Exploring perceptual and cognitive processings using frequency-tagging paradigms

Parvaneh Adibpour

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

- Event-Related Potentials (ERPs) :
  - Isolated, discrete stimulus event
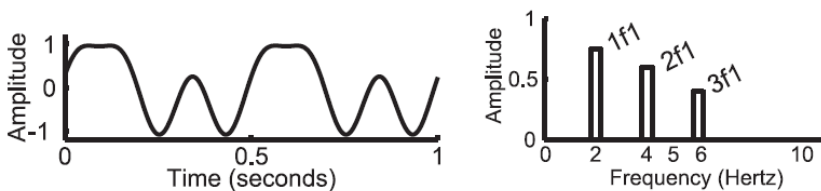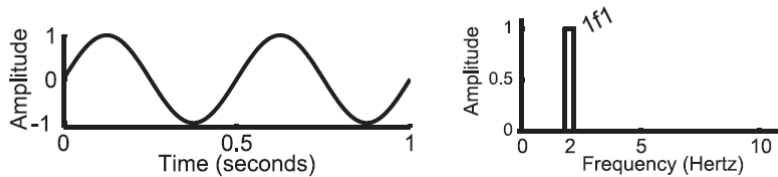 - Large/variable inter-stimulus intervals
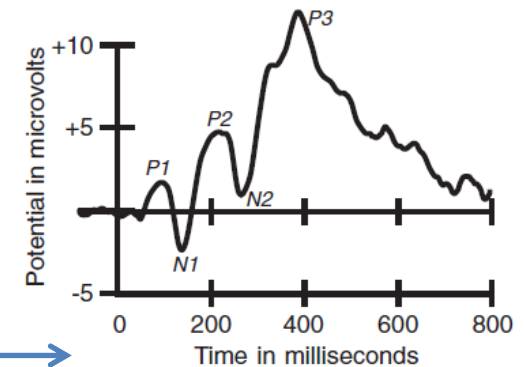
- Steady-State Visual Evoked Potentials (SSVEPs)   (Regan, 1966)
  - Periodic visual stimulation (stimuli train) at a predefined frequency
  - Short inter-stimulus intervals
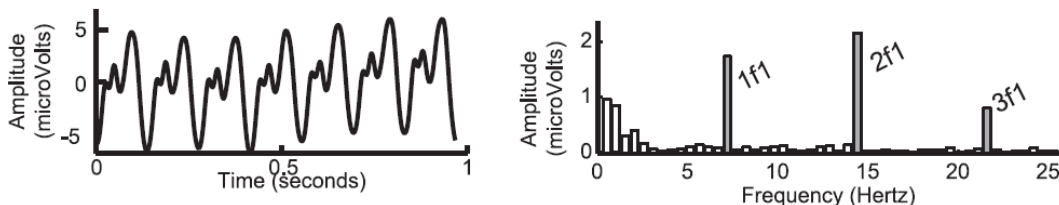 - Overlapping-responses
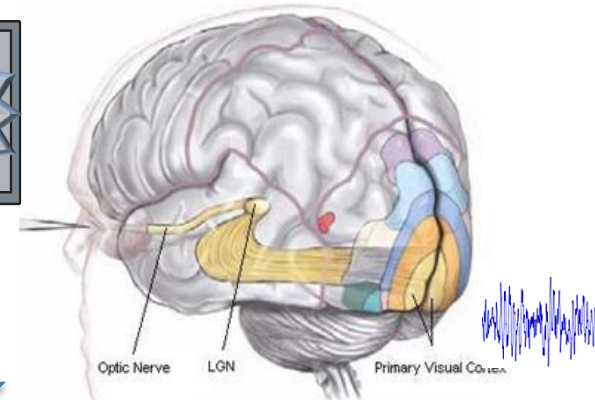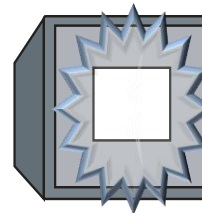
Frequency domain responses

Responses at the stimulation frequency (F) and its harmonics (2F, 3F, 4F):
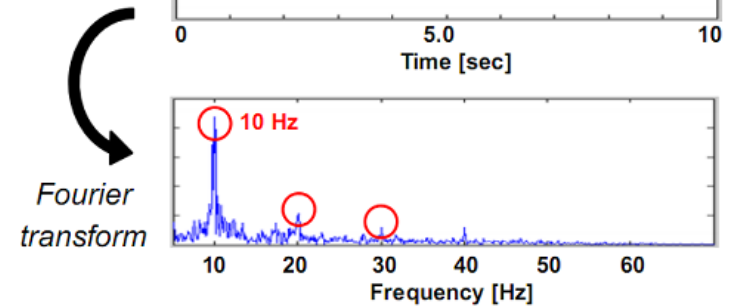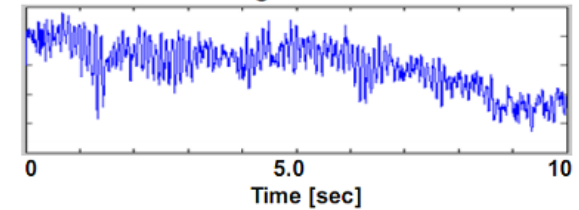
→ Nonlinearity of the visual system

