BMS-EEG-Research-Hub

Lecture 1: On the Limits of ERPology and Fourierology

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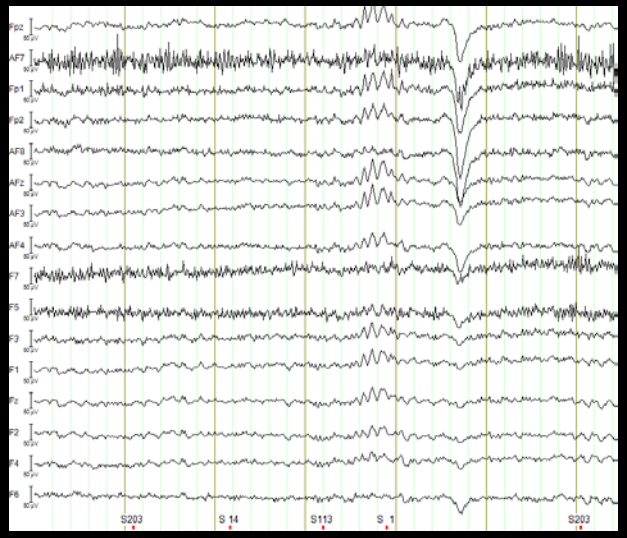

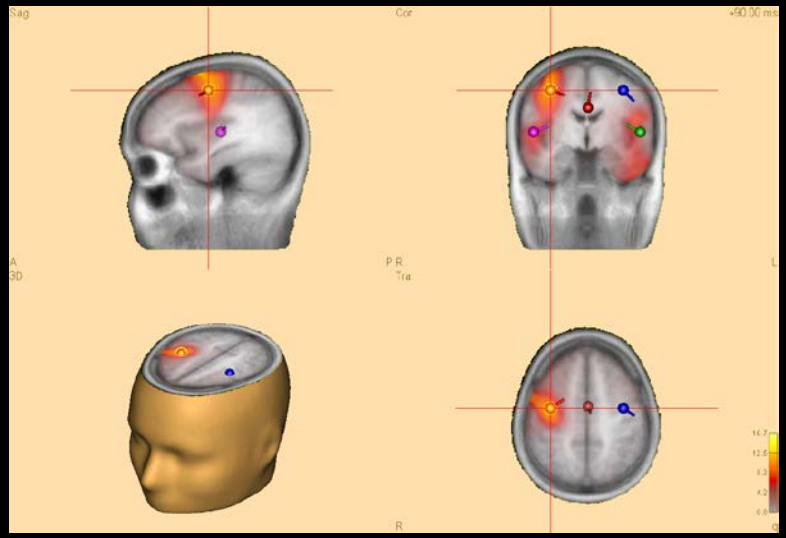

An Introduction to the event-related potential technique (Luck, 2014)

. I ran a quick Google Scholar search and found more than 27,000 articles that refer to "P3" or "P300" along with "event-related potential." This is an impressive amount of P3-related research. In addition, the Sutton et al. (1965) paper has been cited more than 1150 times. There is no doubt that many millions of dollars have been spent on P3 studies (not to mention the many euros, pounds, yen, yuan, etc.).

During the 15 years after the publication of this paper, a great deal of research was conducted that focused on identifying various cognitive ERP components and developing methods for recording and analyzing ERPs in cognitive experiments. Because people were so excited about being able to record human brain activity related to cognition, ERP papers in this period were regularly published in *Science* and *Nature*. Most of this research was focused on discovering and understanding ERP components rather than using them to address questions of broad scientific interest. I like to call this sort of experimentation "ERPology" because it is simply the study of ERPs.

ERPology experiments do not directly tell us anything important about the mind or brain, but they can be very useful in providing important information that allows us to use ERPs to answer more broadly interesting questions. A great deal of ERPology continues today, resulting in a refinement of our understanding of the components discovered in previous decades and the discovery of new components.

ERPology and Fourierology

ERPology: “the use of ERP components as markers of specific cognitive processes”

Fourierology: “the use of power in specific frequency bands as markers of specific cognitive processes”

