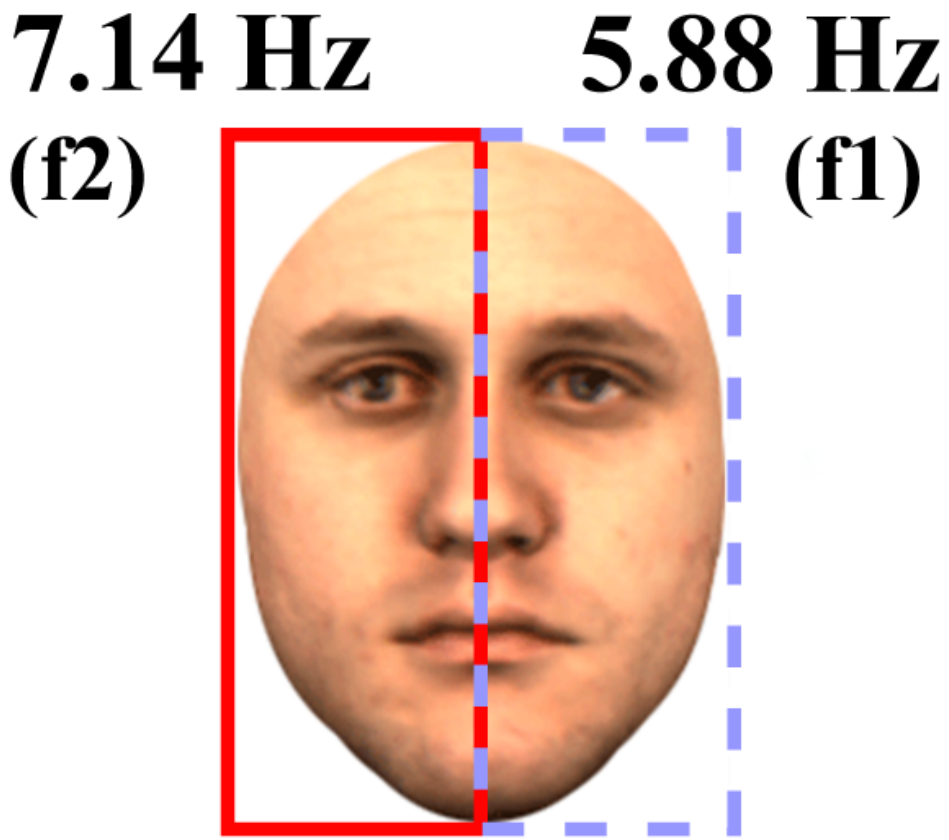


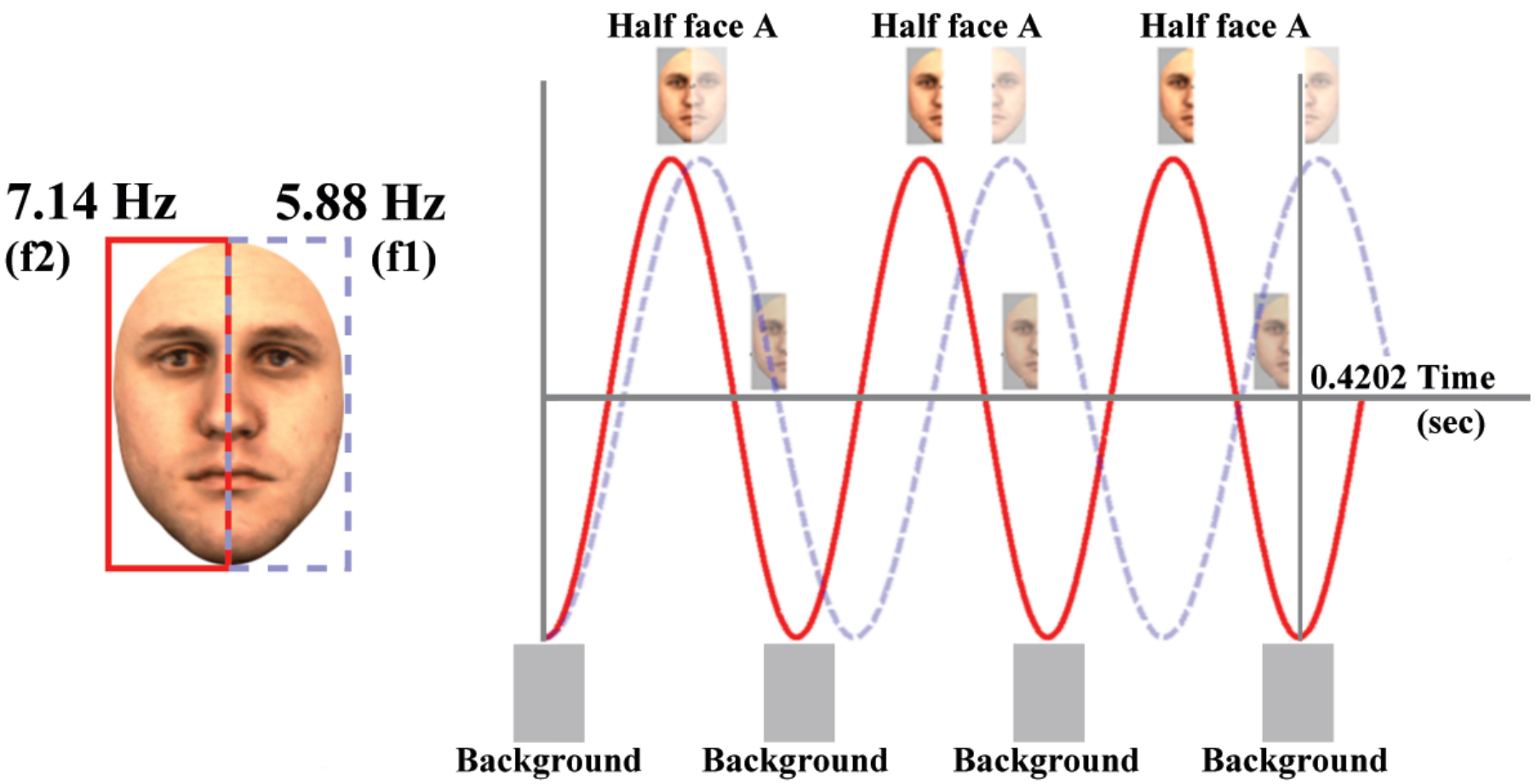
Can we find and objective signature of the integration of face parts in the human brain?

Two issues:

* Isolating the representation of each the parts

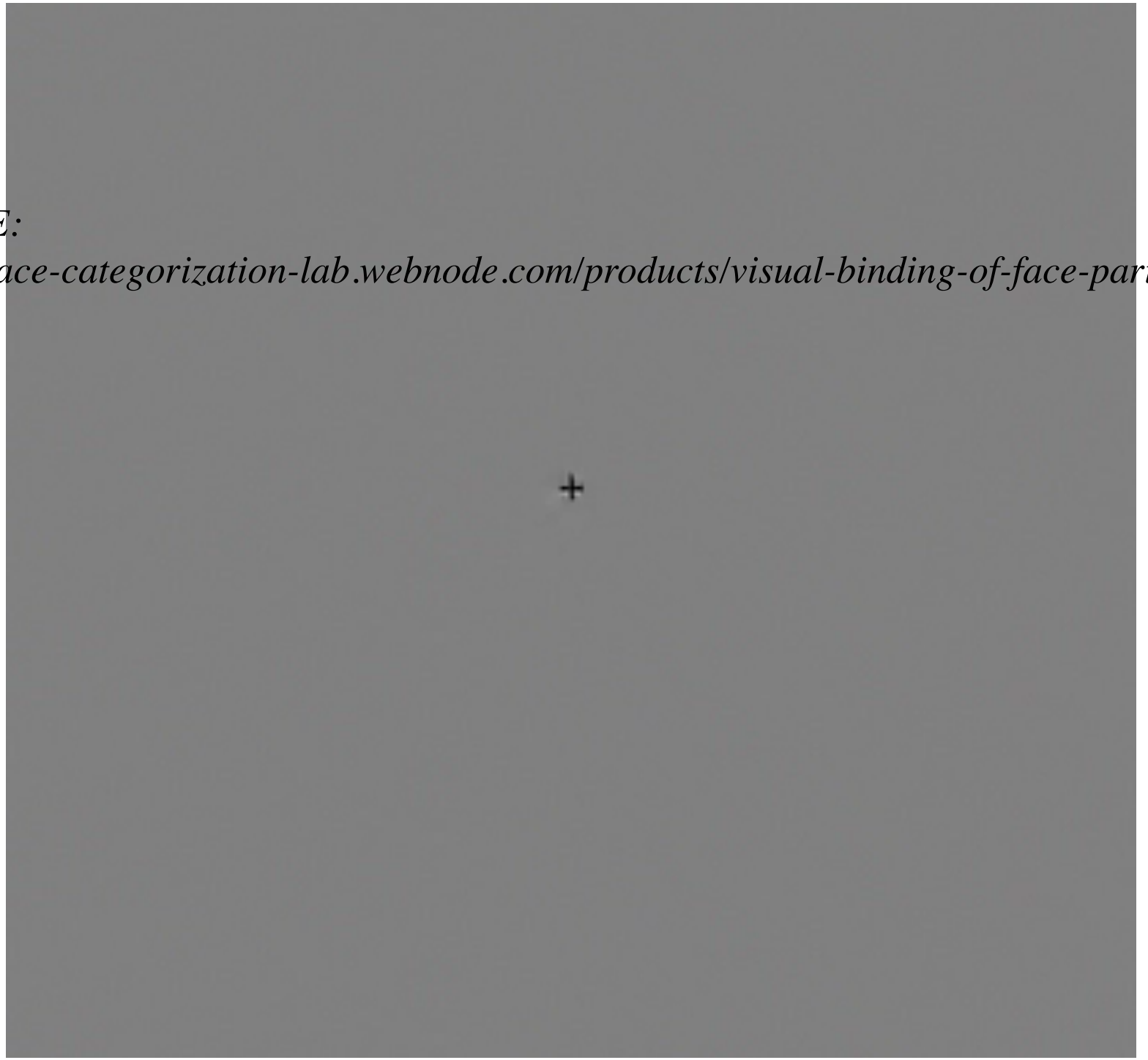
* Disentangling the representation of the parts from the whole