10 Hz stimulus

EEG signals at Oz

Fourier transform

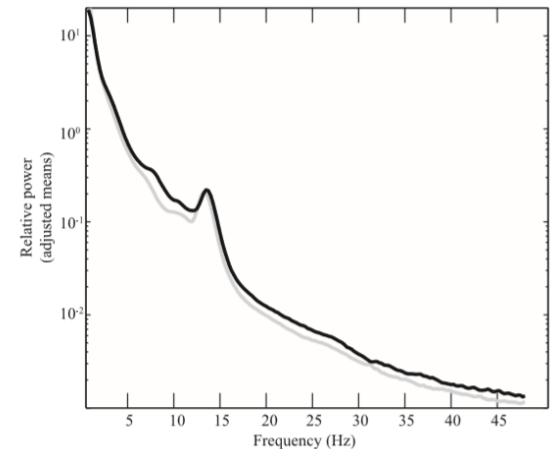❑Objective signature of the response frequency contents (predefined stimulation rate)

❑ 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

SSVEP

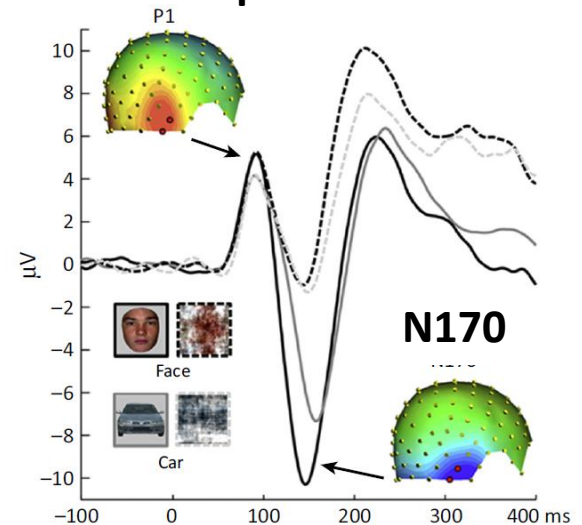(Norcia et al., Journal of Vision, 2015)

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

N170

➔ 1/170 ms = 5.88 HZ

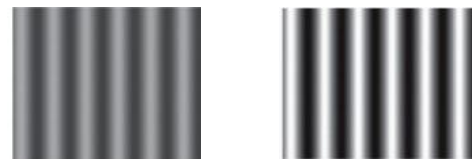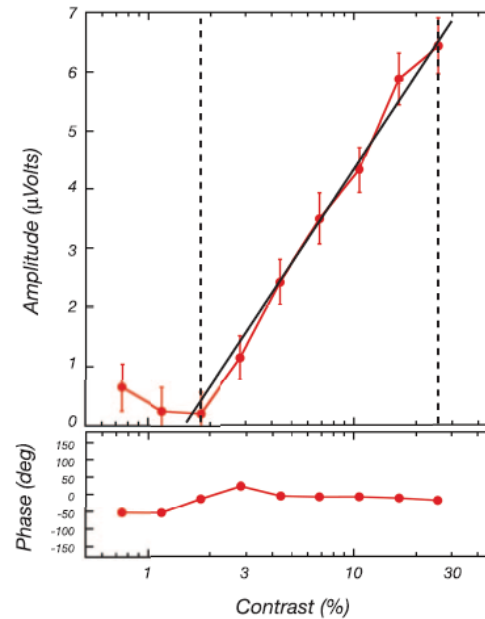# SSVEP responses reflecting low level visual processes

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)
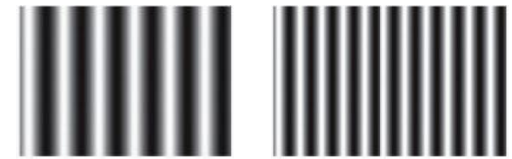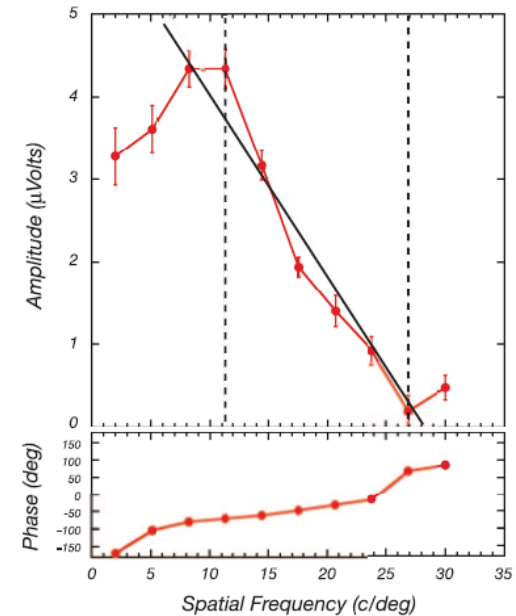
Contrast sensitivity

