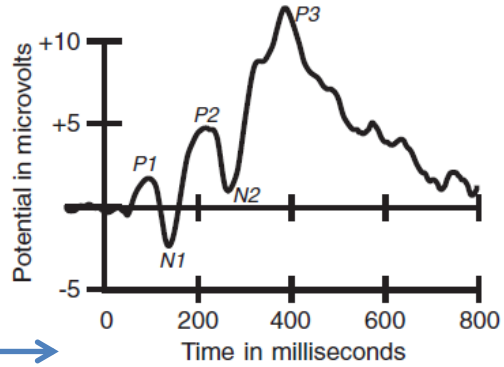
Exploring perceptual and cognitive processings using frequency-tagging paradigms

Parvaneh Adibpour

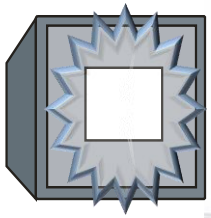
11e journée Cogiter, CASC, Sciences cognitives et activité électrique cérébrale
November 2018

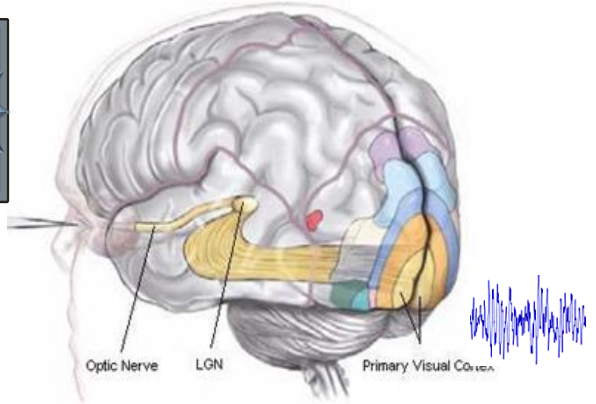
From Event-Related Potentials to Steady-State Visual Evoked Potentials

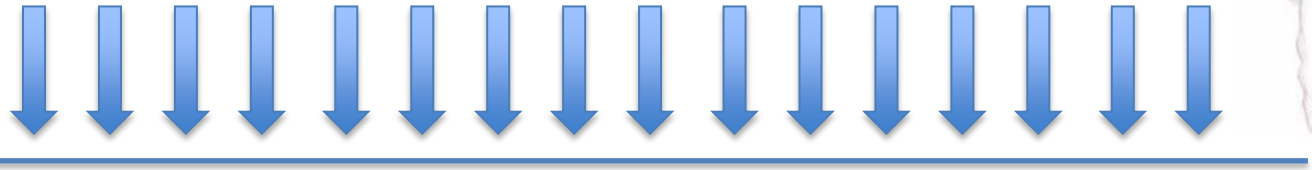
- Event-Related Potentials (ERPs) :
  - Isolated, discrete stimulus event
  - Large/variable inter-stimulus intervals



- Steady-State Visual Evoked Potentials (SSVEPs) (Regan, 1966)
  - Periodic visual stimulation (stimuli train) at a predefined frequency
  - Short inter-stimulus intervals
  - Overlapping-responses



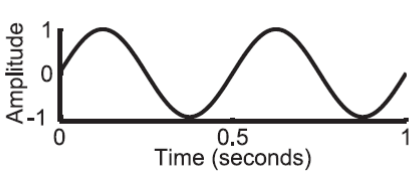


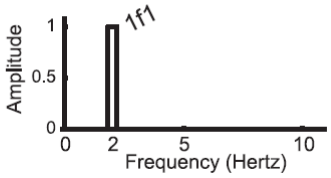


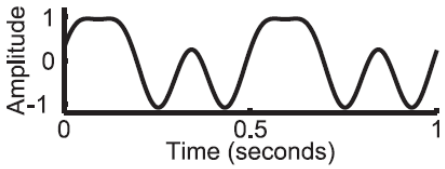
Frequency domain responses

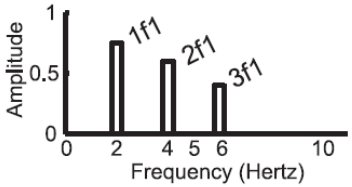
Responses at the stimulation frequency (F) and its harmonics (2F, 3F, 4F):

→ Nonlinearity of the visual system

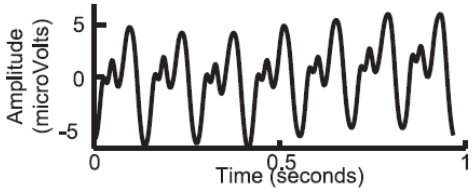


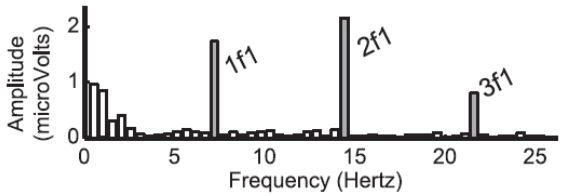




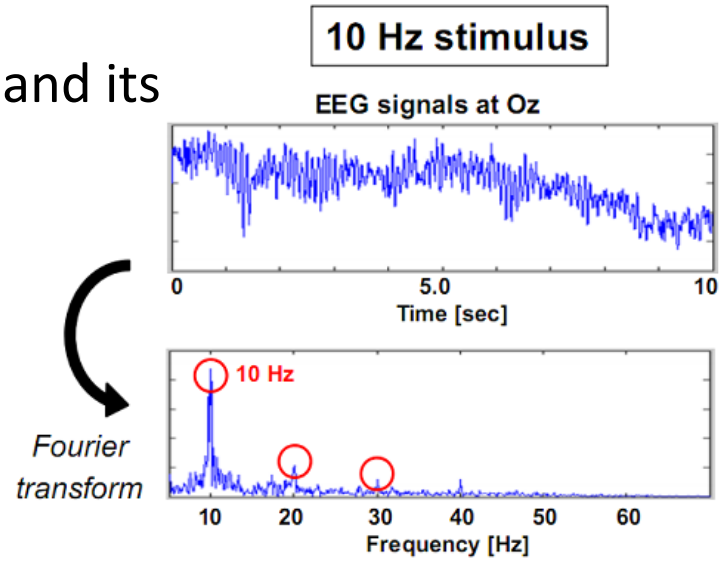


SSVEP





(Norcia et al., Journal of Vision, 2015)



❑Objective signature of the response frequency contents (predefined stimulation rate)

❑ Since SSVEP is narrowband (Regan 1989), only a small fraction of the noise is present at the frequency of interest. (High Signal to Noise Ratio -SNR).