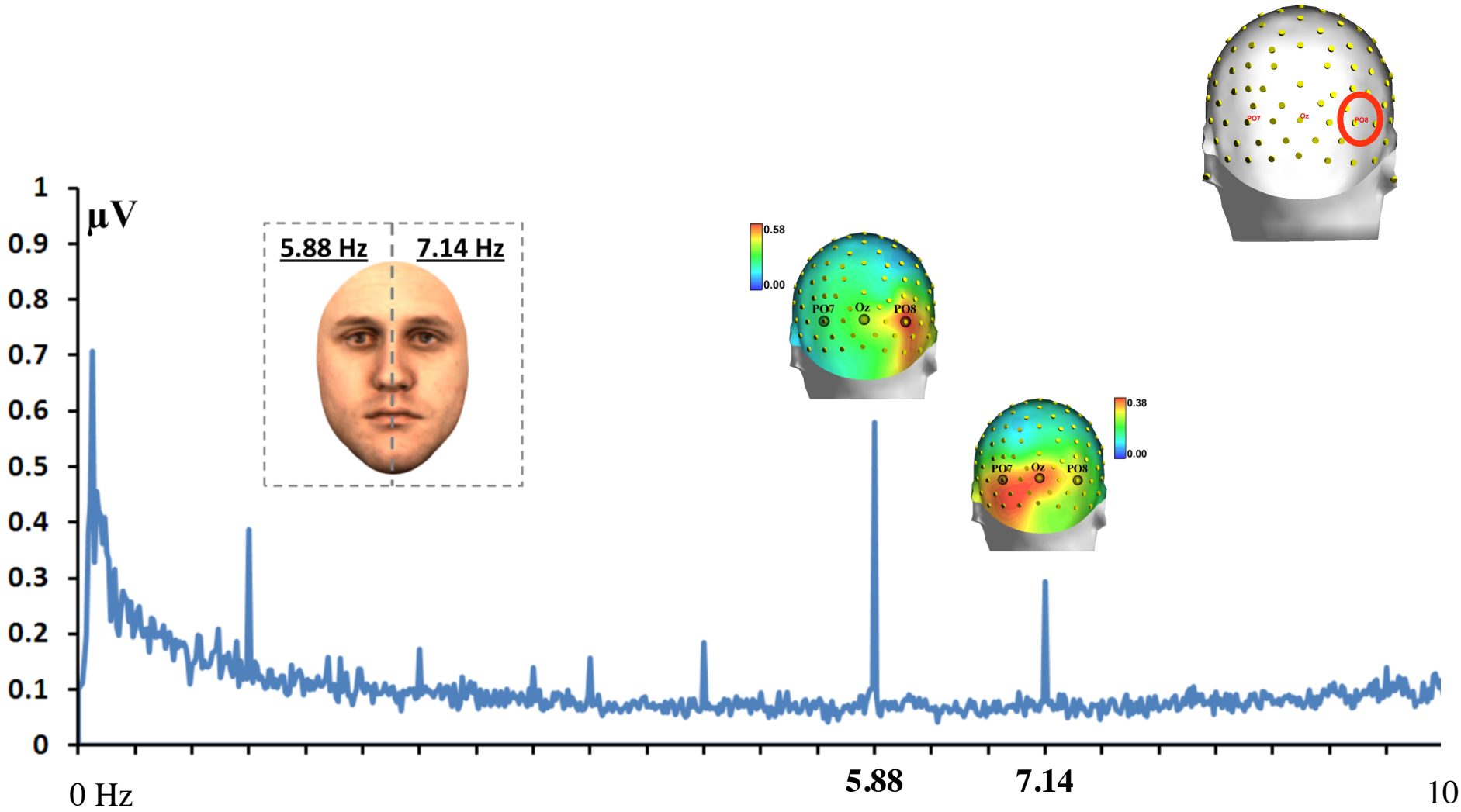

7.14 Hz
(f2)
5.88 Hz
(f1)

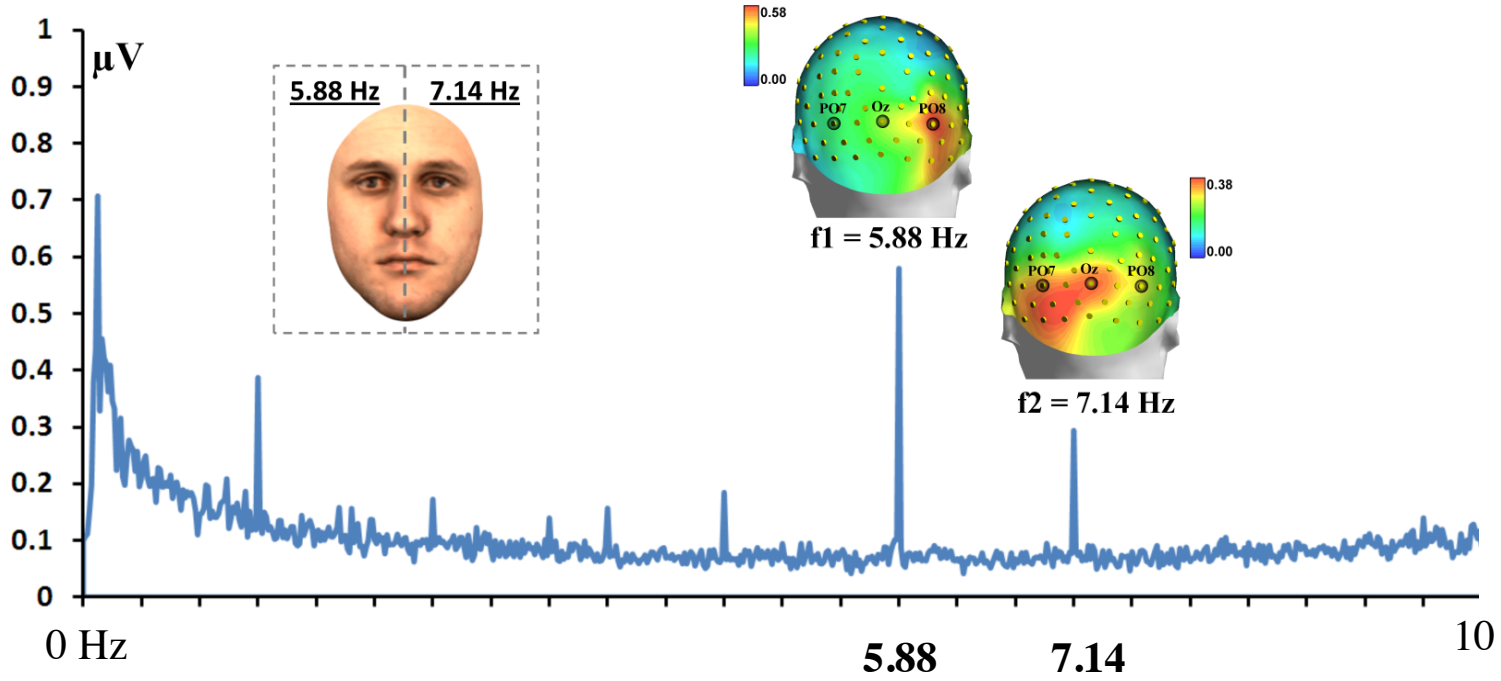


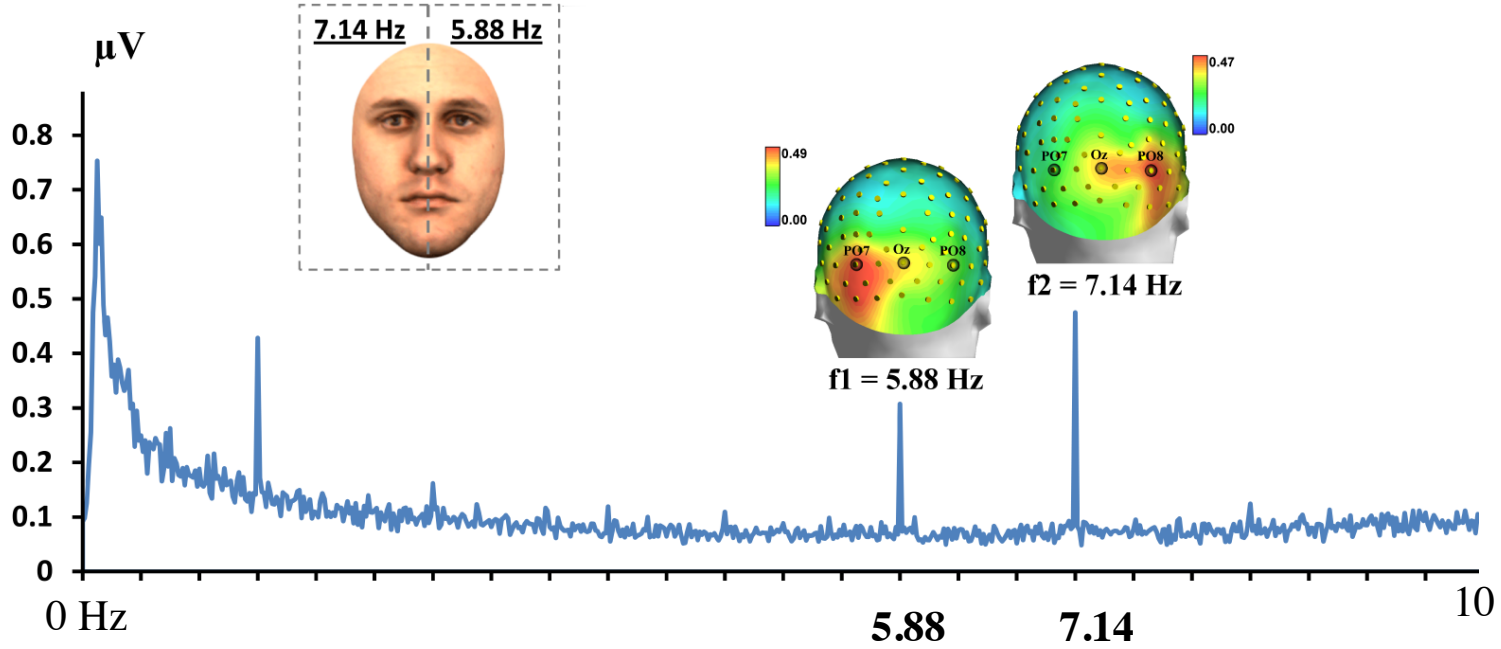
Boremanse, Norcia, Rossion, 2013

MOVIE:
http://face-categorization-lab.webnode.com/products/visual-binding-of-face-parts/