Spatial acuity

Low contrast → High contrast

low spatial freq → high spatial freq

Parametric modulation of contrast

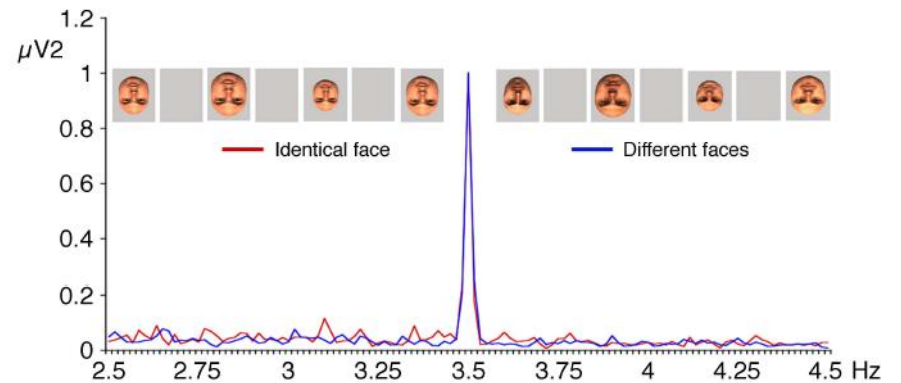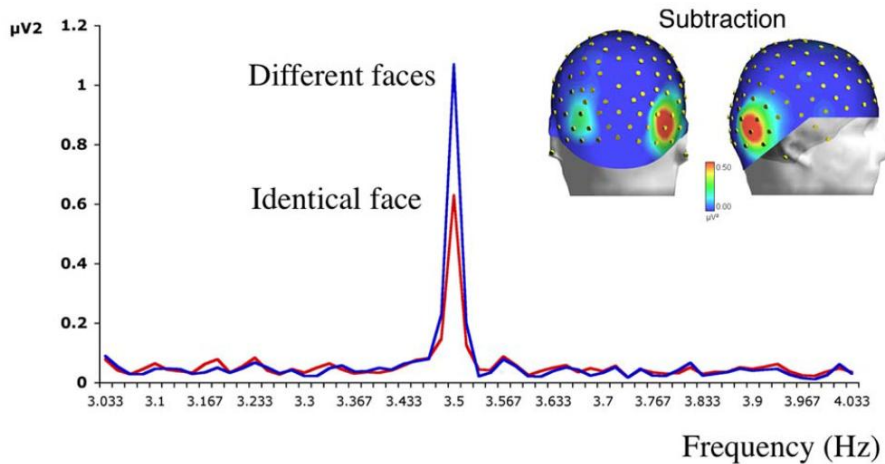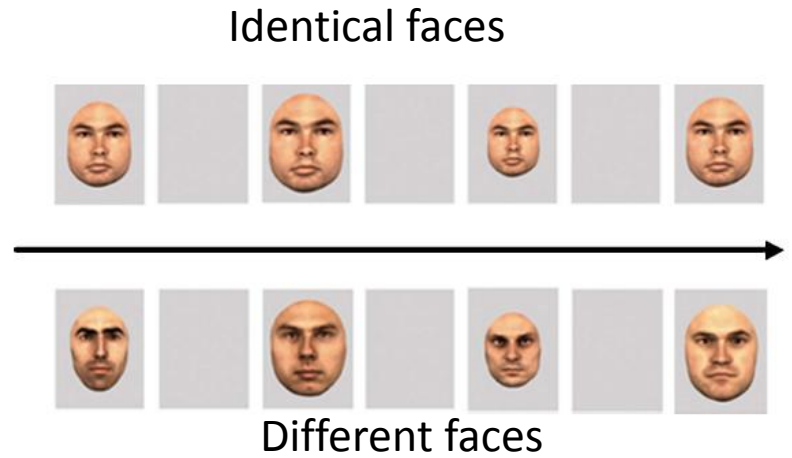Parametric modulation of spatial frequency