❑Short stimulation duration

Choice of the stimulus frequency

• The experimental noise is present over all frequencies with more noise in low frequencies. (challenges for very low frequencies)

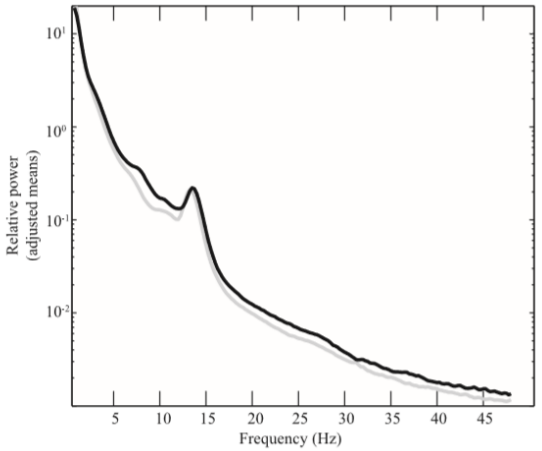
• Higher stimulation rates for low-level processings

• Lower stimulation rates may be necessary to record SSVEPs generated by higher level visual processes, for instance the discrimination of complex stimuli such as faces (i.e., about 6 Hz)

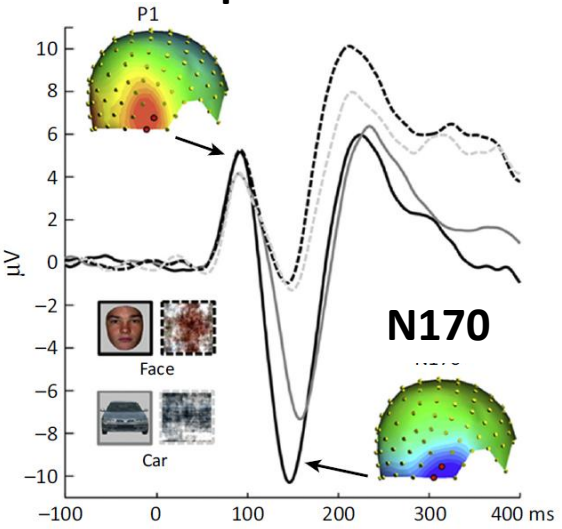
• SSVEP responses decrease over the occipito-temporal cortex at rates above 8 Hz

(Alonso-Prieto, Belle, Liu-Shuang, Norcia, & Rossion, 2013)

EEG power spectrum



ERP response to faces



➔ 1/170 ms = 5.88 HZ

SSVEP responses reflecting low level visual processes

Sweep paradigms:

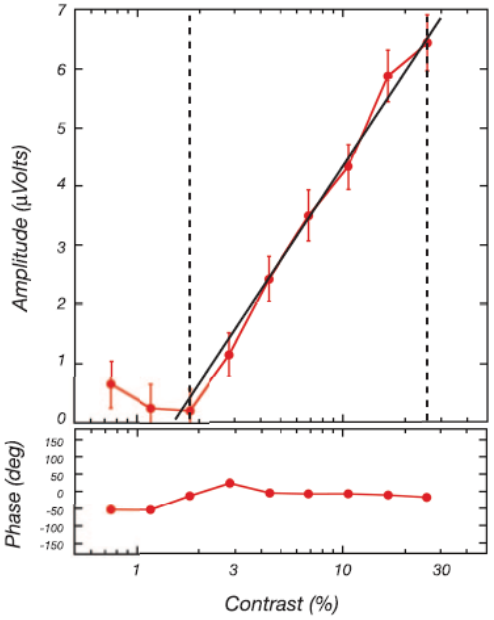
- The SSVEP is measured in response to a stimulus that is parametrically varied (swept) over a range of values, rather than being presented at a fixed, unchanging value

- Short stimulation periods (~2mins)

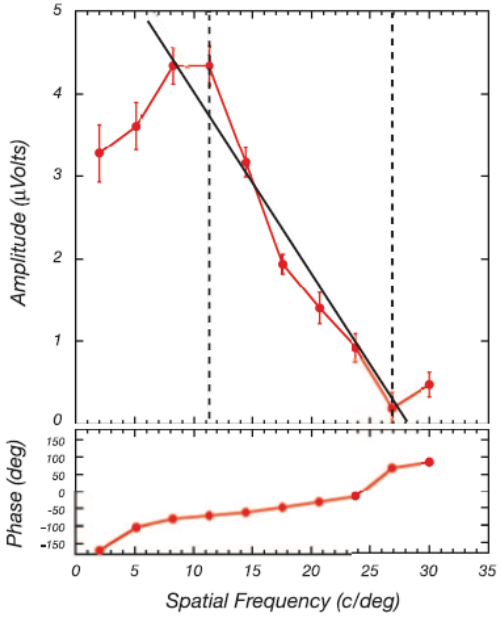
- Correlations between threshold from behavioral evaluations and neural responses

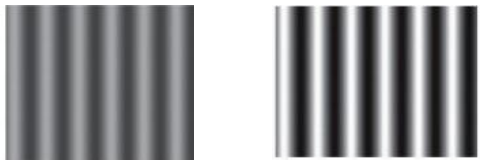
(Nelson et al., Vision Research, 1984)
(Allen et al., Am J of Optometry Physiological Optics, 1986)