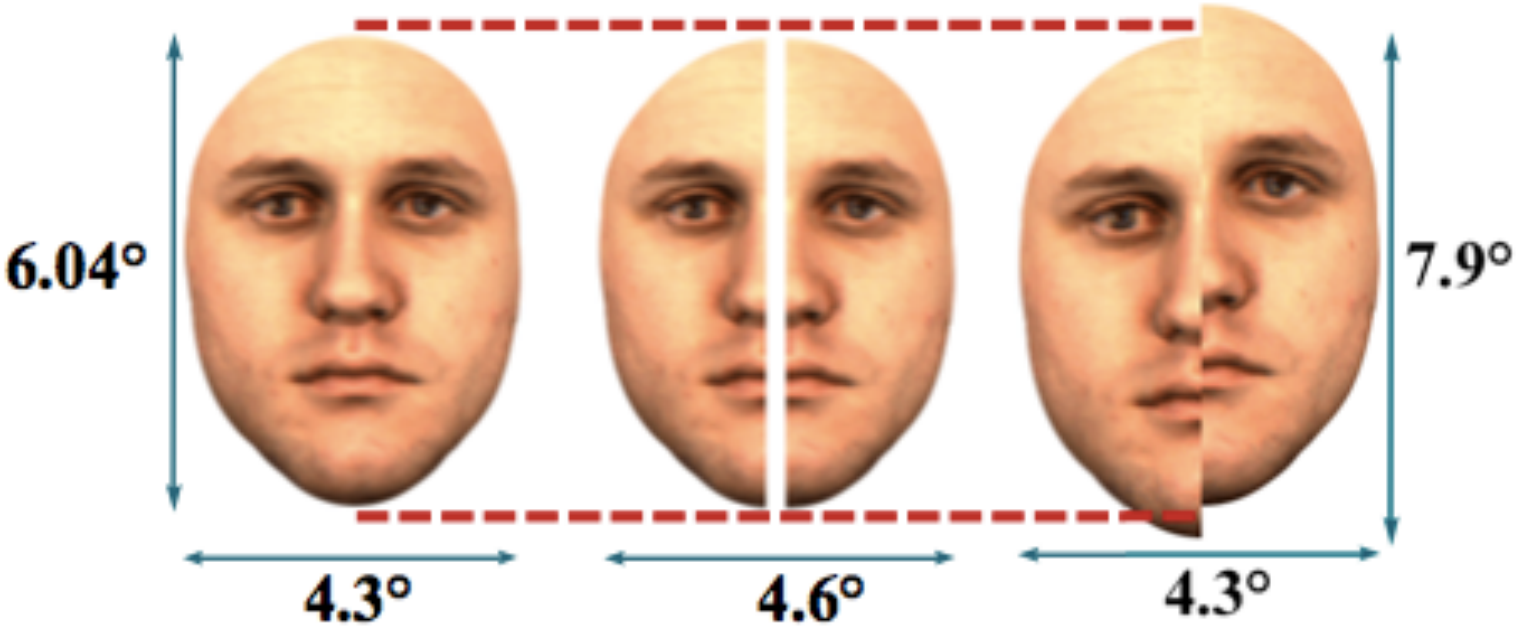


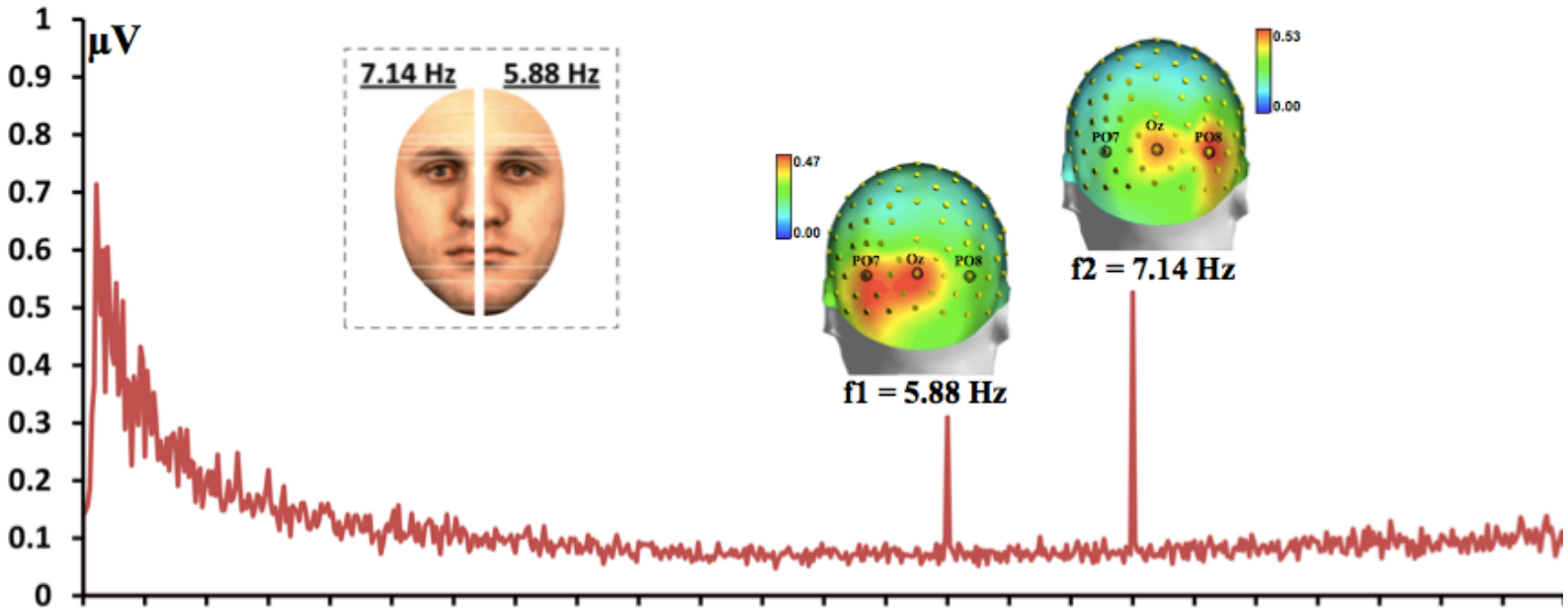

μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5.88 Hz
7.14 Hz
0.58
0.00
PO7
Oz
PO8
0.38
0.00
PO7
Oz
PO8
PO7
Oz
PO8
0 Hz
5.88
7.14
10

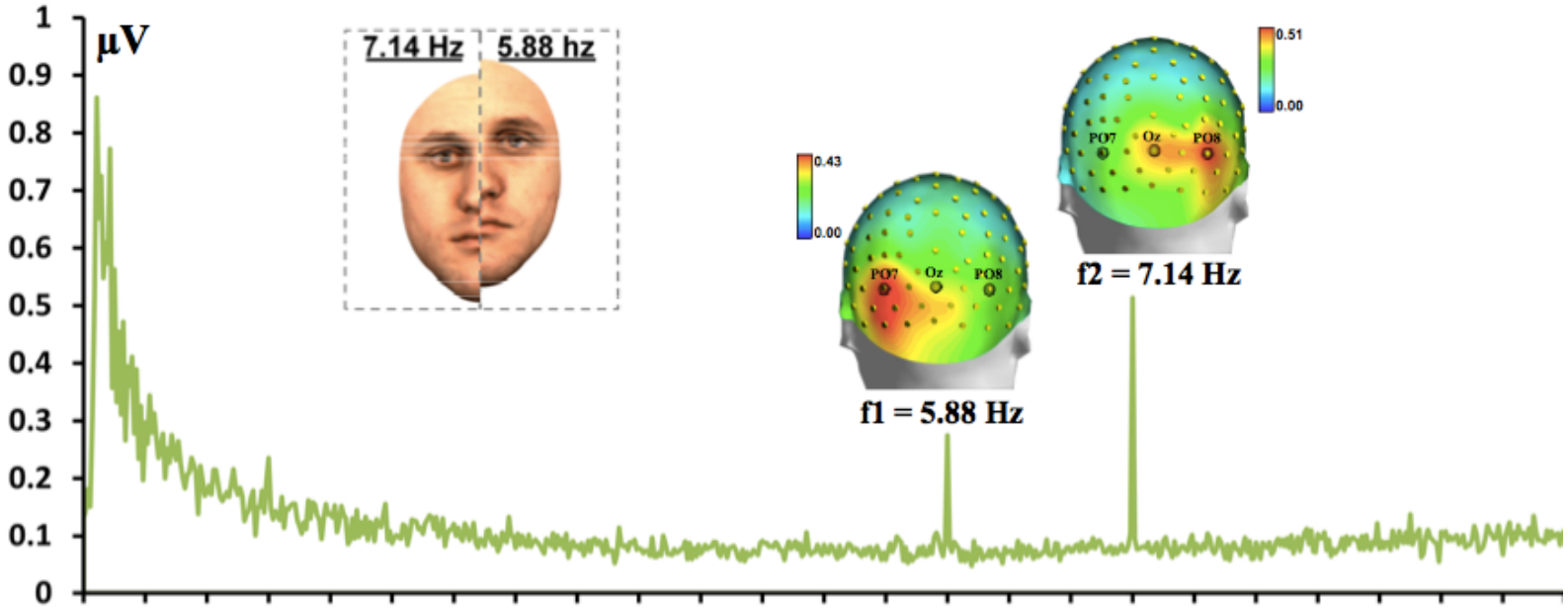

μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5.88 Hz
7.14 Hz
0.58
0.00
PO7
Oz
PO8
f1 = 5.88 Hz
0.38
0.00
PO7
Oz
PO8
f2 = 7.14 Hz
0 Hz
5.88
7.14
10


μV
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.14 Hz
5.88 Hz
0.49
0.00
PO7
Oz
PO8
f1 = 5.88 Hz
0.47
0.00
PO7
Oz
PO8
f2 = 7.14 Hz
0 Hz
5.88
7.14
10

What's happening if we break the whole stimulus in two distinct parts?