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

Increase in visibility with time

20 seconds

Hypothetical EEG response

1 second

3Hz

Mean response time

Key: ● Signal
— Noise

Ales et al., Journal of vision, 2011
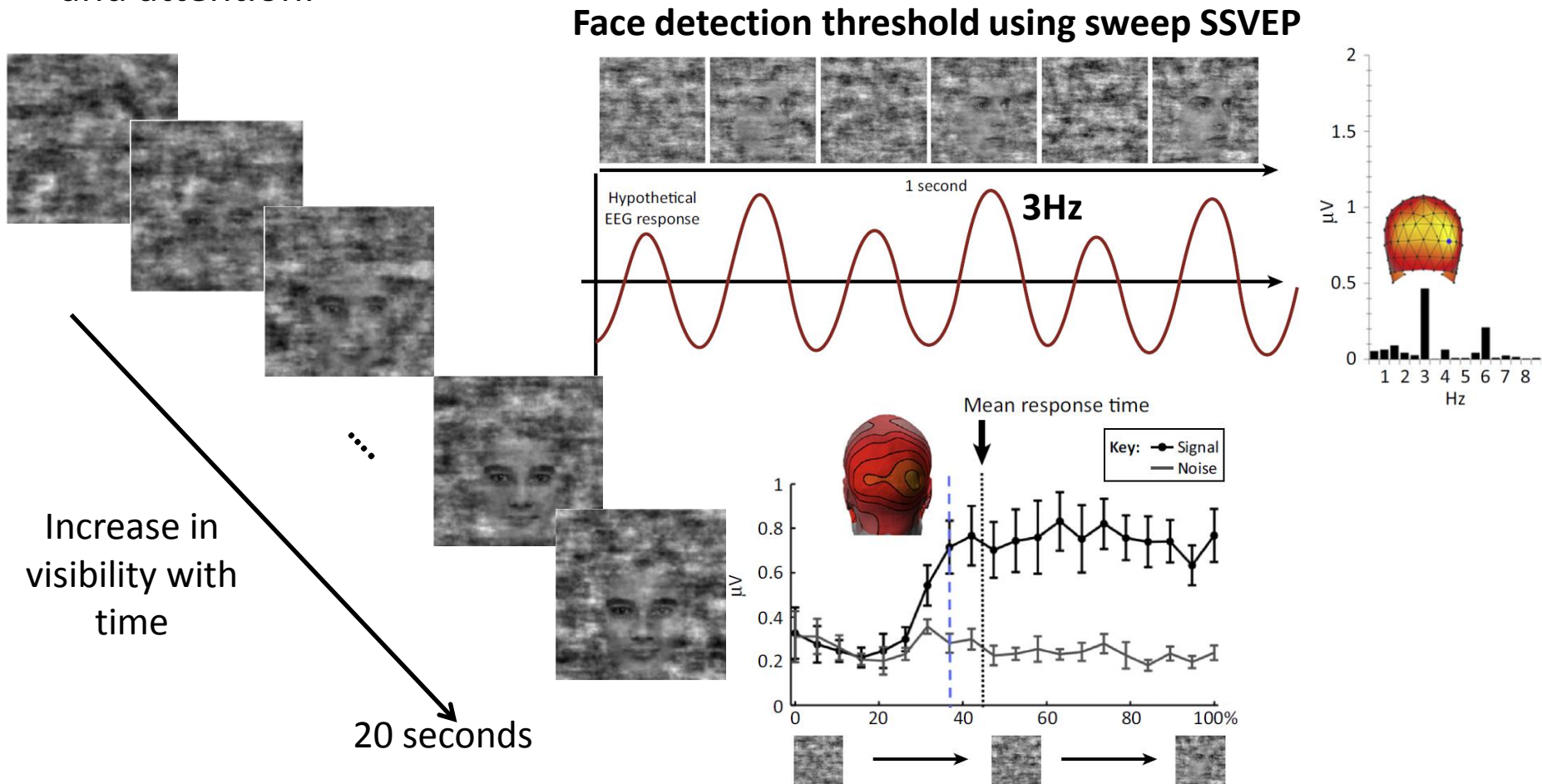
Face identity processing
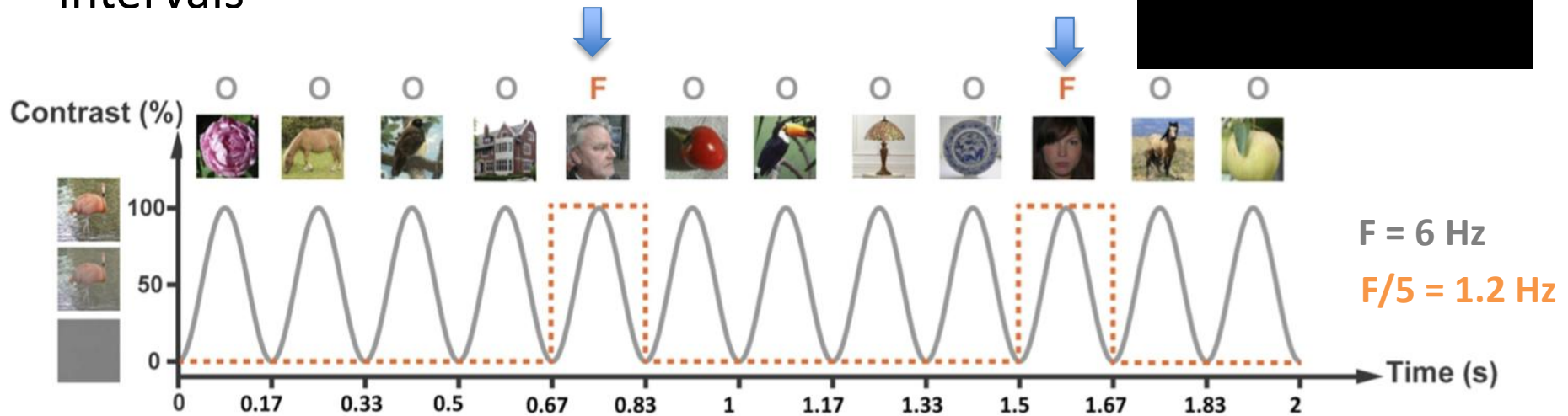
- Periodic presentation of identical or different faces

Identical faces

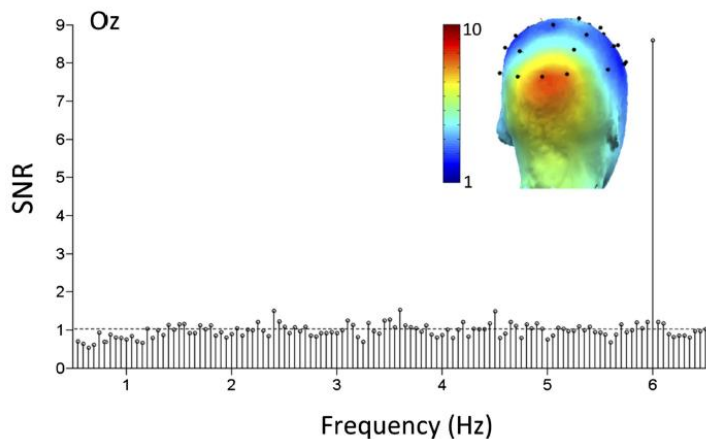Different faces

Subtraction
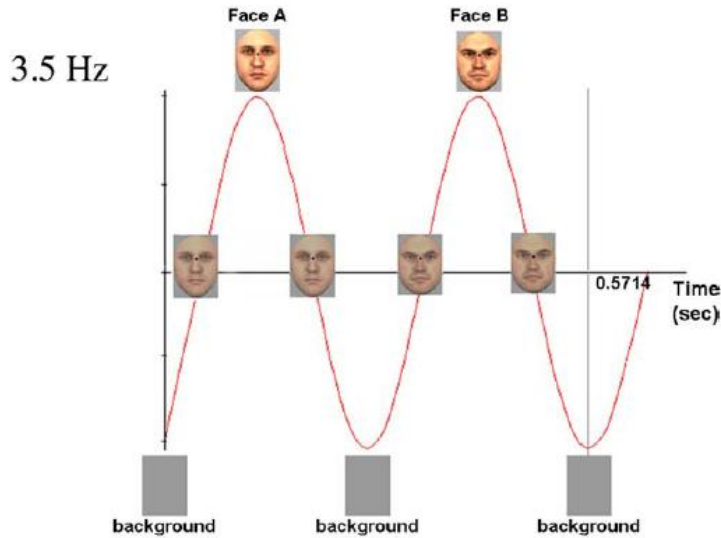
(Rossion & Boremanse, Journal of vision, 2011)