P300 or P3 or P3a or P3b

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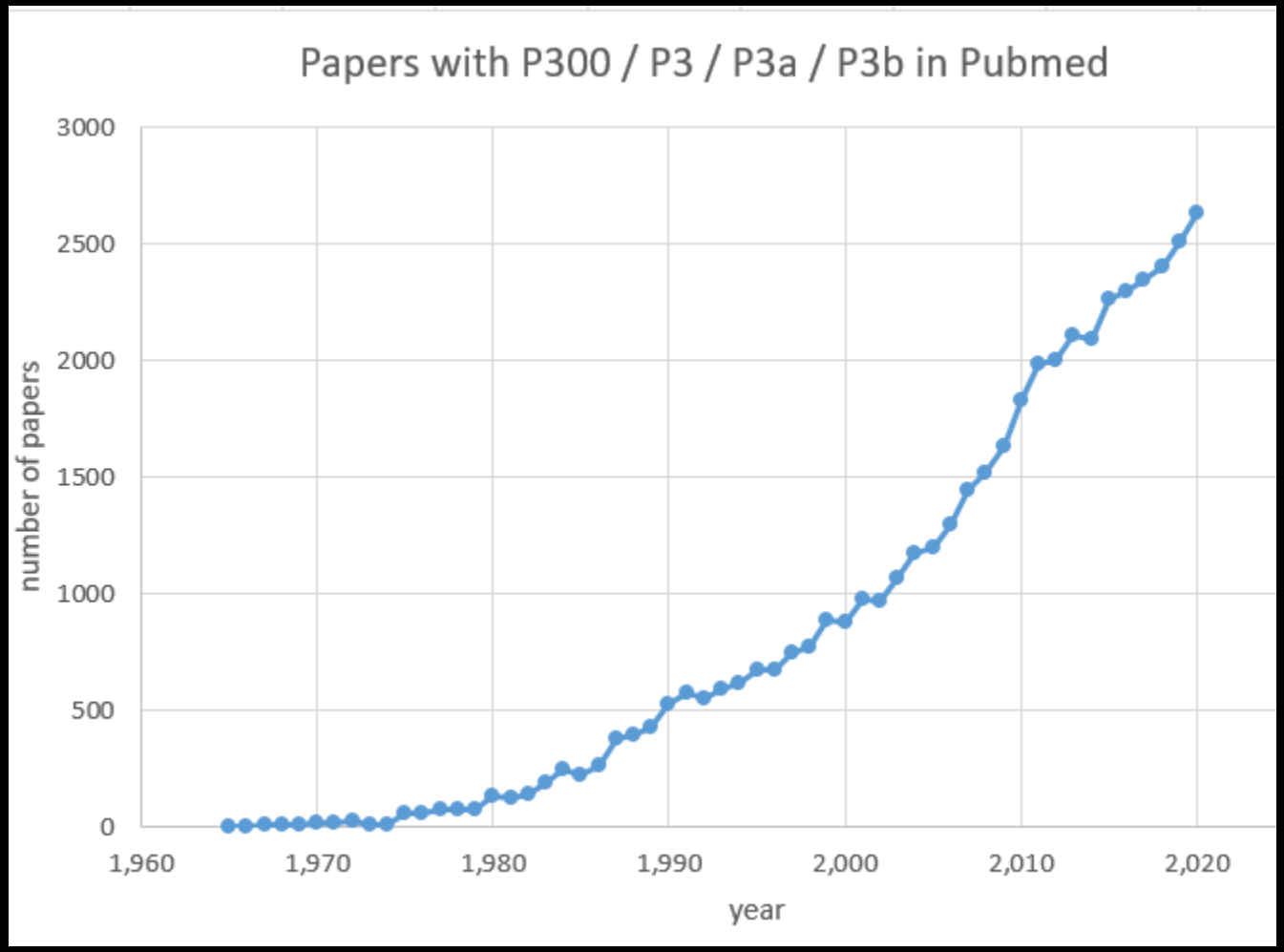
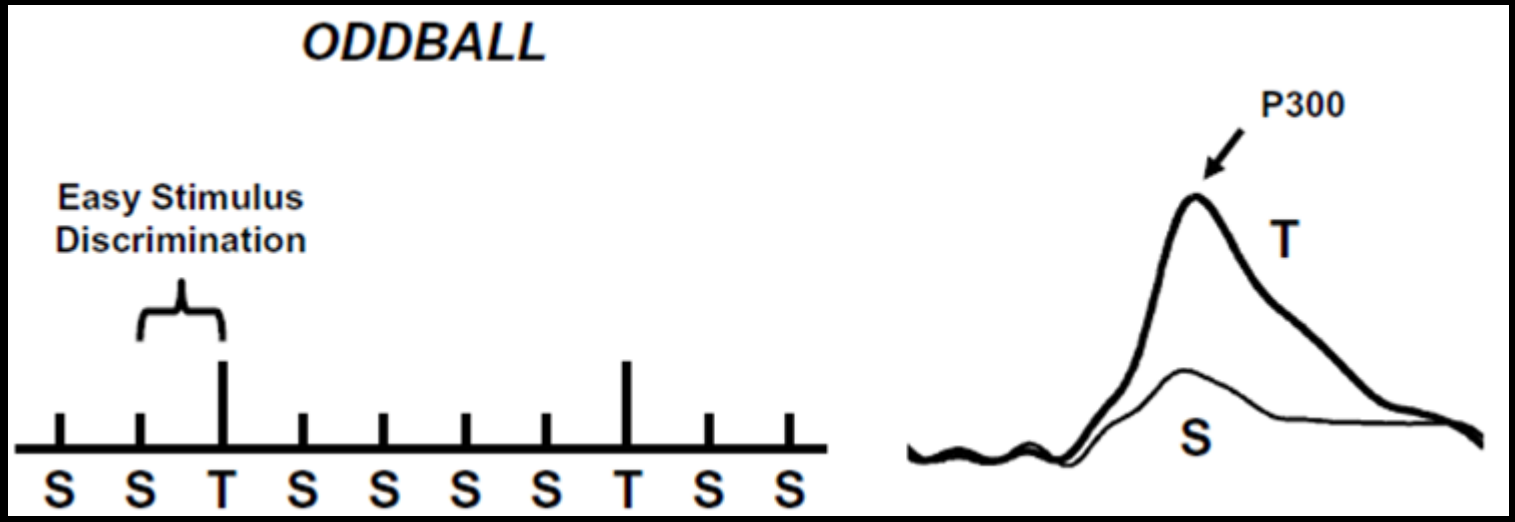


The Oddball P3

Polich (2007)



Verleger (2020) in the special issue of Psychophysiology: Fifty years of P300: where are we now?

1) The oddball effect is mainly an effect of temporal infrequency.