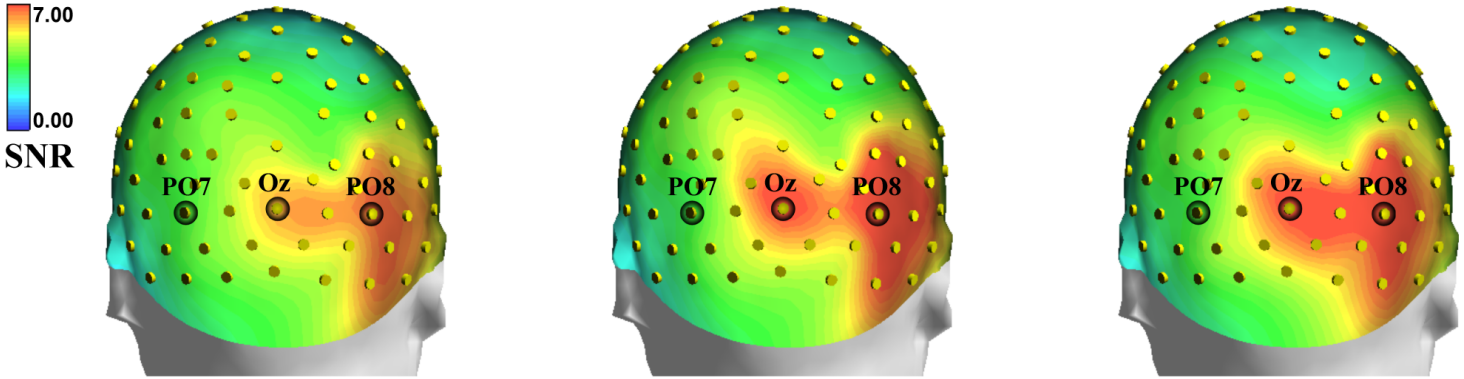


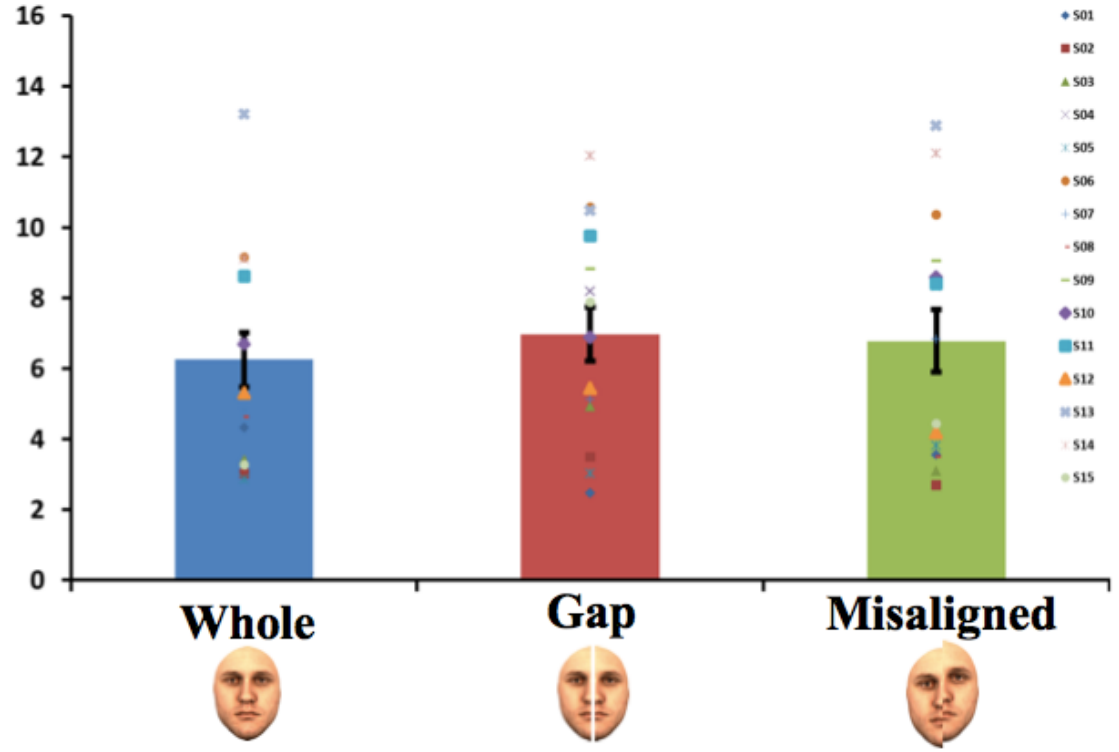

μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.14 Hz
5.88 Hz
0.47
0.00
PO7
Oz
PO8
f1 = 5.88 Hz
0.53
0.00
PO7
Oz
PO8
f2 = 7.14 Hz


μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.14 Hz
5.88 hz
0.43
0.00
PO7
Oz
PO8
f1 = 5.88 Hz
0.51
0.00
PO7
Oz
PO8
f2 = 7.14 Hz