Contrast sensitivity



Spatial acuity





Low contrast → **High contrast**

Parametric modulation of contrast

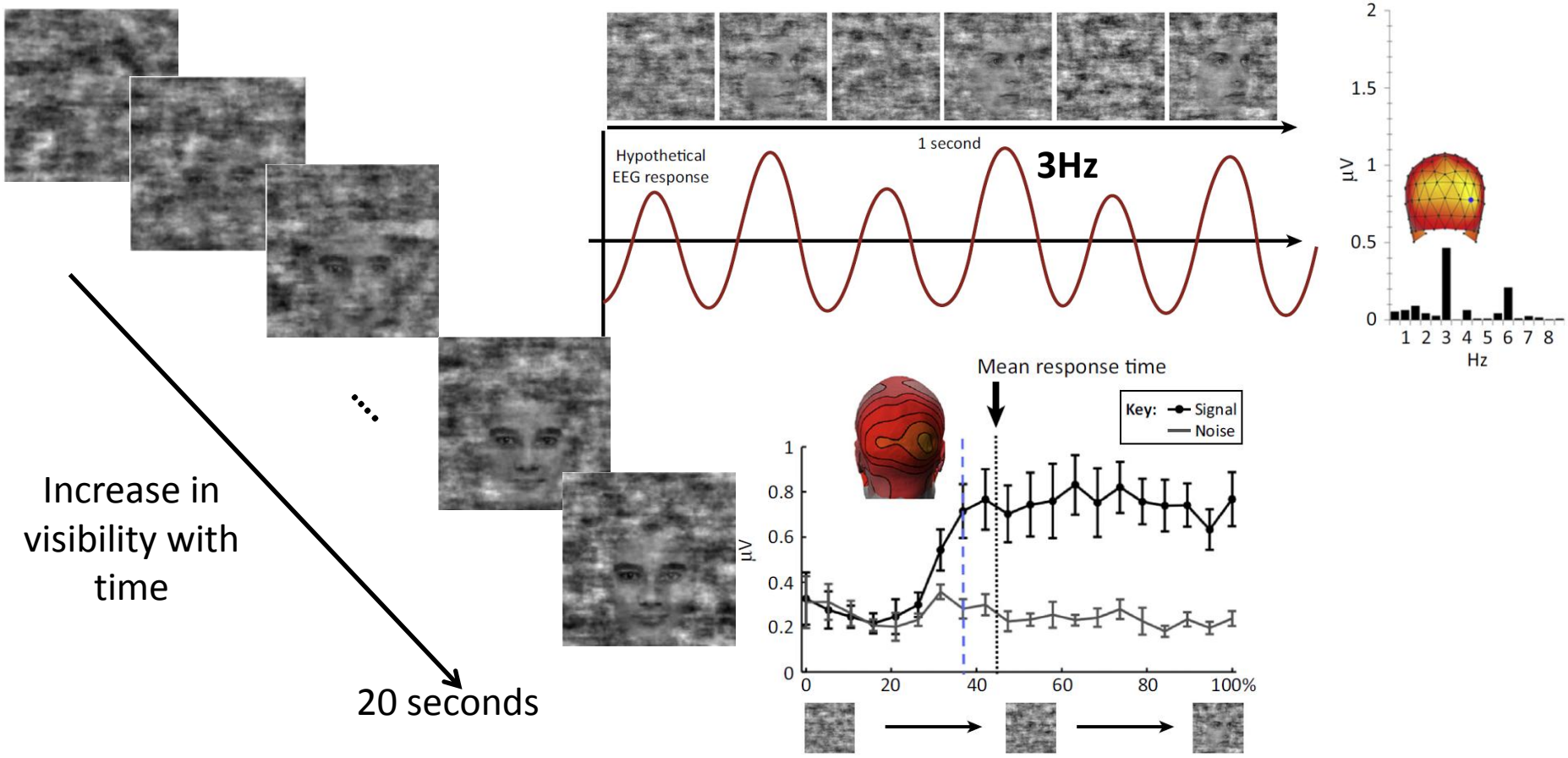
low spatial freq → **high spatial freq**

Parametric modulation of spatial frequency

SSVEP responses reflecting higher level visual processes

- SSVEP approach can be used to study not only sensory processes but also higher level visual processes (i.e., object, face, or visual-scene perception), and attention.

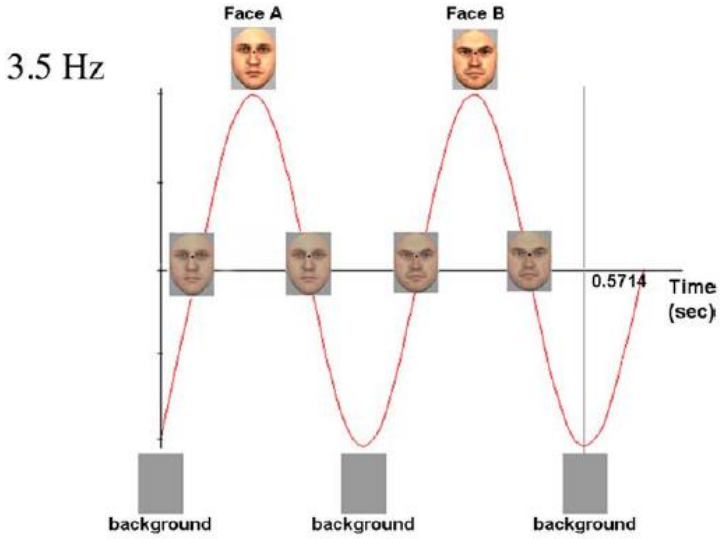
Face detection threshold using sweep SSVEP