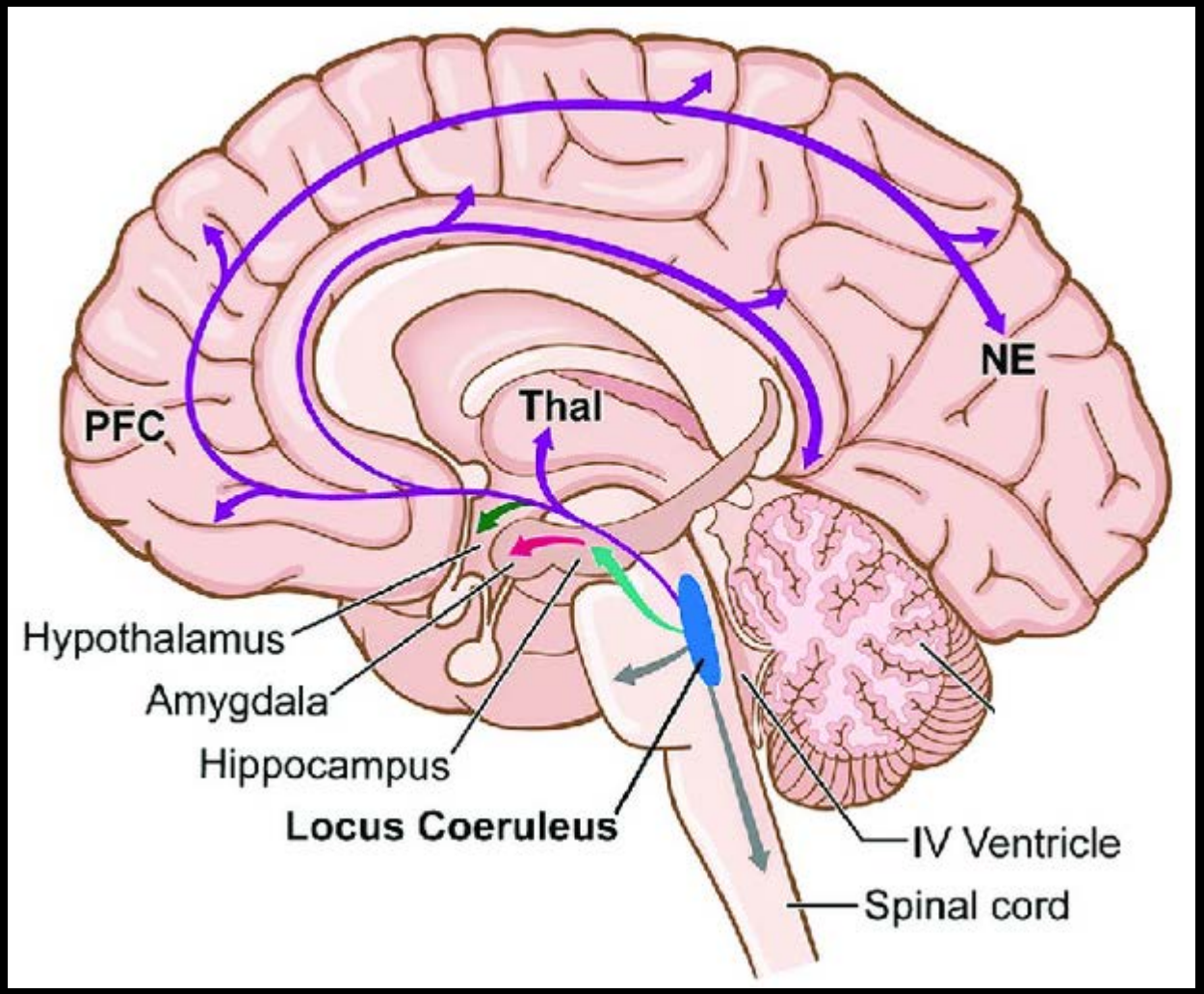
2) The effect of stimulus infrequency is actually an effect of response-defined stimulus infrequency.

3) With stimuli to be predicted, the effect of frequency manifests as effect of frequency of outcomes (i.e., the specific combinations of prediction and stimulus) rather than of frequency of stimuli.

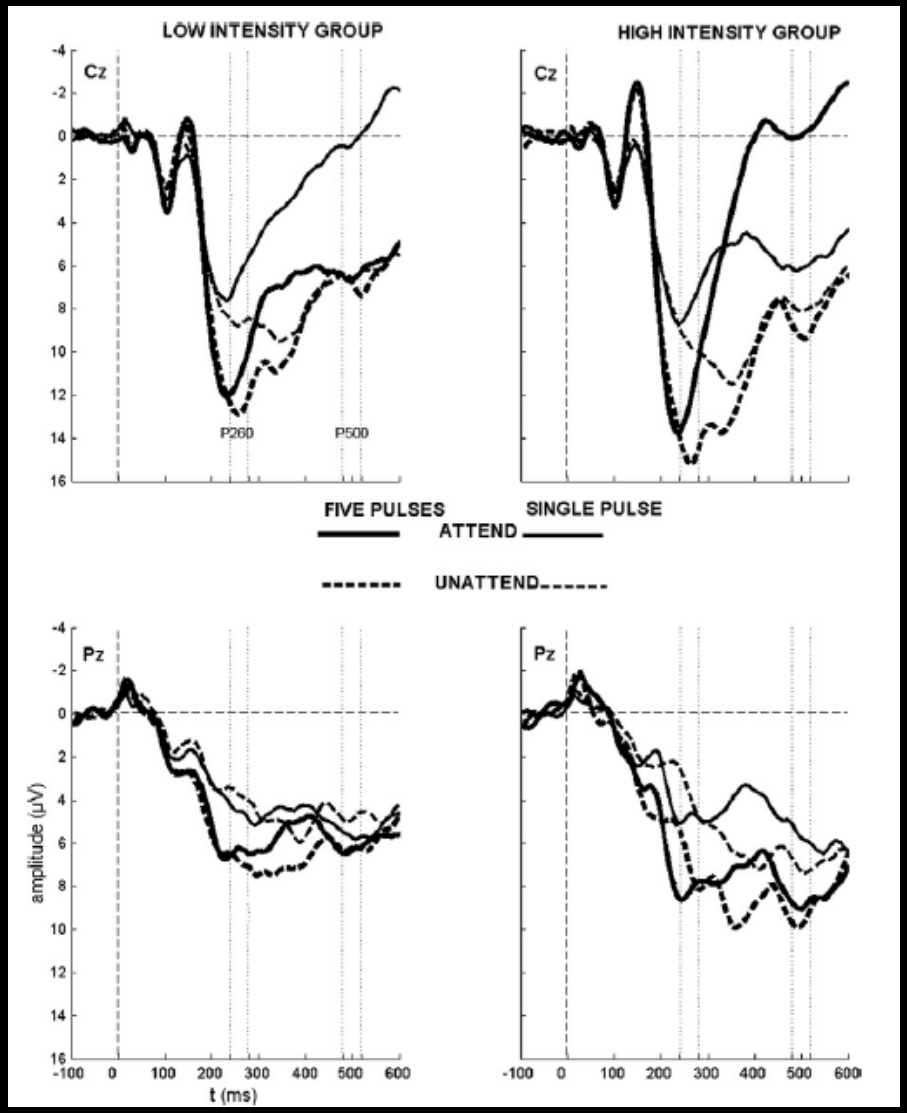
4) In signal detection, P3b is determined by frequency of hits rather than by frequency of signals.