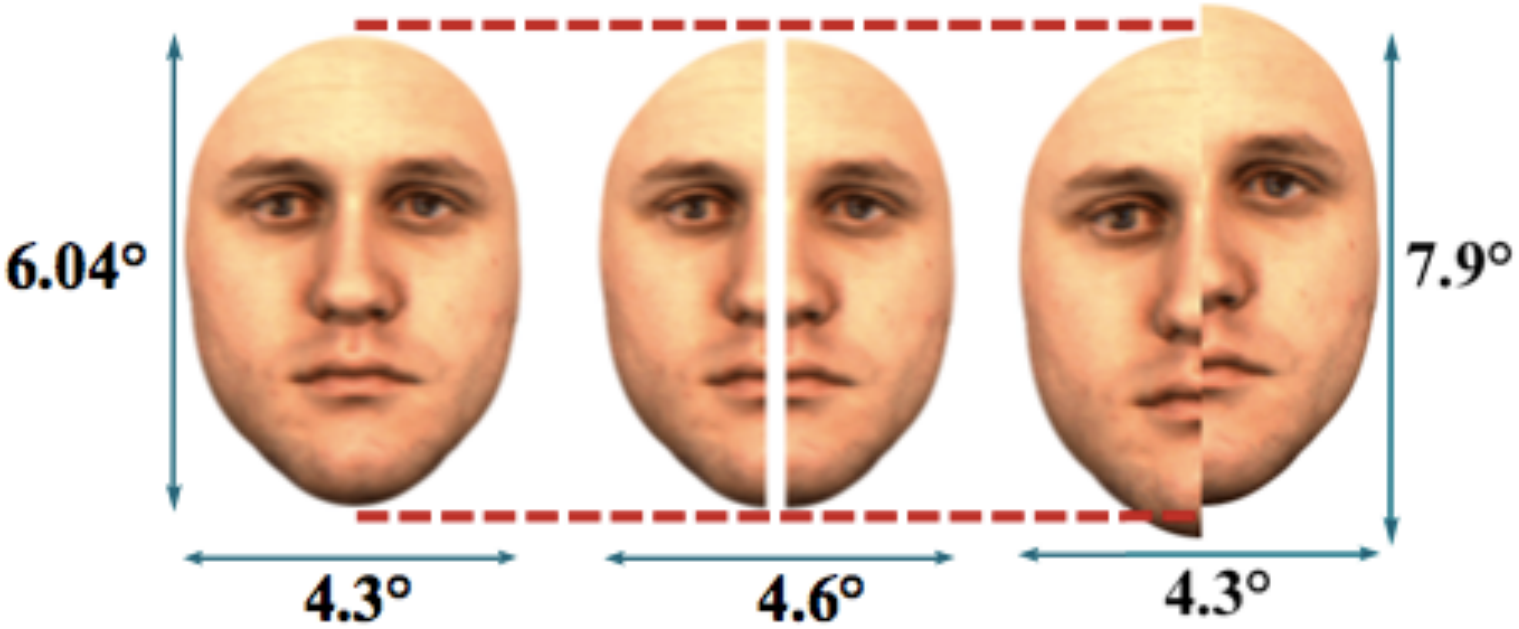
LVF stimulation

PART-BASED RESPONSES

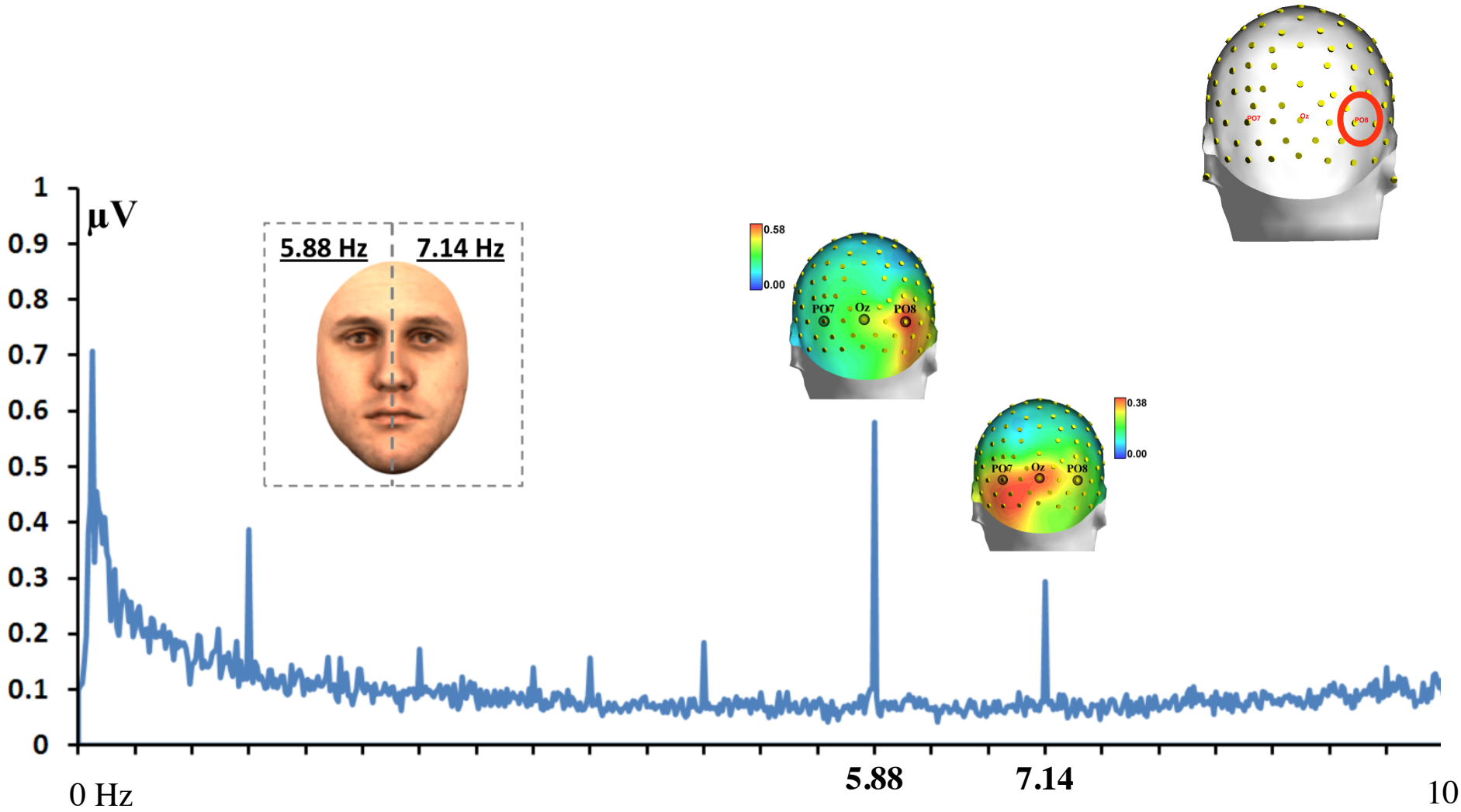


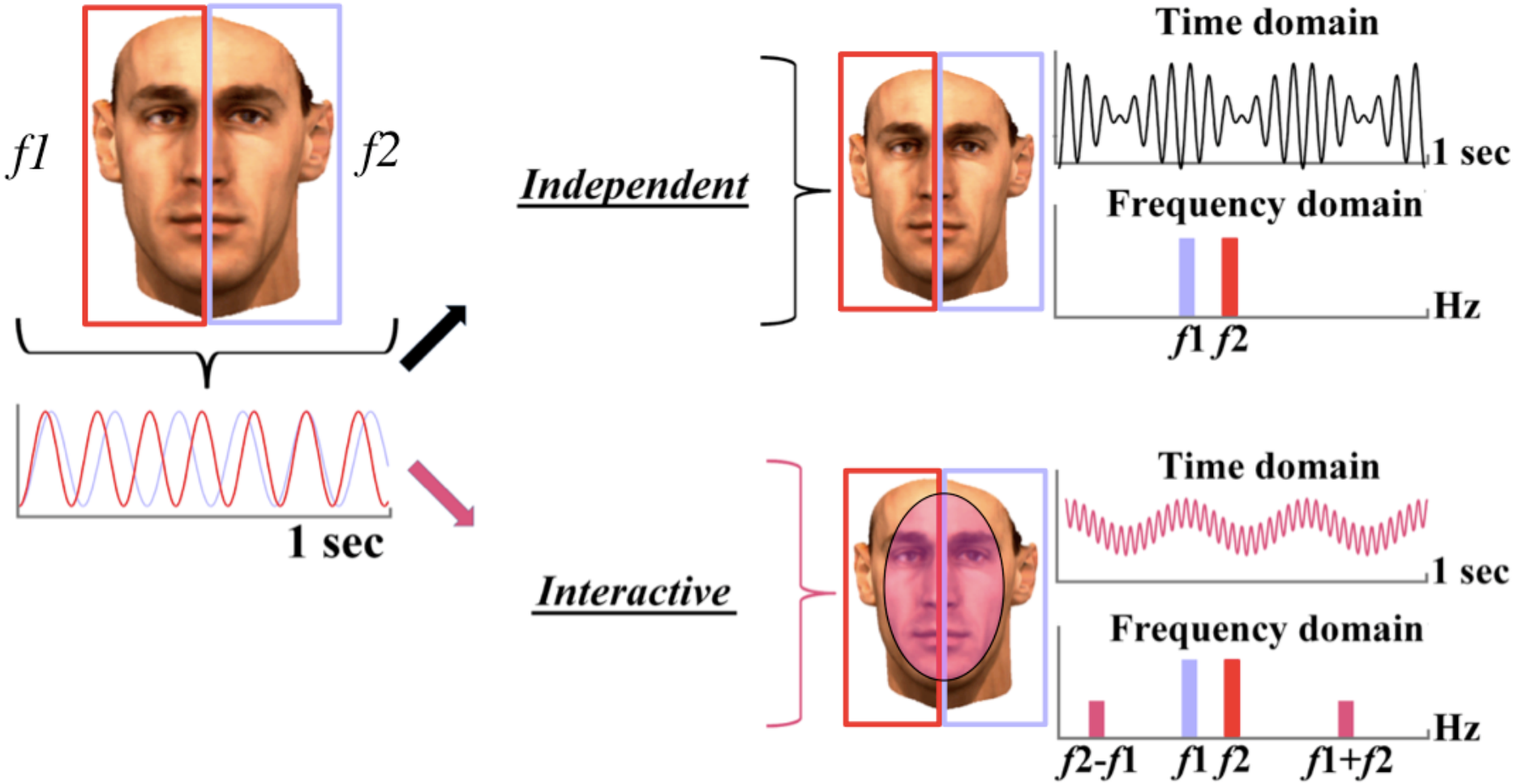


What's happening if we break the whole stimulus in two distinct parts?



Nothing … the parts of the face are not affected !

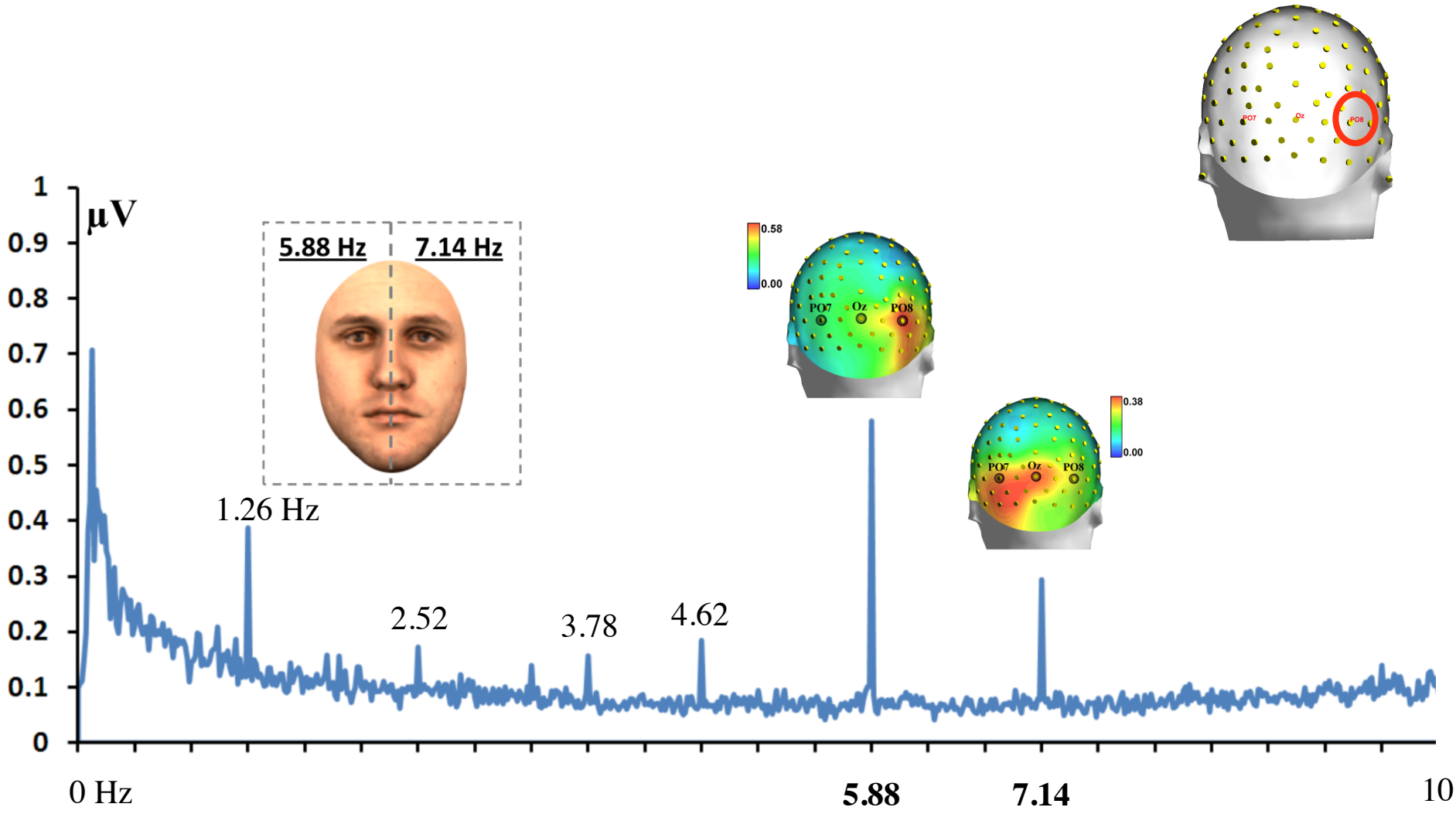

μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5.88 Hz
7.14 Hz
0.58
0.00
PO7
Oz
PO8
0.38
0.00
PO7
Oz
PO8
0 Hz
5.88
7.14
10