Face categorization

Stream of images with faces inserted at regular intervals
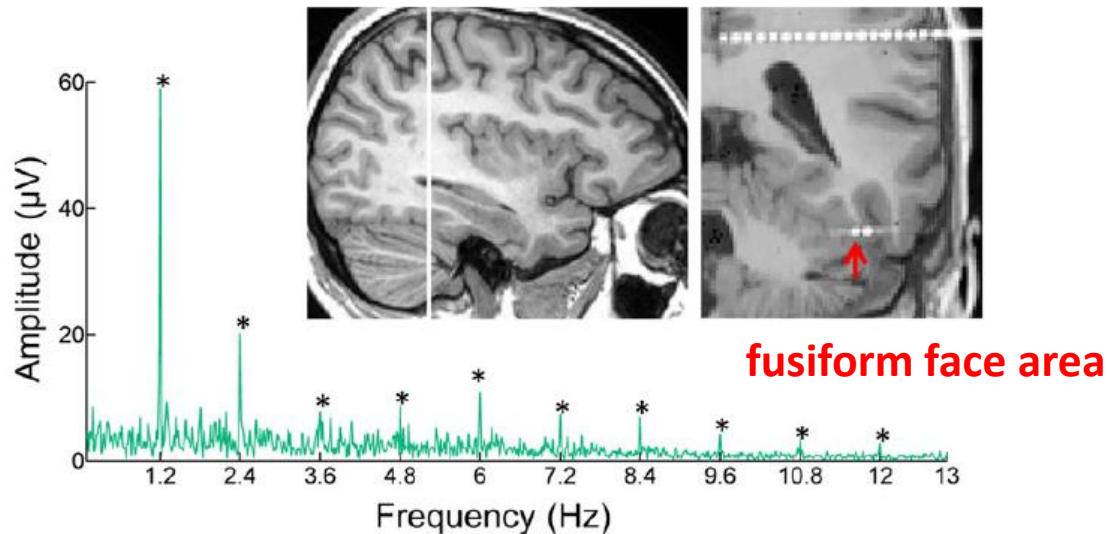

F = 6 Hz

F/5 = 1.2 Hz

Response at base stimulation

Response at face rate

de Heering, Rossion eLife 2015
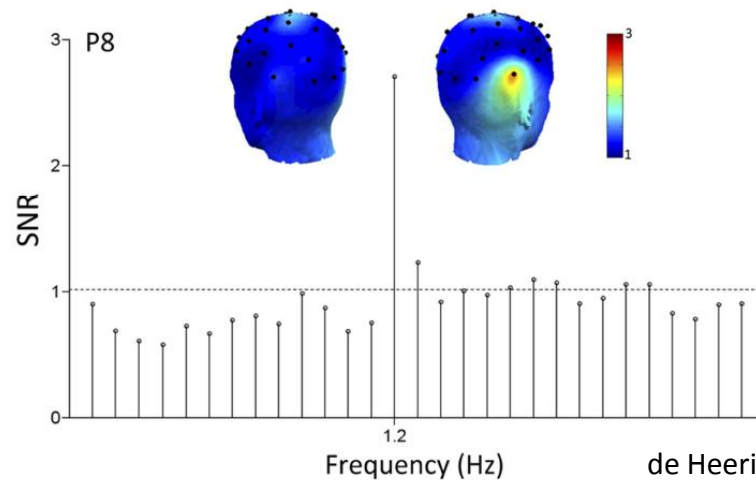
Face categorization in the ventral occipitotemporal cortex with direct neural intracranial recordings