5) The oddball effect is substantially increased when there is a task associated with the stimuli.

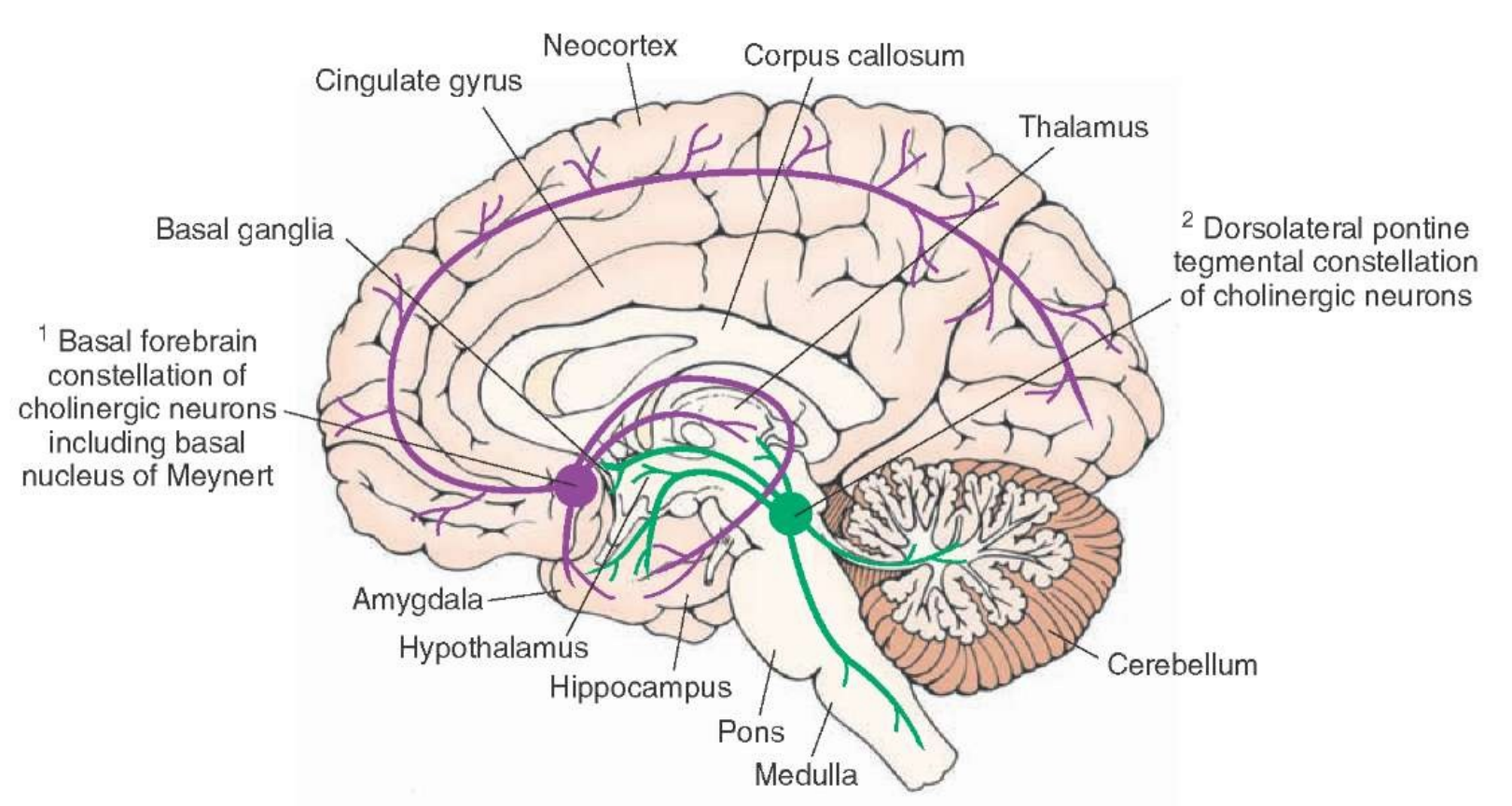
Locus coeruleus-norepinephrine system



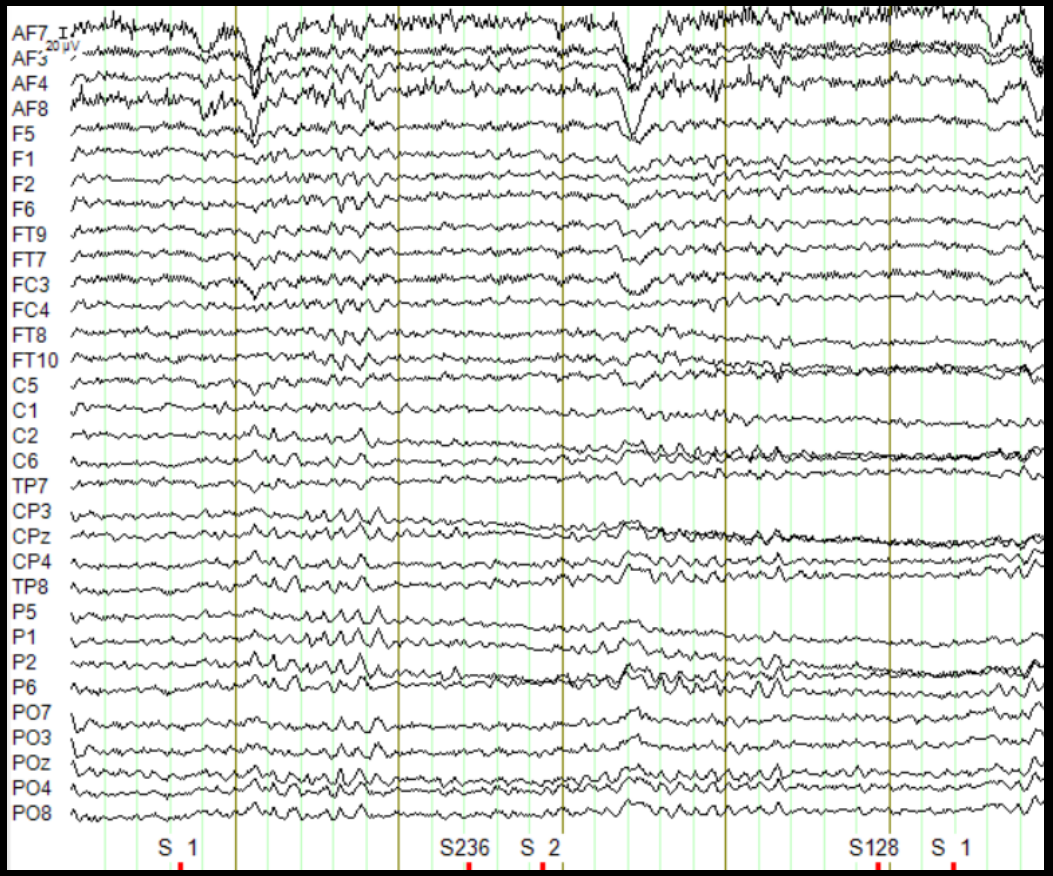