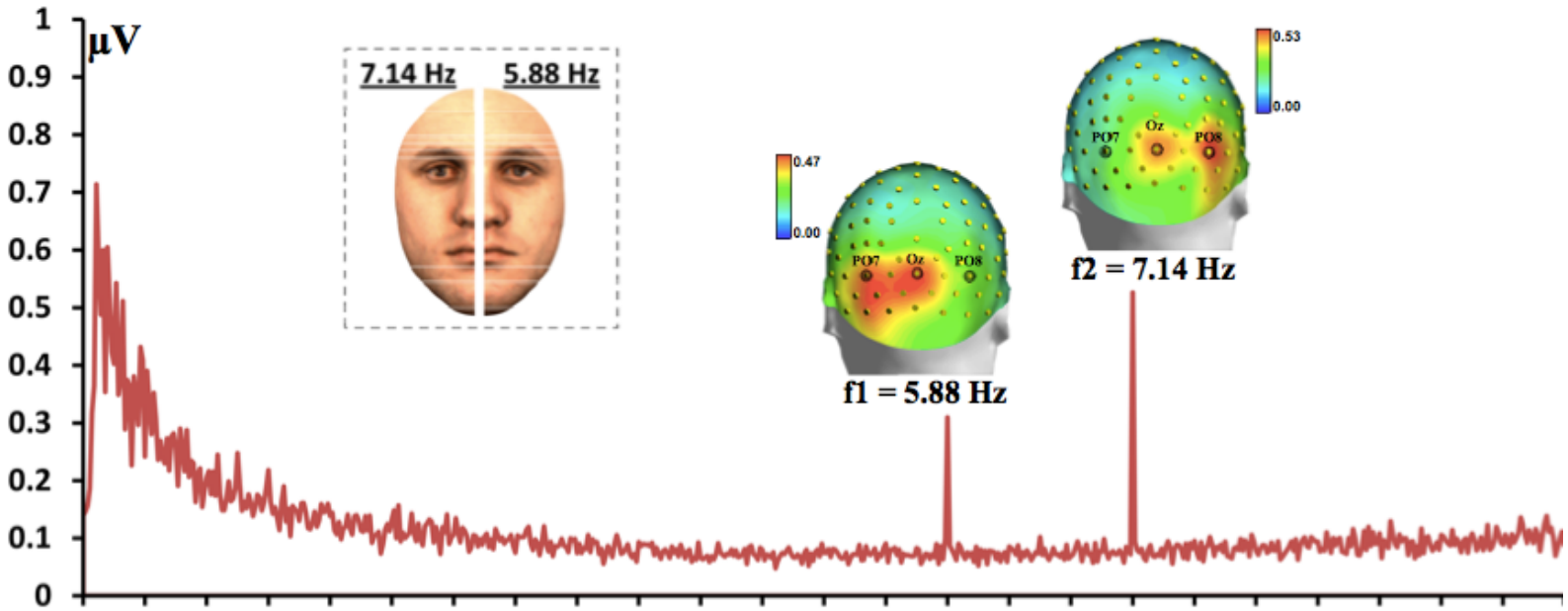


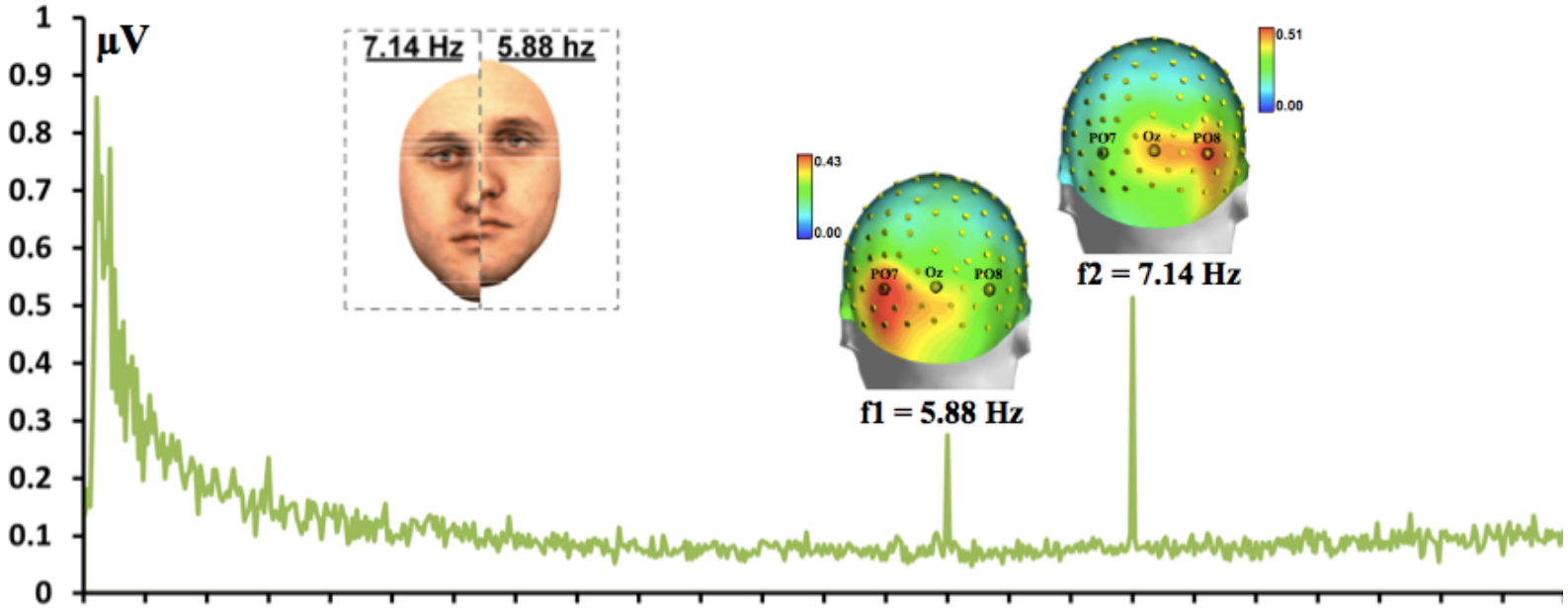
*Intermodulations (*IMs*)*: *f2-f1*; *f1+f2*

- (Nonlinearities): they are NOT present in the stimulus
- Can only appear if *interaction* of the two signals

Regan & Regan (1988); Zemon & Ratliff (1984); *Appelbaum et al., 2009*: figure and background interaction; *Sutoyo & Srinivasan (2009)*: interocular binding


μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5.88 Hz
7.14 Hz
1.26 Hz
2.52
3.78
4.62
0.58
0.00
PO7
Oz
PO8
0.38
0.00
PO7
Oz
PO8
PO7
Oz
PO8
0 Hz
5.88
7.14
10


μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.14 Hz
5.88 Hz
0.47
0.00
PO7
Oz
PO8
f1 = 5.88 Hz
0.53
0.00
PO7
Oz
PO8
f2 = 7.14 Hz


μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.14 Hz
5.88 hz
0.43
0.00
PO7
Oz
PO8
f1 = 5.88 Hz
0.51
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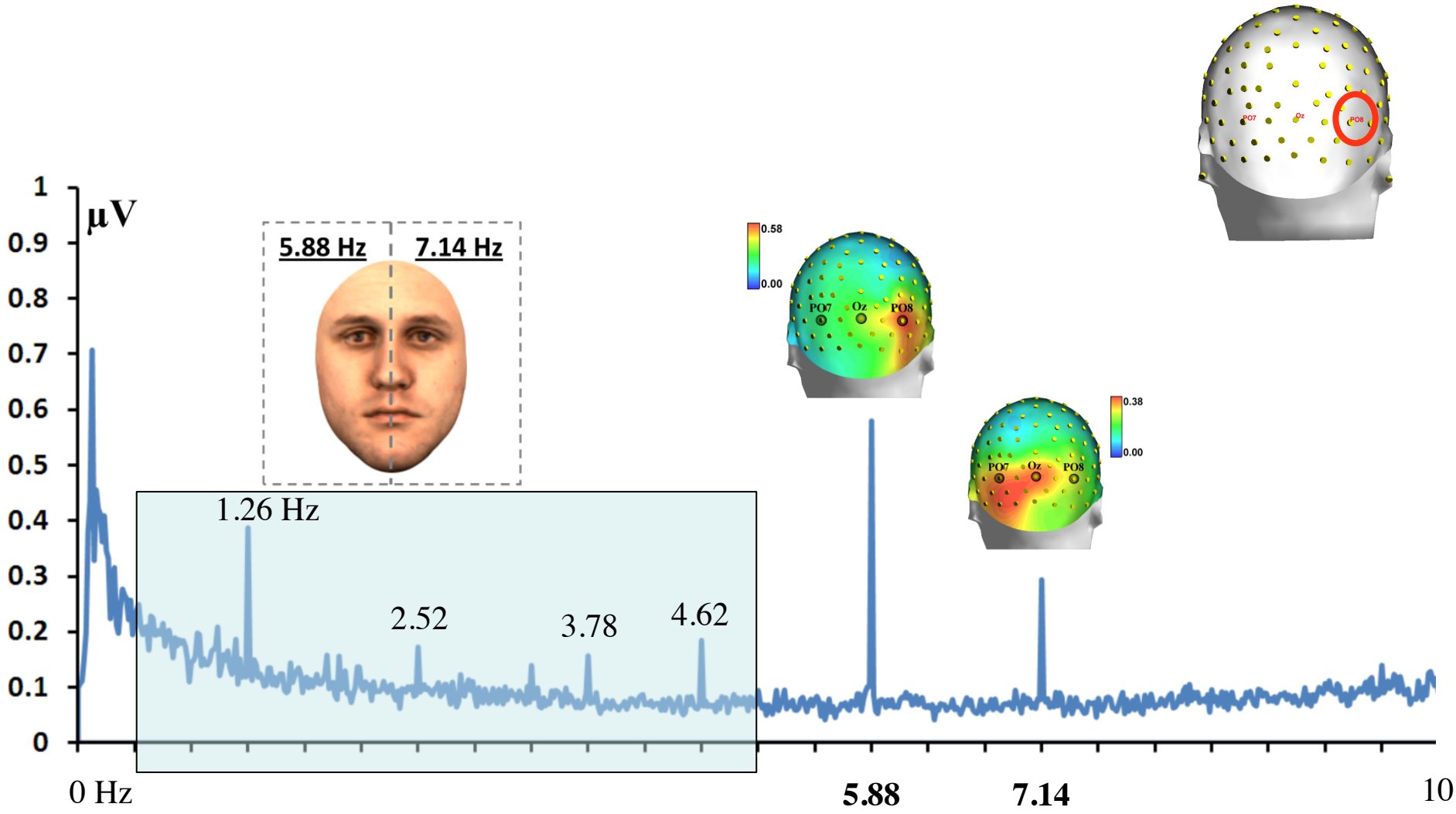
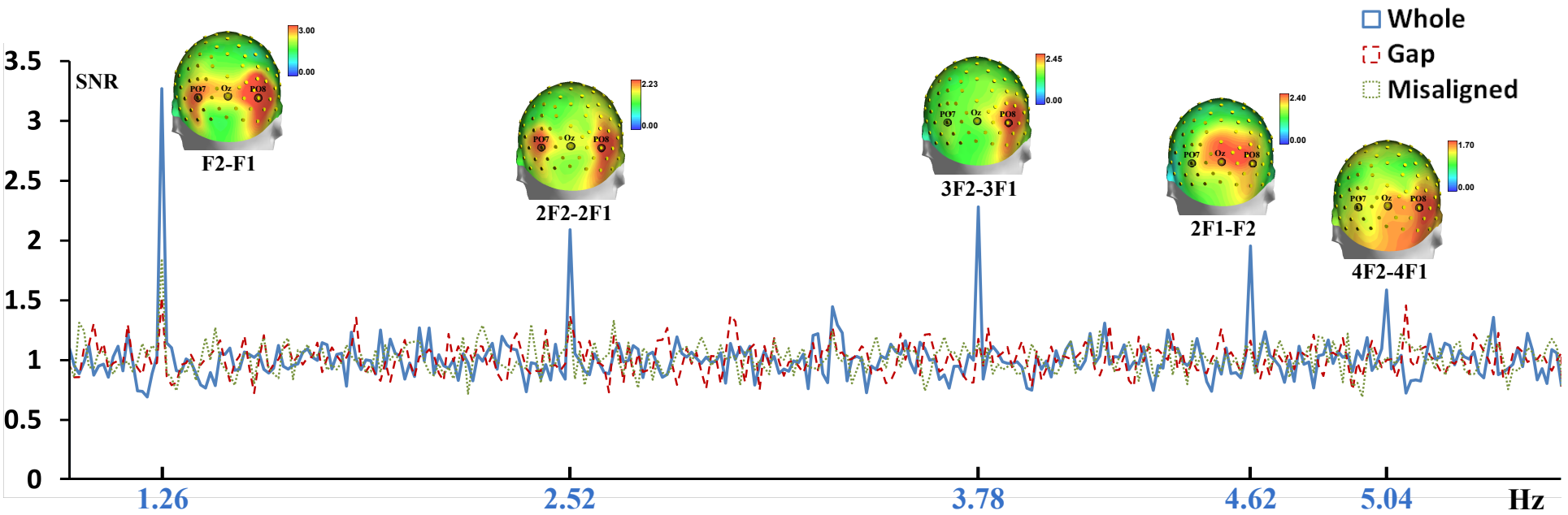
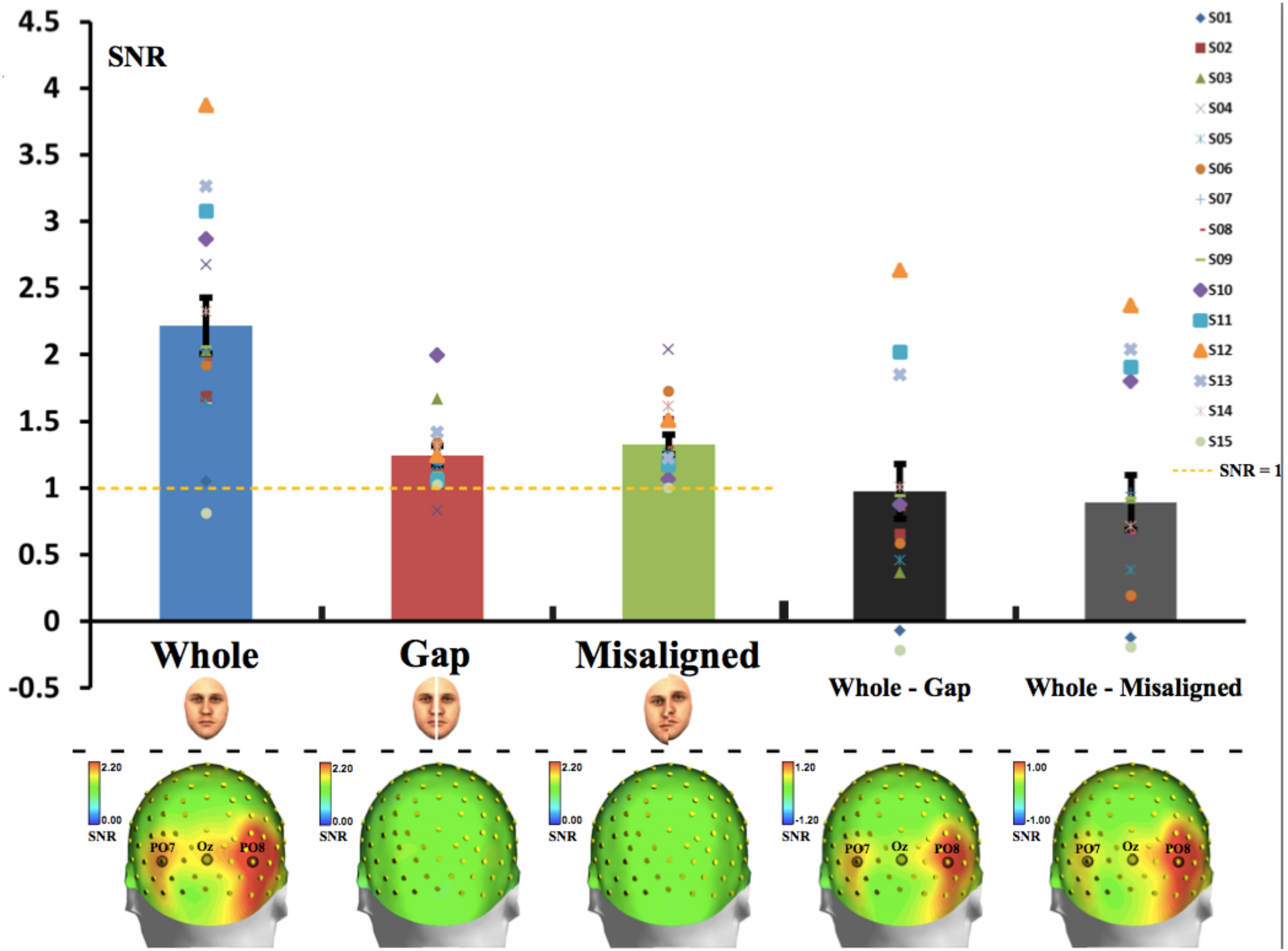
PO7
Oz
PO8
f2 = 7.14 Hz