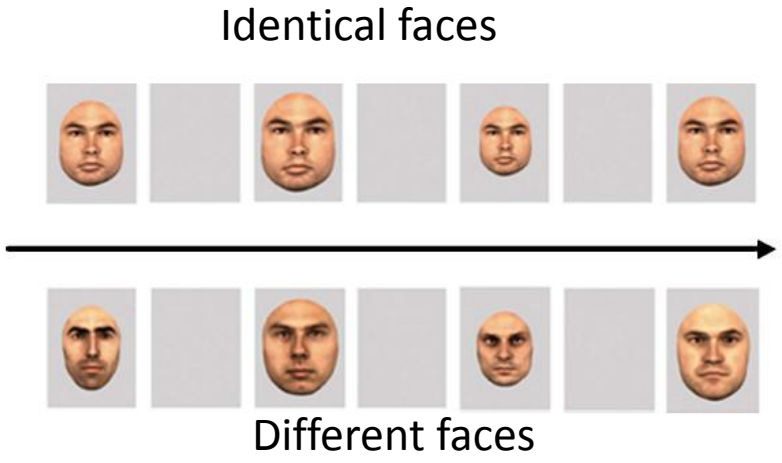


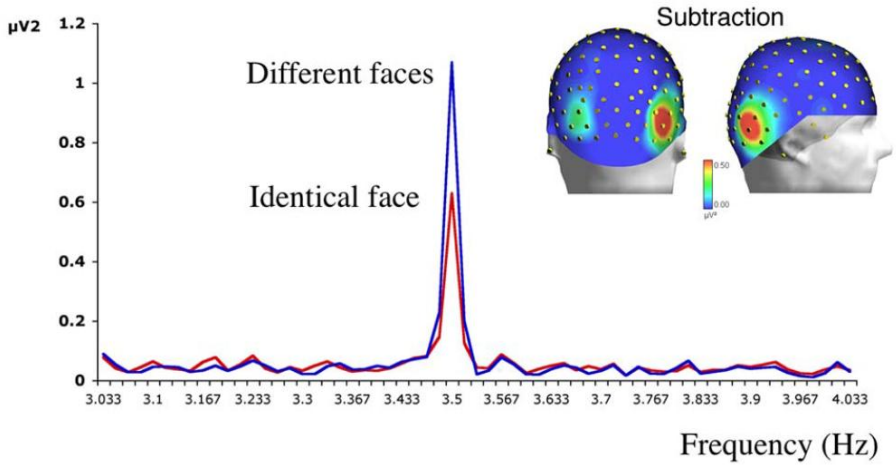
Ales et al., Journal of vision, 2011

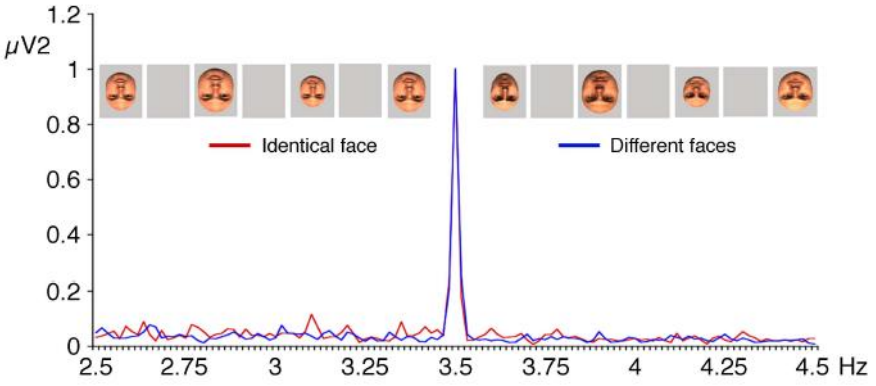
Face identity processing

- Periodic presentation of identical or different faces





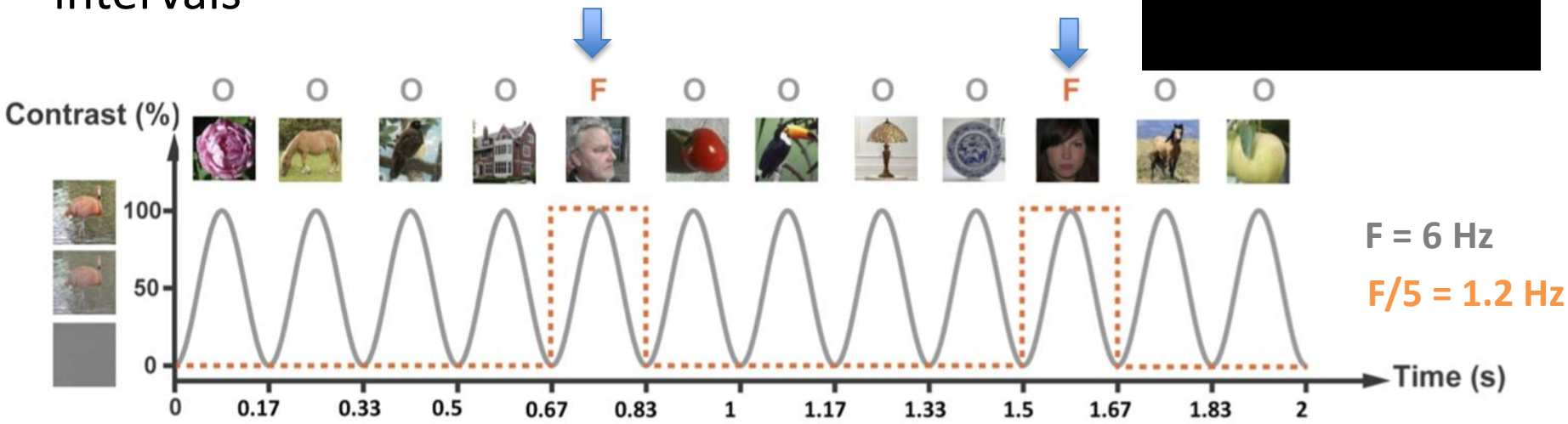




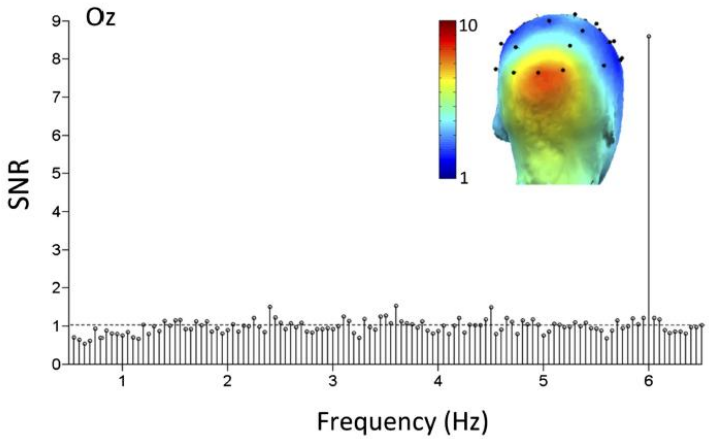
(Rossion & Boremanse, Journal of vision, 2011)