An example of ERPs with P3a and P3b-like components Van der Lubbe et al., (2012)



The cholinergic system

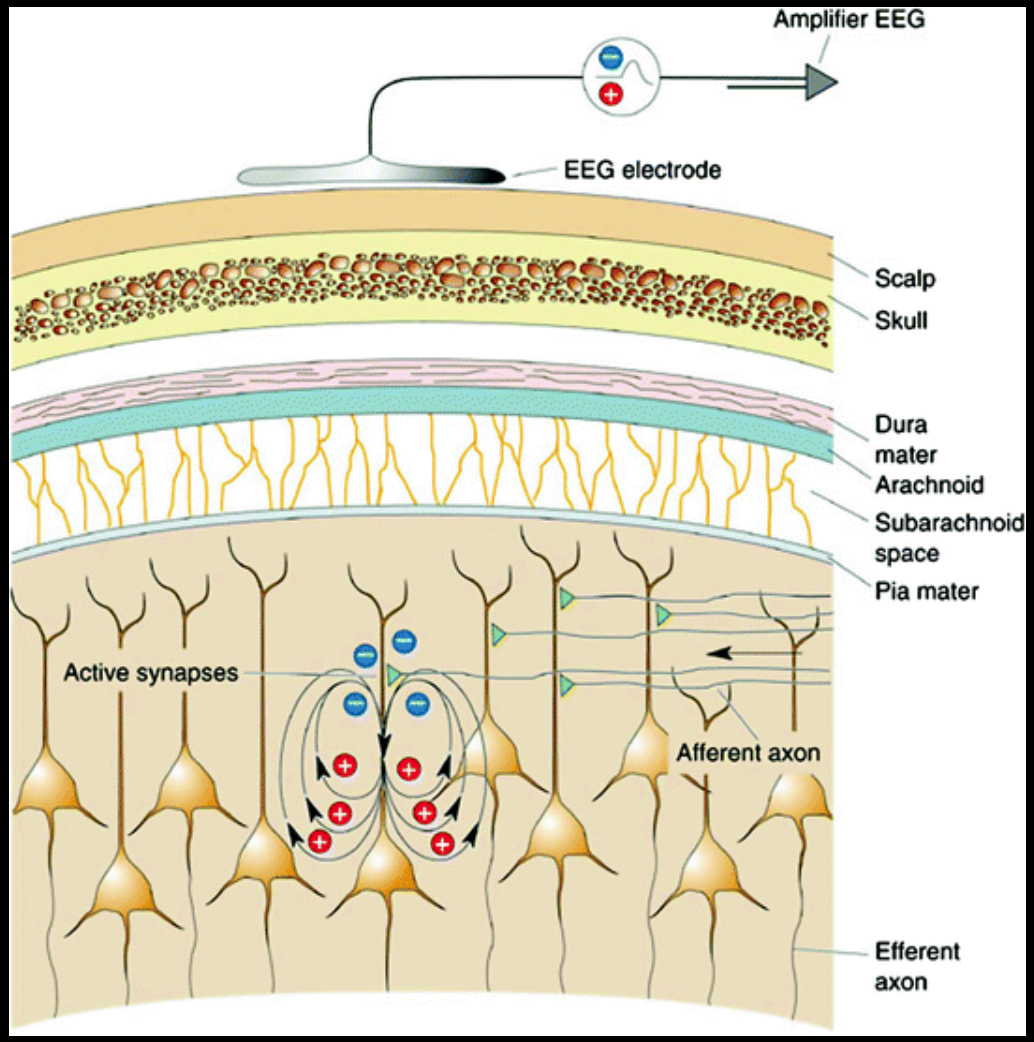


ERPS must be somehow related to the raw EEG or ?