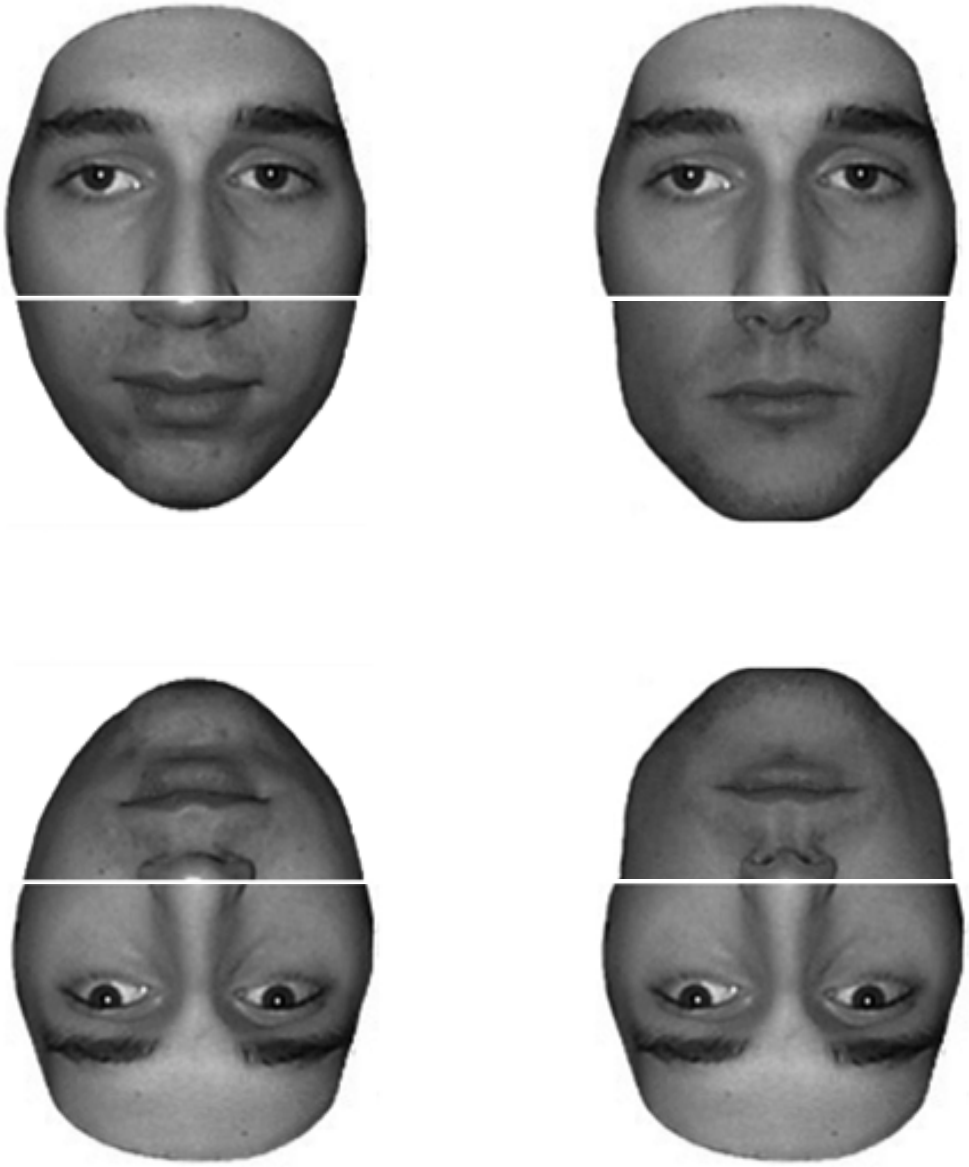

μV
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5.88 Hz
7.14 Hz
1.26 Hz
2.52
3.78
4.62
0.58
0.00
PO7
Oz
PO8
0.38
0.00
PO7
Oz
PO8
PO7
Oz
PO8
0 Hz
5.88
7.14
10

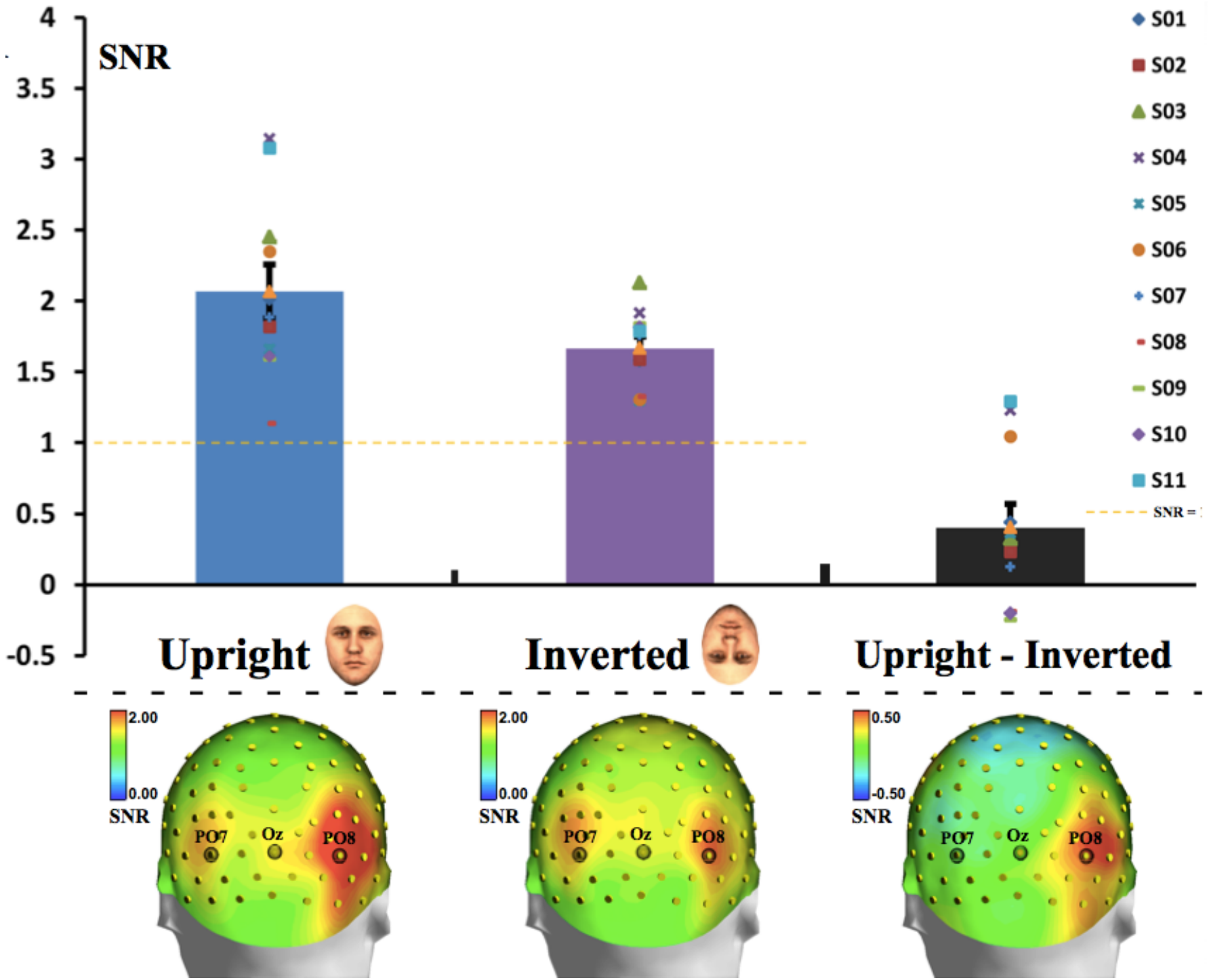
Intermodulation (whole-based) responses



Boremanse, Norcia, & Rossion, 2013
Boremanse, Norcia, & Rossion, 2014


SNR
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
S01
S02
S03
S04
S05
S06
S07
S08
S09
S10
S11
S12
S13
S14
S15
SNR = 1
Whole
Gap
Misaligned
Whole - Gap
Whole - Misaligned
2.20
0.00
SNR
PO7
Oz
PO8
1.20
-1.20
1.00
-1.00




SNR
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
S01
S02
S03
S04
S05
S06
S07
S08
S09
S10
S11
SNR =
Upright
Inverted
Upright - Inverted
2.00
0.00
SNR
PO7
Oz
PO8
2.00
0.00
SNR
PO7
Oz
PO8
0.50
-0.50
SNR
PO7
Oz
PO8