Face categorization

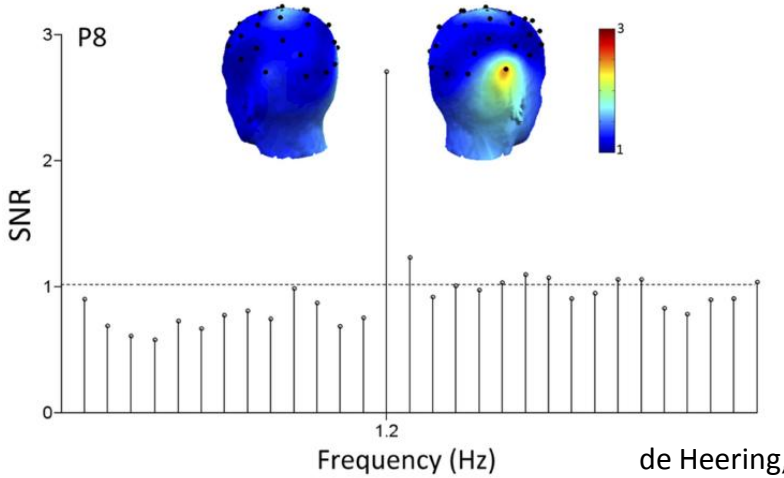
Stream of images with faces inserted at regular intervals



Response at base stimulation

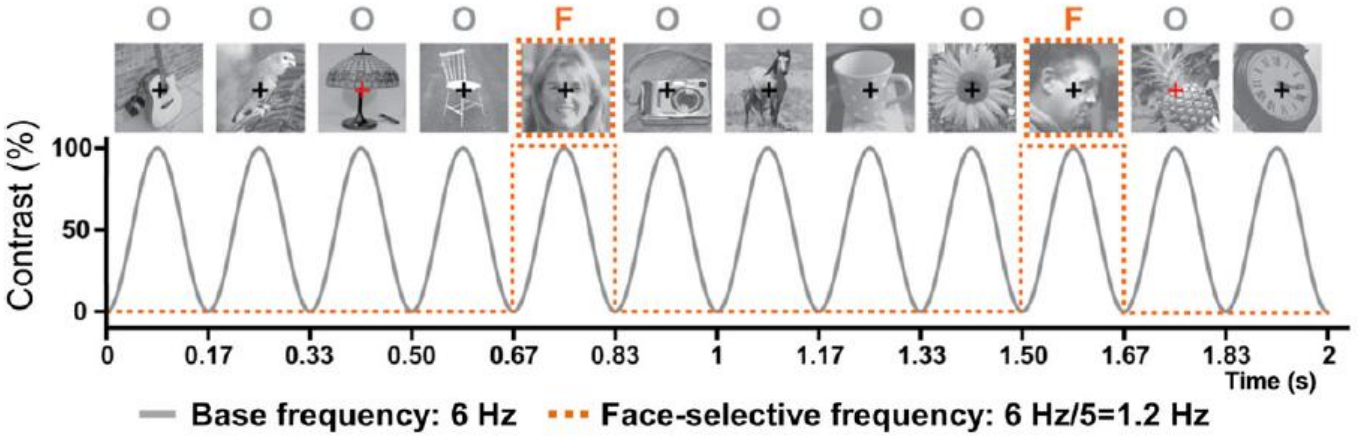


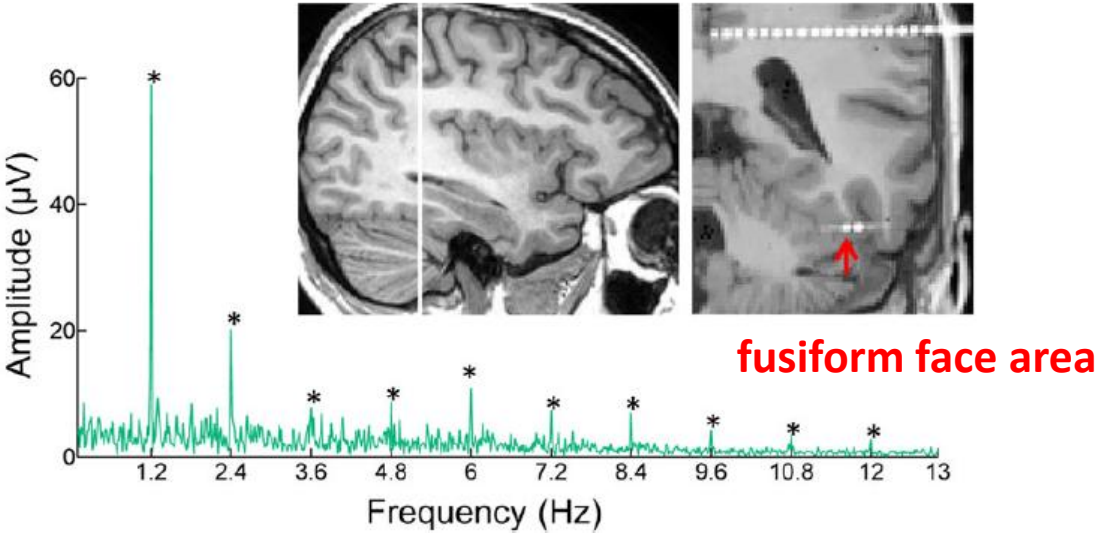
Response at face rate



de Heering, Rossion eLife 2015

Face categorization in the ventral occipitotemporal cortex with direct neural intracranial recordings