But what do we pick up with the raw EEG?

excitatory/inhibitory post-synaptic potentials

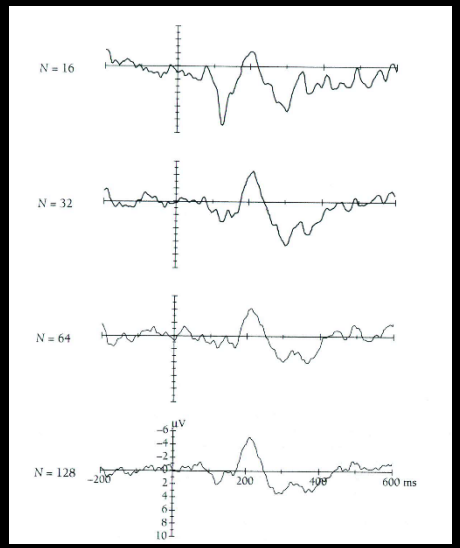


ERP: an average of several single trial EEG measurements

Assumptions:

1) The relevant signal related to an event is superimposed on the background EEG
2) Averaging reduces background EEG (with $\sqrt{n}$)
3) The relevant signal (ERP) remains

The “pebble in the sea” analogy (Thierry, 2019)



But the sea may not be that calm...

Conditional reasoning applied to neuroimaging data (Iannetti et al., 2013; see also Luck & Kappenman, 2012)

Example 1 * When John does laundry, he uses more electricity. * John is doing laundry. * Therefore, he is using more electricity. (modus ponens)

Example 2 * When John does laundry, he uses more electricity. * John is using more electricity. * Therefore, he is doing laundry. (affirming the consequent)

Conditional reasoning applied to ERPs
(see also Luck & Kappenman, 2012)

If a stimulus is relevant (P) then (Q) a P3 component will be elicited

- No P3 component means a stimulus is not relevant
- But presence of a P3 component does not imply that the stimulus was relevant (Affirming the consequent); see OEPs Jongsma et al., 2004
- ERP components cannot so easily be used as markers of cognitive processes

The Pain matrix

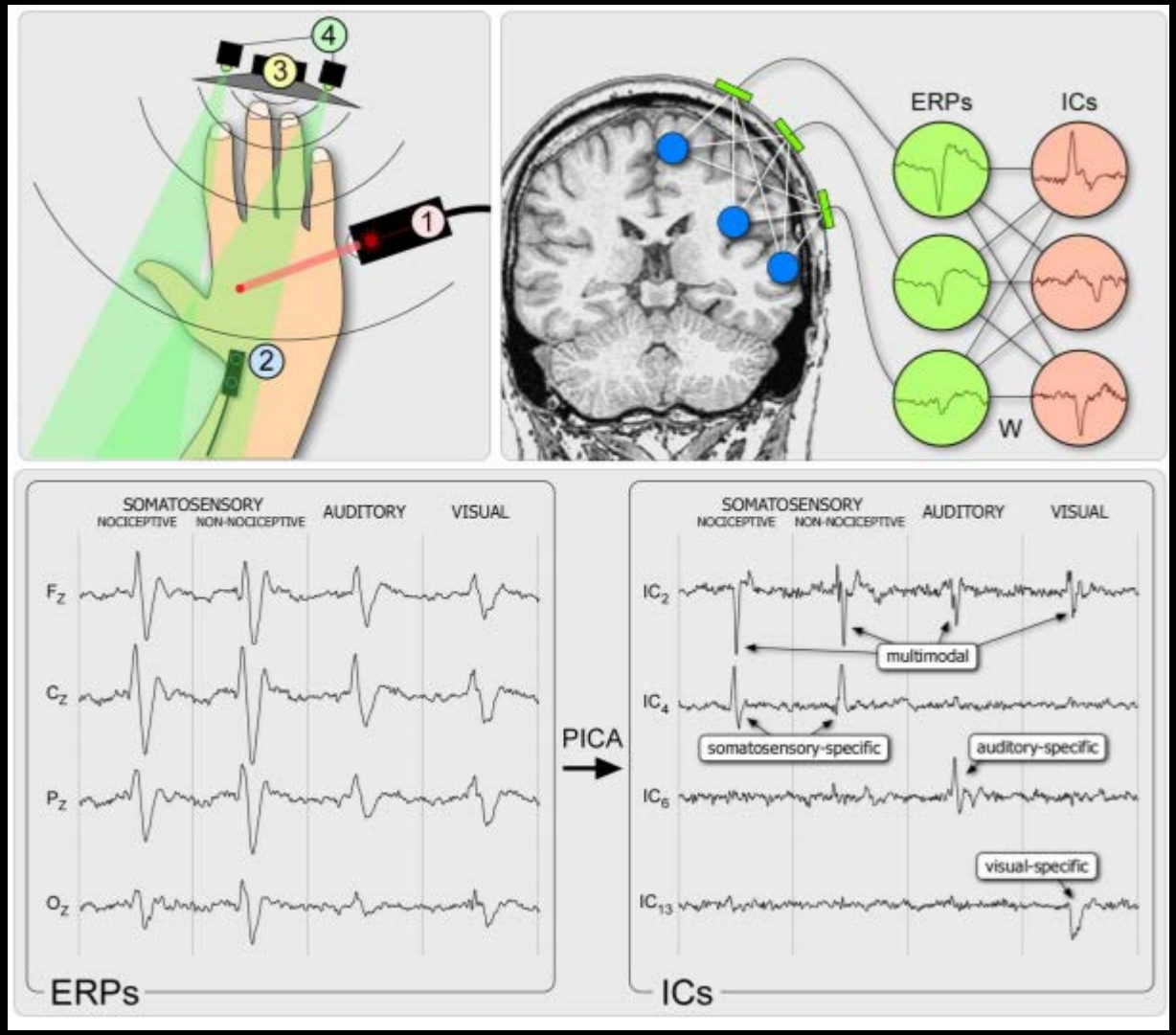
- Painful (nociceptive) stimuli that selectively activate Aδ and C fibers activate a network of brain areas (SI, SII, insula, ACC), that became known as the pain matrix.