Conclusions

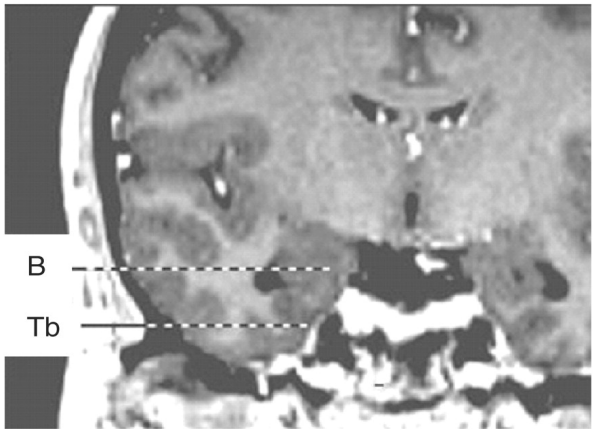
* Objective (and rapid) dissociation between the representation of the parts of a face and an *integrated* representation of the face

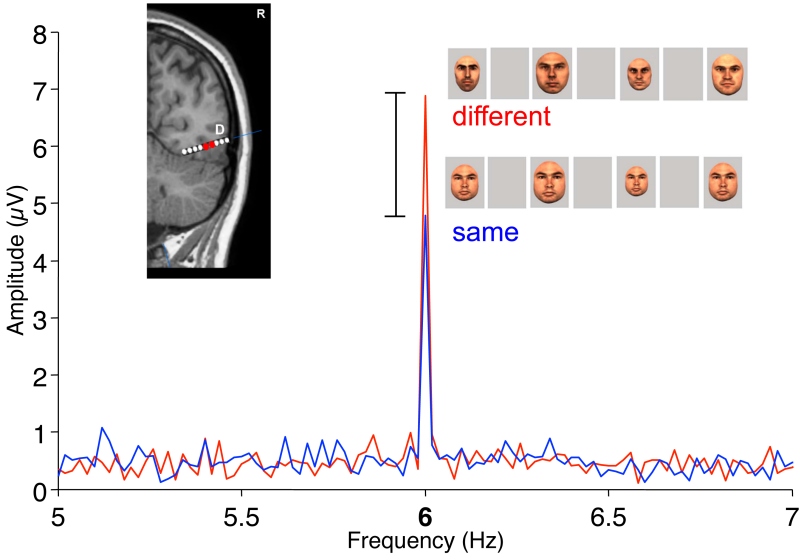
"Holistic Face Perception"

* "A face is more than the sum of its parts"

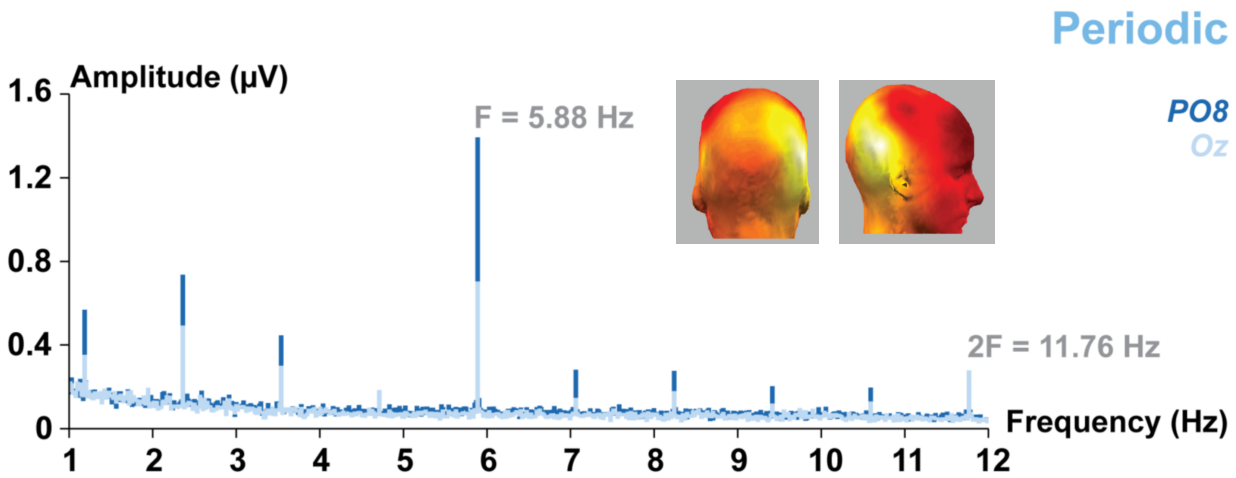
* Dominance of the right hemisphere for perceptual integration of face parts

WPE001: Intracerebral electrical stimulation of an occipital face-selective area impairs individual face discrimination:

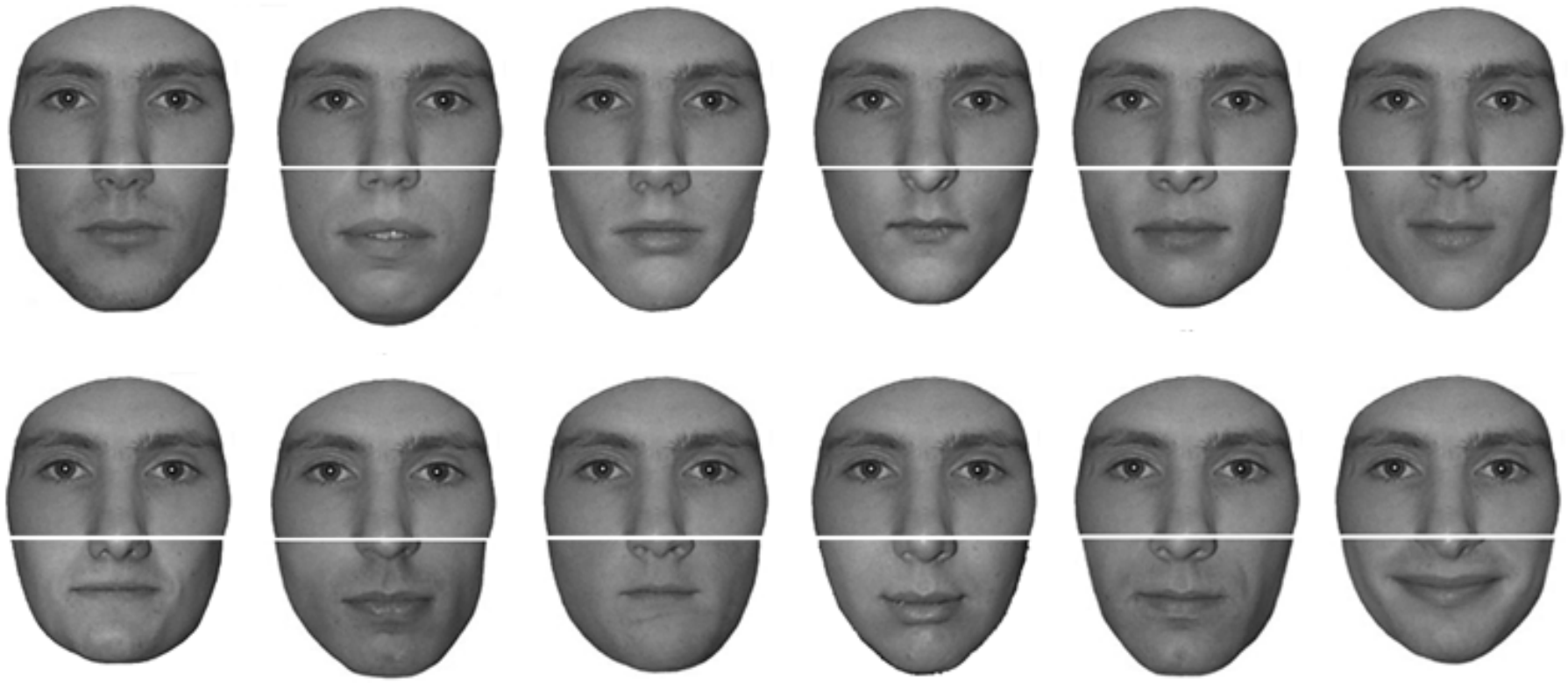




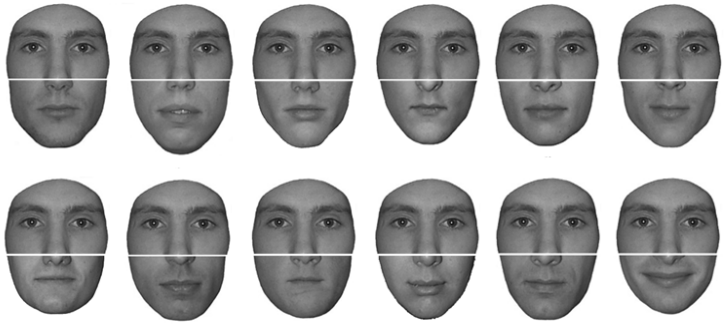
WPE002: Rapid definition of objective electrophysiological face-selective responses by means of fast periodic visual stimulation

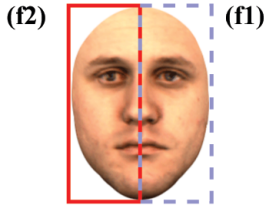


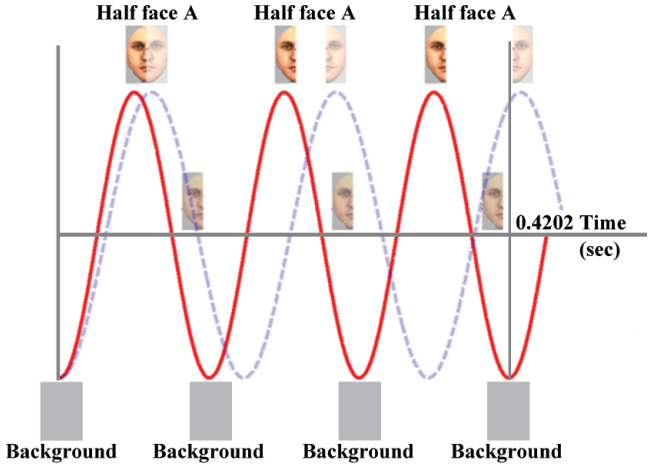
Thank you

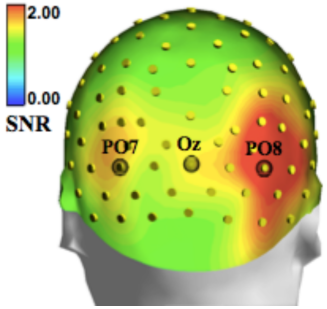


Objective evidence for perceptual integration by means of frequency-tagging EEG









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An objective signature for visual binding of face parts in the human brain

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Whether and how the parts of a visual object are grouped together to form an integrated ("holistic")

Introduction

EJN European Journal of Neuroscience FENS Federation of European Neuroscience Societies

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Dissociation of part-based and integrated neural responses to faces by means of electroencephalographic frequency tagging

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Keywords: face perception, frequency tagging, human, intermodulation, repetition suppression, steady-state visual evoked potential