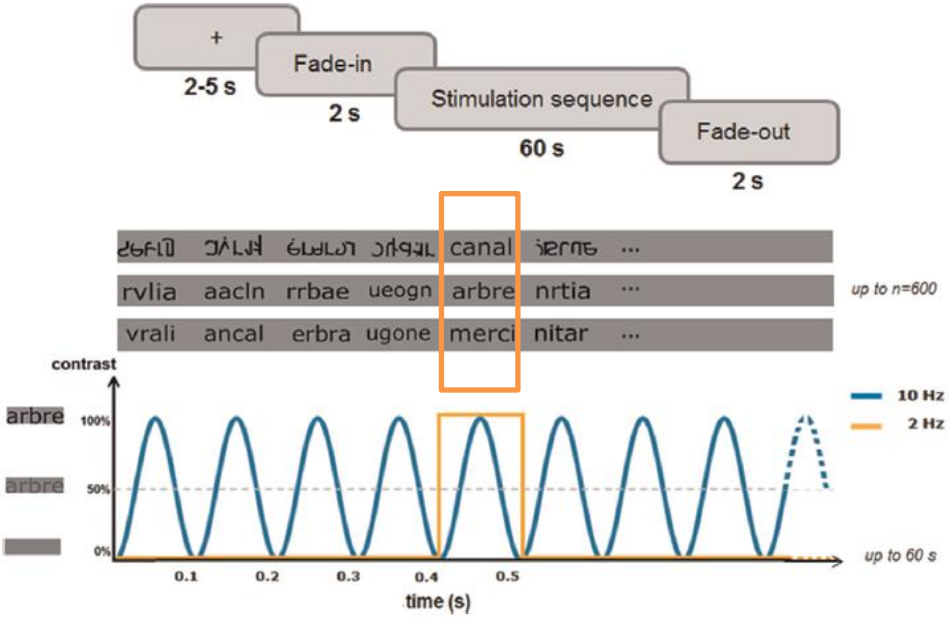




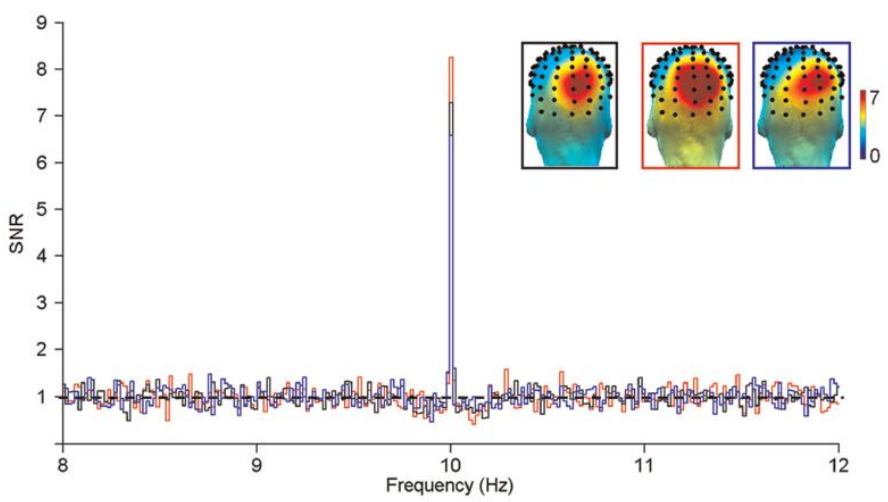
fusiform face area

Rossion, Jacques and Jonas, Annuals of NY academy of sciences 2018

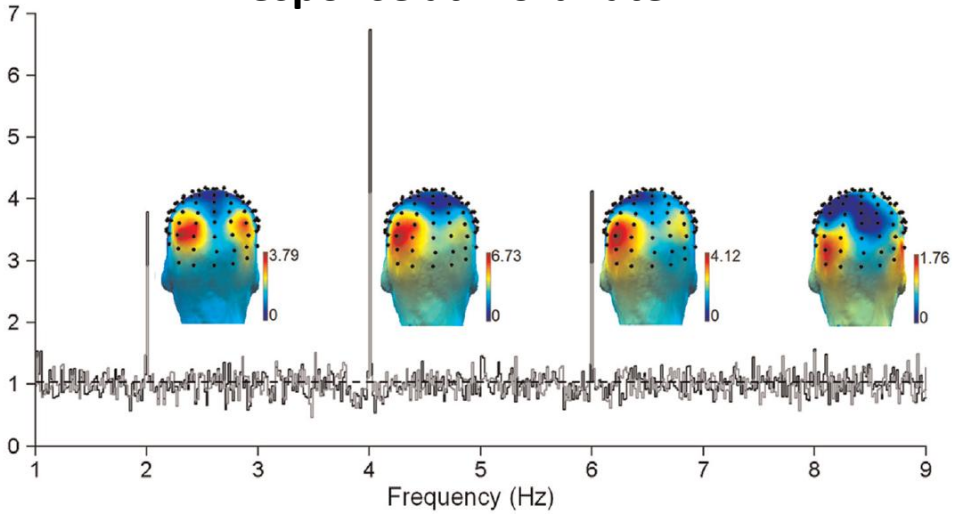
Visual word categorization



Response at base stimulation



Response at word rate

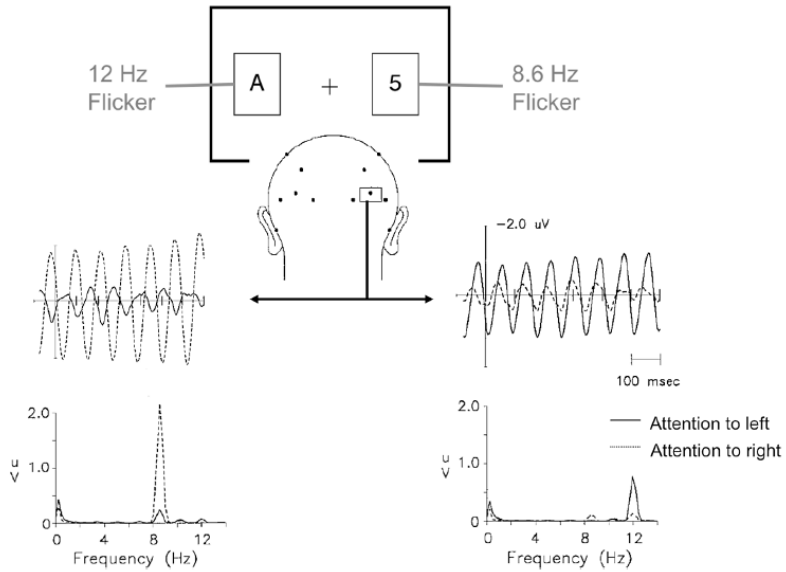


Lochy, Van Belle, & Rossion, Neuropsychologia., 2014

Multiple periodic visual inputs

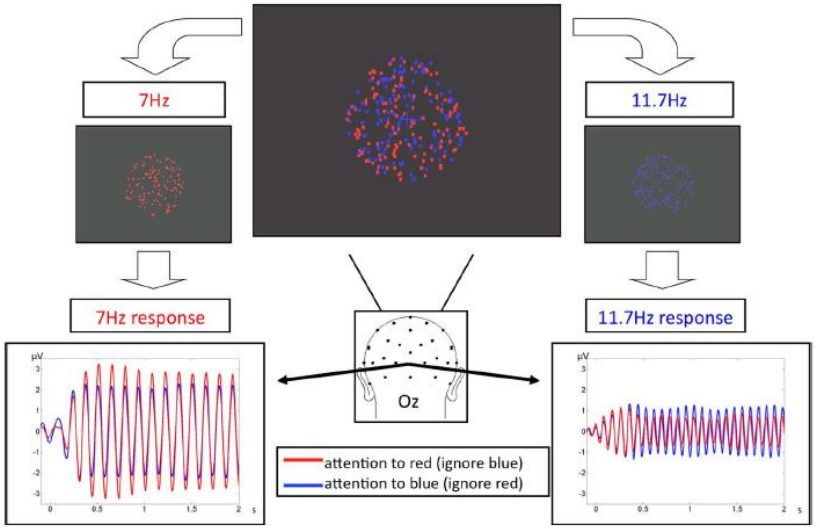
- Studying attention and perceptual grouping

Spatial locations tagging



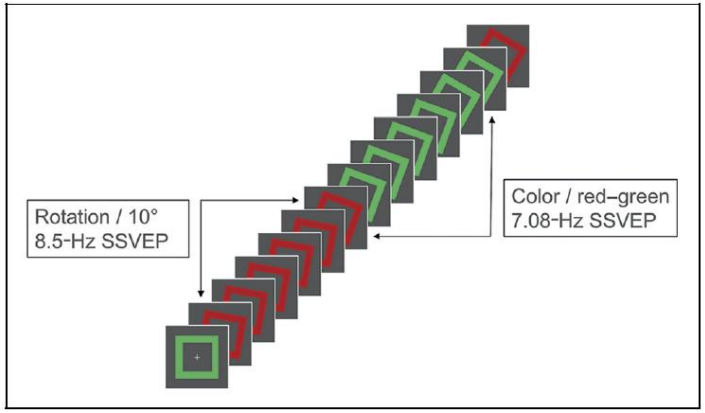
(Morgan, Hansen & Hillyard., pnas 1996)

Feature tagging



(Muller et al., pnas 2006)