Base frequency: 6 Hz — Face-selective frequency: 6 Hz/5=1.2 Hz

fusiform face area
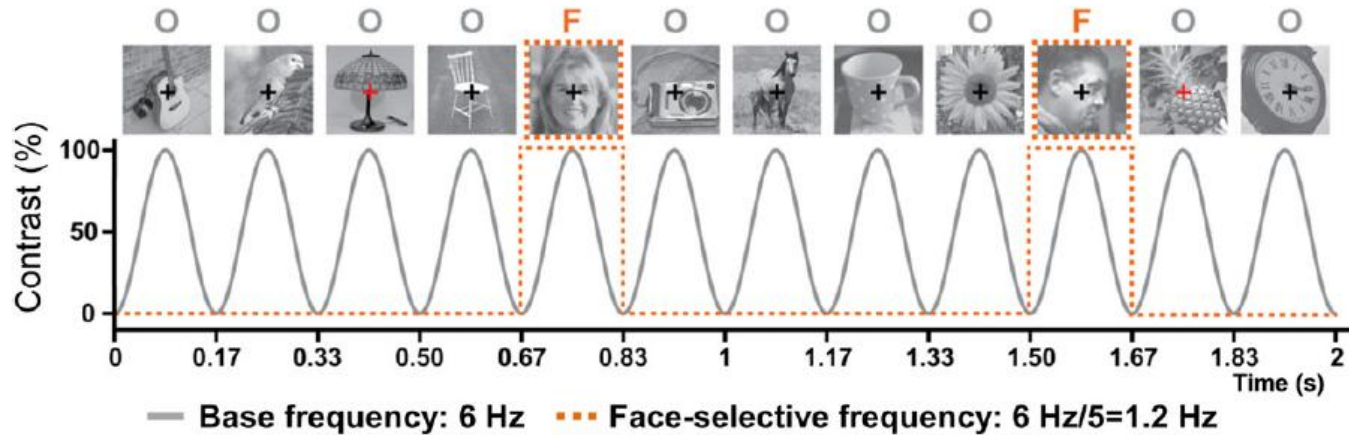
Visual word categorization
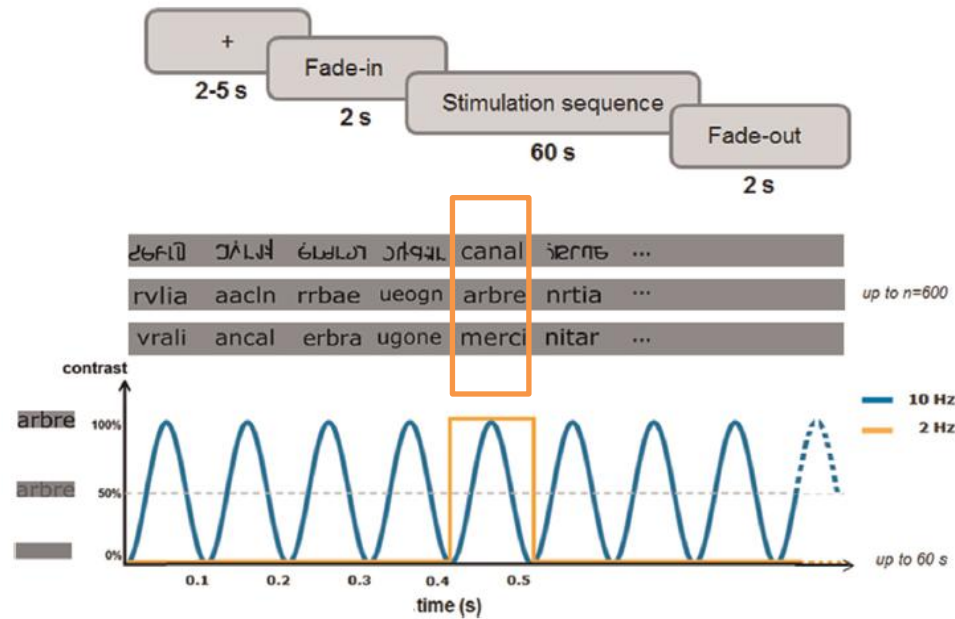
Response at base stimulation
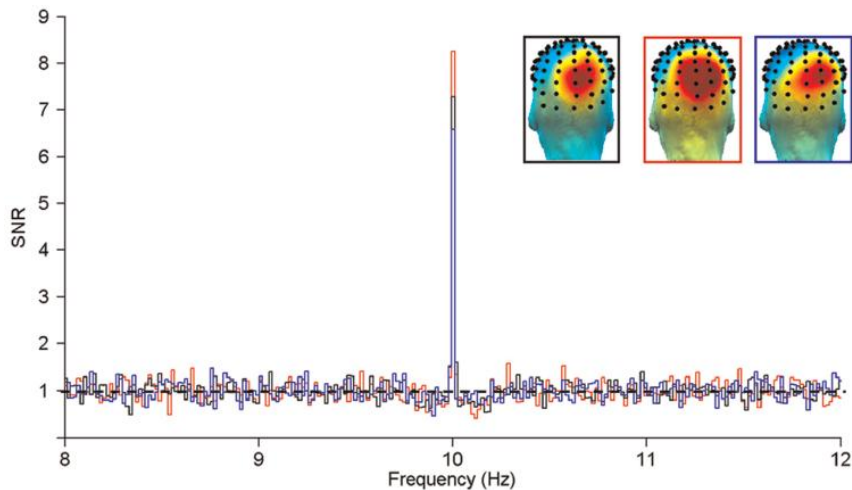
Response at word rate

Lochy, Van Belle, & Rossion, Neuropsychologia., 2014
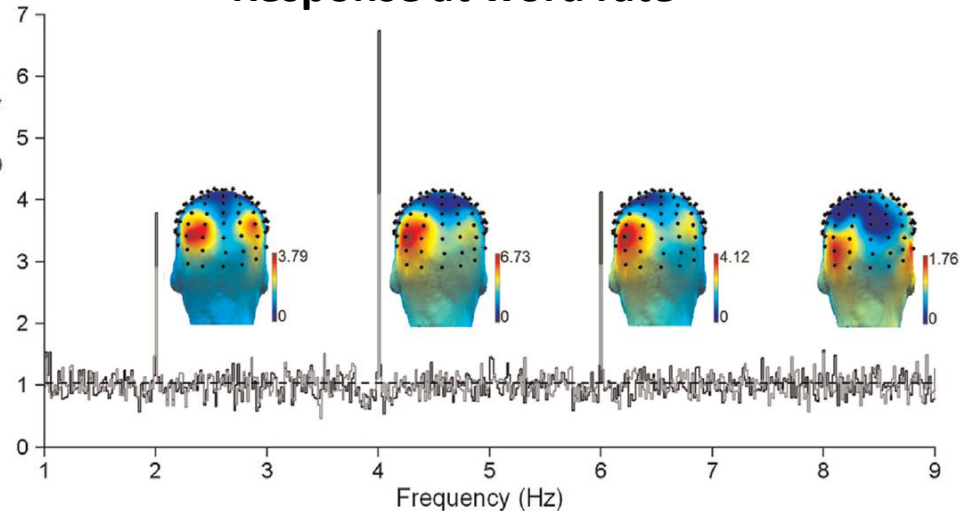
Multiple periodic visual inputs