- As the experience of social distress activates these same regions, researchers (e.g., MacDonald & Leary, 2005) concluded that “social distress really hurts”

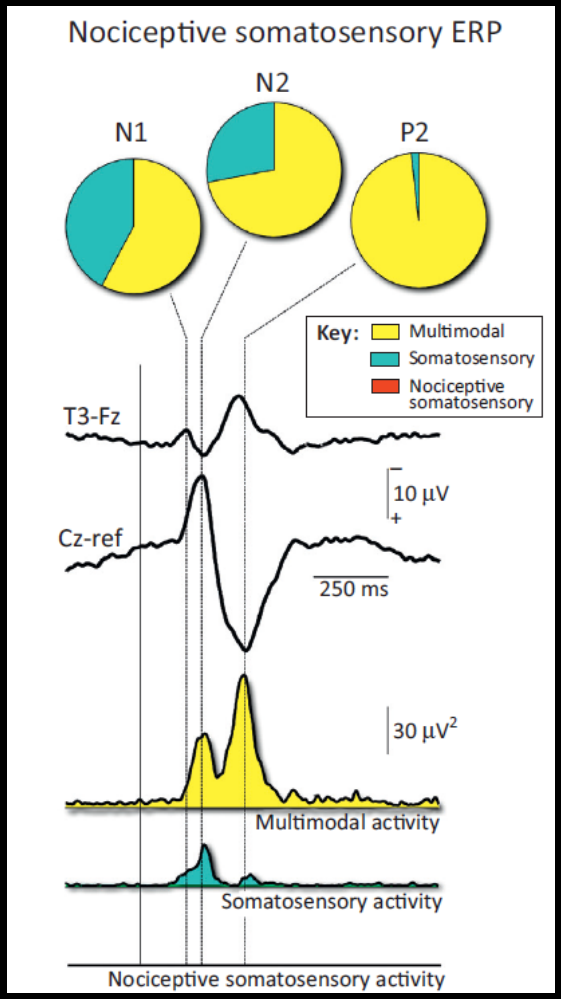
But ...

- Example 3 * If an individual feels pain, the pain matrix is activated. * The pain matrix is activated. * Therefore, the individual is experiencing pain.

And … (Mouraux & Iannetti, 2009)



There seems to be no unique nociceptive response …



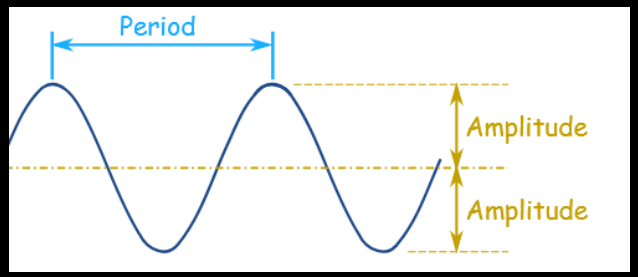
How to avoid the logical error of “affirming the consequent”?

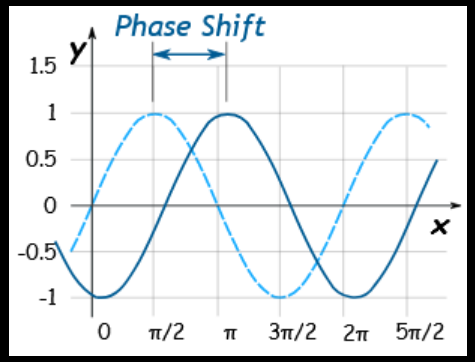
- Apply the “falsification principle” of Popper (1934), seek for failures in the literature of proposed hypotheses, one failure is enough …
- Do not blindly follow interpretations presented in the literature (also not from respected researchers)
- Use straightforward and highly selective measures (e.g., sensory components, lateralized components that crucially depend on motor activation (i.e., the LRP) or spatial attention (i.e., PCN or N2pc; e.g., see Van der Lubbe et al., 2001)
- Set up crucial experiments that allow for falsification

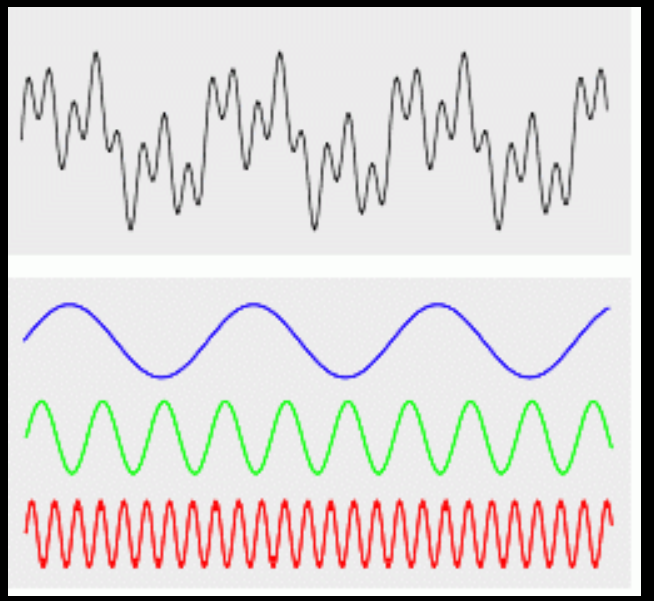
Fourier analysis

What is Fourier analysis?