Multiple feature tagging

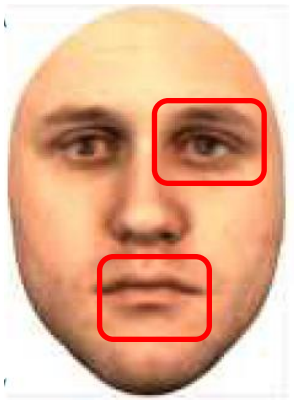


(Brummerloh, Gundlach, & Müller., J of Cog Neuroscience, 2018)

- Applications to brain-computer interfaces

Perceptual grouping: integrating parts into a whole

- A visual scene or object is composed of parts



- How does the brain put these parts together?

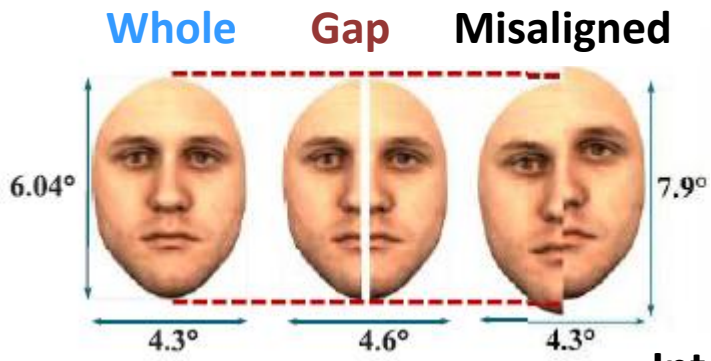
  - Presentation of a whole entity (object, event,etc) same as the summed representation of its parts in isolation

  - Presentation of a whole is beyond sum of parts: Some IT neurons do not respond to object parts but only the whole objects

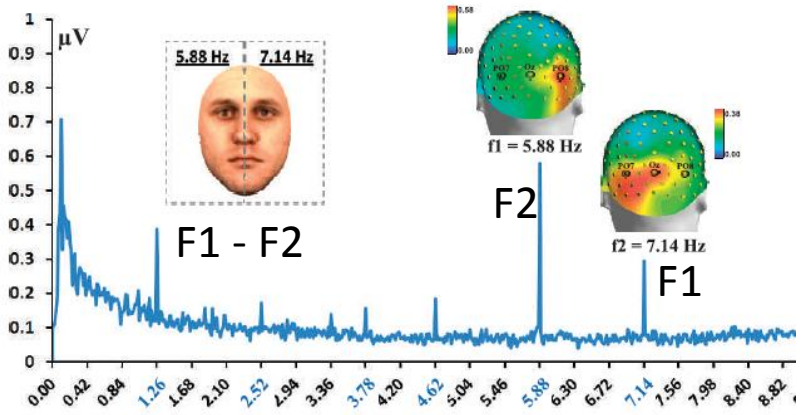
(Fujita et al., 1992; Tsunoda et al., 2001)