• Studying attention and perceptual grouping

Spatial locations tagging

Feature tagging

(Muller et al., pnas 2006)
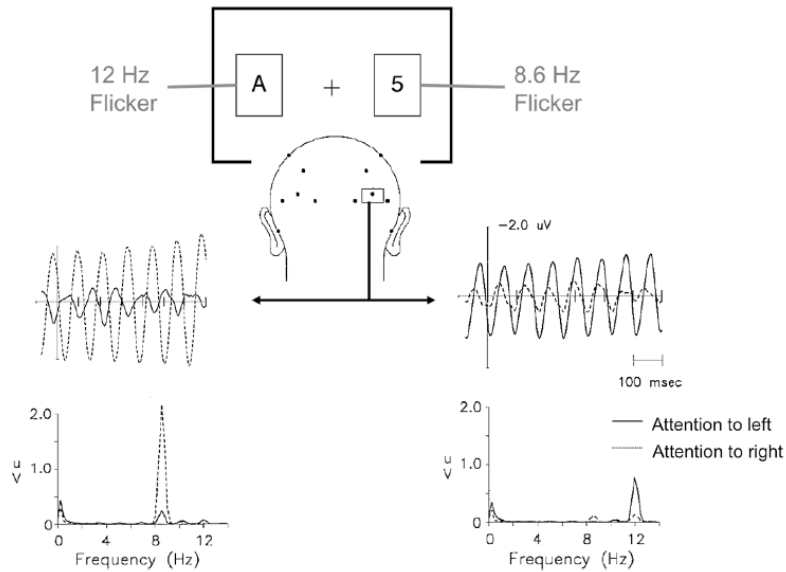
(Morgan, Hansen & Hillyard., pnas 1996)

Multiple feature tagging

• Applications to brain-computer interfaces
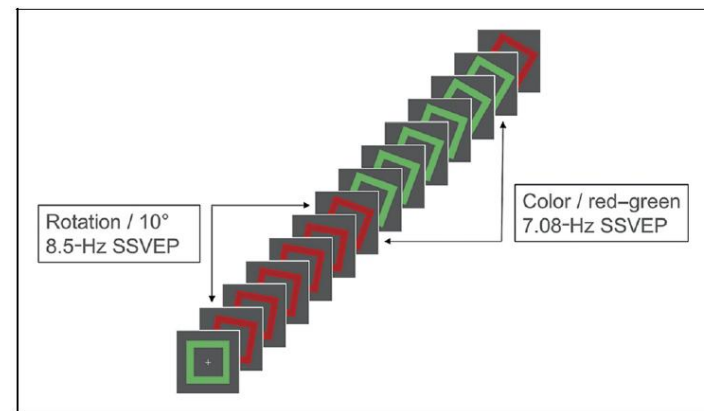
(Brummerloh, Gundlach, & Müller., J of Cog Neuroscience, 2018)

Perceptual grouping: integrating parts into a whole

❑ A visual scene or object is composed of parts
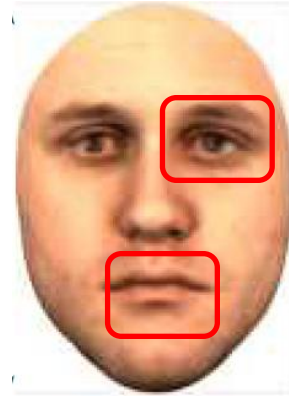
❑ How does the brain put these parts together?

■ 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.

Whole   **Gap**   **Misaligned**
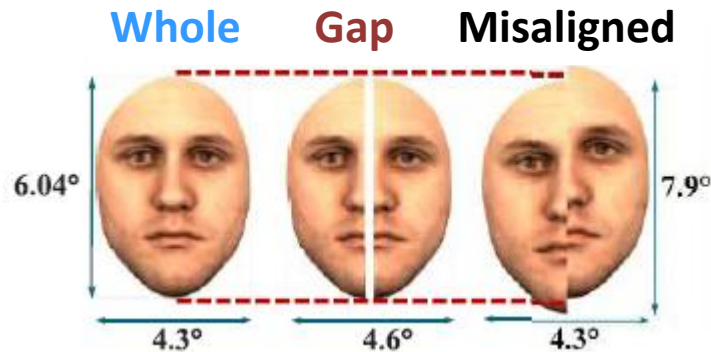

Response to part and whole faces   **Integration (whole-base responses)**
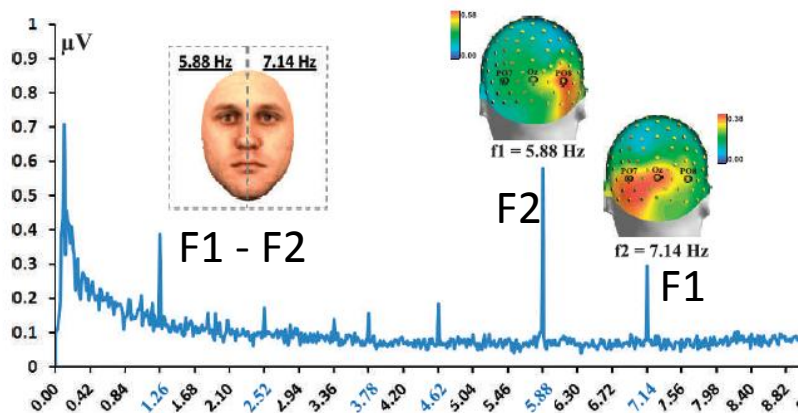
F1 - F2