Visual binding of face parts

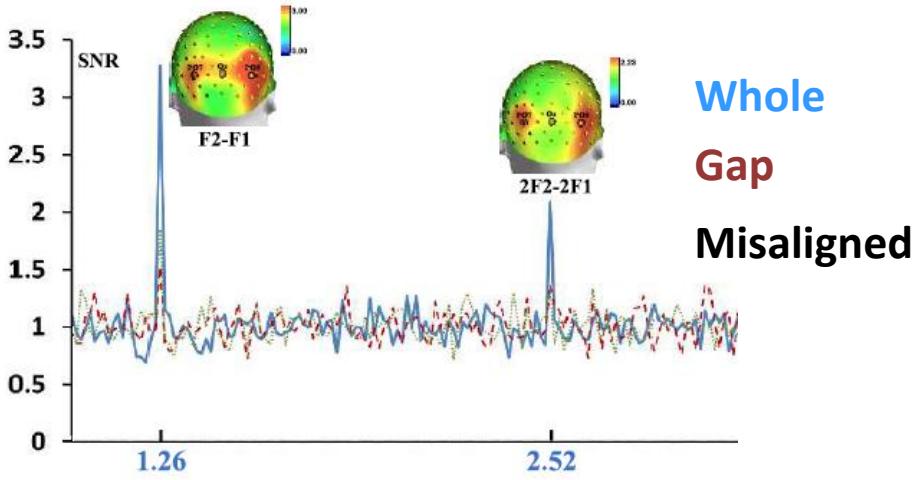
• Integration of face halves into a unified representation, a so-called holistic representation.



Response to part and whole faces



Integration (whole-base responses)



- The response to parts and whole in the same block (same time)
- The response to whole is not only the sum of the independent parts

(Boremanse et al., *Journal of Vision*, 2013)

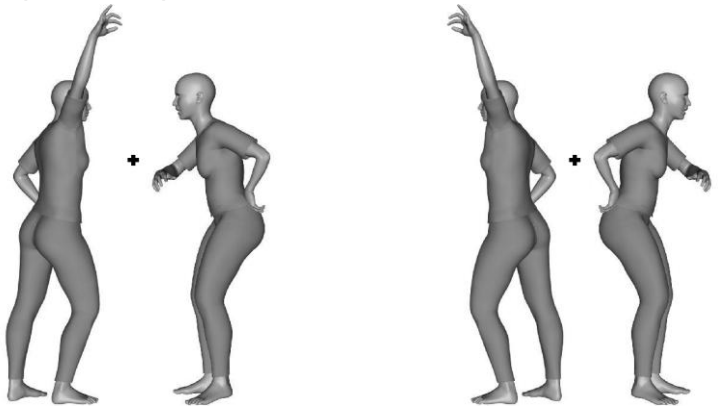
Visual binding of individual bodies into groups of interacting bodies

Perception of individual bodies :
Responses at F1 (6.66Hz) and F2 (5.45 Hz)

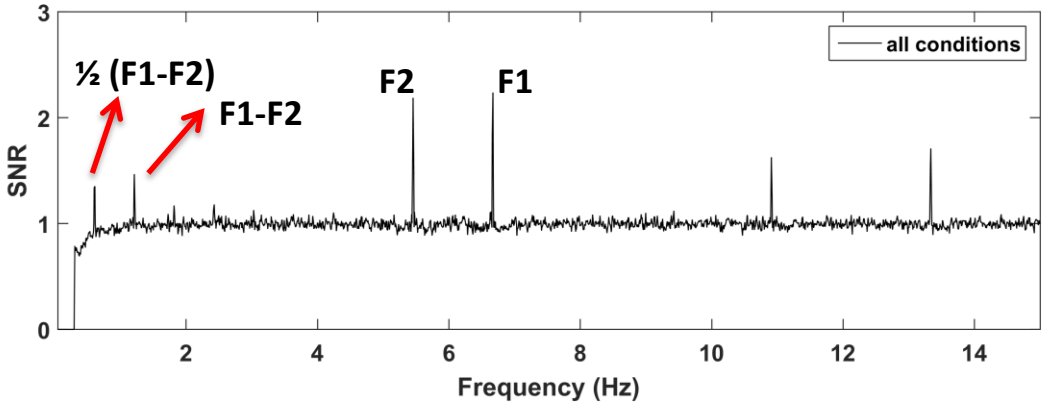
Perception of body dyads :
Responses at « Integration frequency »

Interacting **Non-interacting**

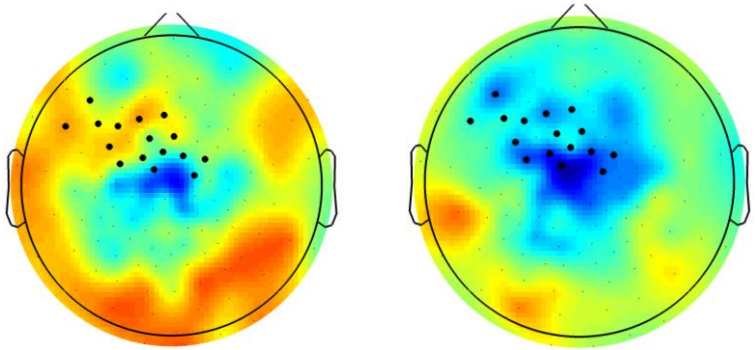
F1 **F2** **F1** **F2**



Whole brain average



Response topography at ½ (F1-F2)



Adibpour, Hochmann and Papeo, In preparation

Summary

• A temporally periodic stimulus leads to a narrowband response in the frequency domain ➔ Objective definition of response component

• Relative high SNR ➔ short duration of stimulation ➔ suitable for infant/patient studies

• Difficult to study the temporal sequence of activation, particularly when high rates of stimulation are used.

• SSVEPs can be used to study both sensory and high level visual processing through different paradigms :

- ❑ Sweep SSVEP (Detection thresholds)
- ❑ Across/within category perception using fast periodic stimulation
- ❑ Multiple object tagging for the studies of attention and also perceptual binding through Intermodulation

• Future perspective for extension of the technique to broader classes of visual (or auditory) stimulation and to studies of multisensory integration.

Reference review : Norcia et al., The steady-state visual evoked potential in vision research: A review. 2015 , Journal of Vision.

Thank you.