F2

F1

Whole

Gap

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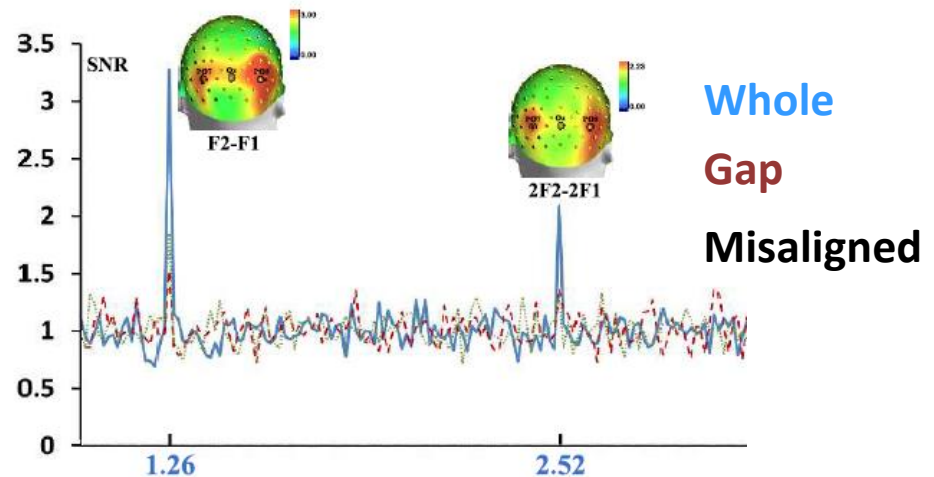
- The response to parts and whole in the same block (same time)
- The response to whole is not only the sum of the independent parts

(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 »

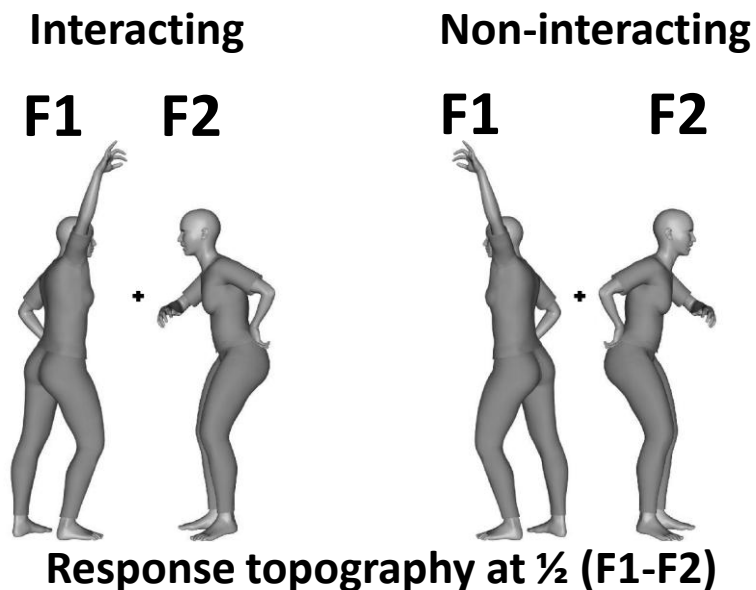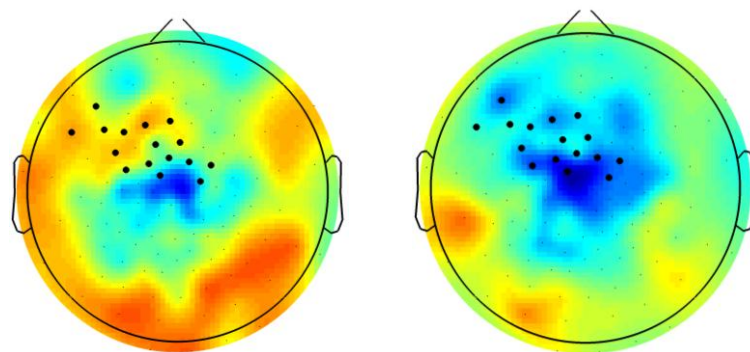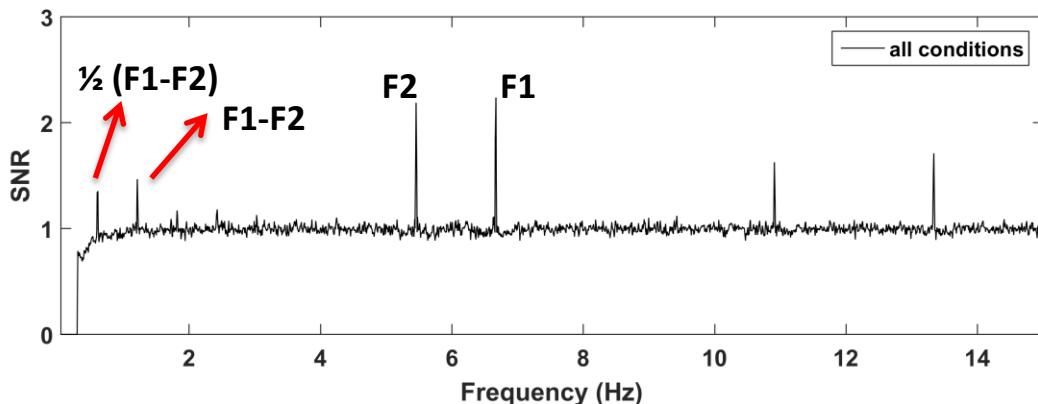**Interacting**   **Non-interacting**

F1   F2   **F1   F2**

Response topography at ½ (F1-F2)

Whole brain average

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.