The decomposition of a complex (e.g., physiological) signal into its basic components that can be described as sinuses with a certain periodicity, amplitude, and phase.







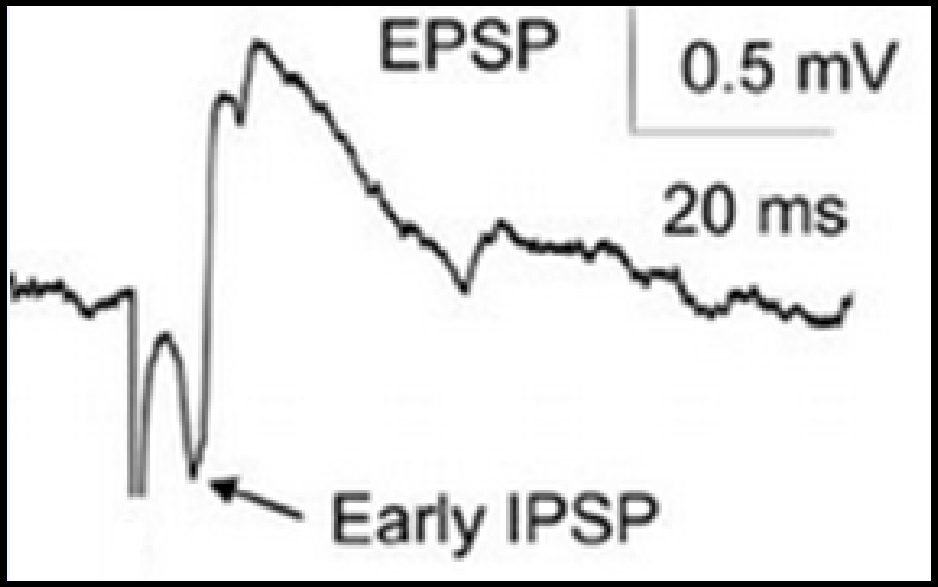
Fourier analysis

On the basis of Fourier analysis of the EEG a distinction has been made between various frequency bands like alpha (~8-12 Hz), beta (~12-24 Hz), theta (~4-8 Hz), delta (~1-4 Hz), sub-delta (< 1 Hz), and gamma (>24 Hz).

Alpha and delta have been related to inhibition, while gamma has been related to attentive processes

But: specific brain areas do not produce sinusoidal signals, but rather complex signals that contain both low and high frequencies, especially when there are sharp peaks.

EPSPs and IPSPs generated by the medial geniculate nucleus of a mouse (Llano et al., 2014)

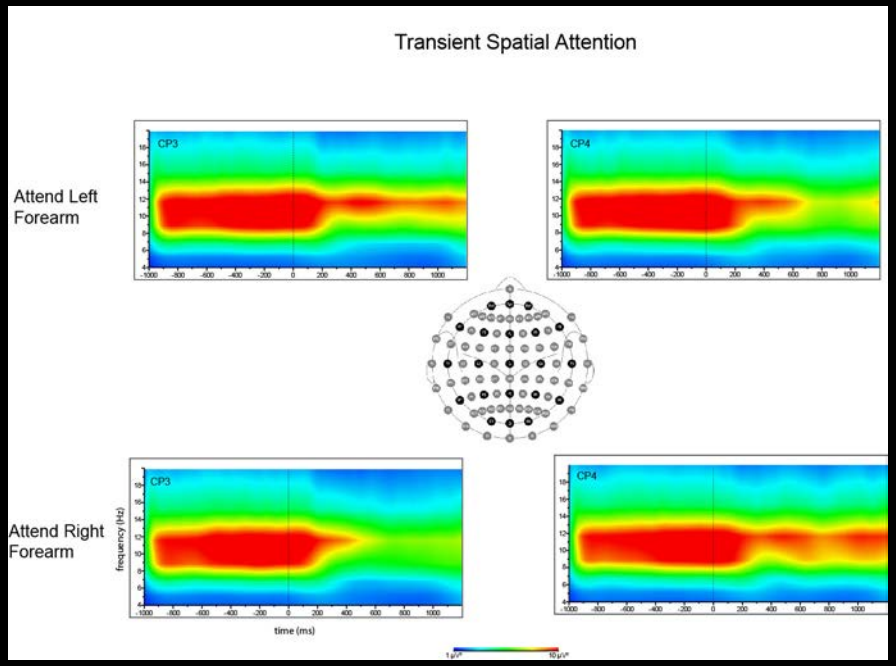


Some implications

- Different frequencies may be related to the same underlying process
- The meaning of different frequency bands may differ between brain areas / topographies
- But, the interpretation of observed activities seems more straightforward than in case of ERPs, e.g., inhibition or activation.

Time-frequency (TF) analyses

- It is also possible to determine the presence or power of a specific frequency band at a moment in time (e.g., with wavelet analyses).

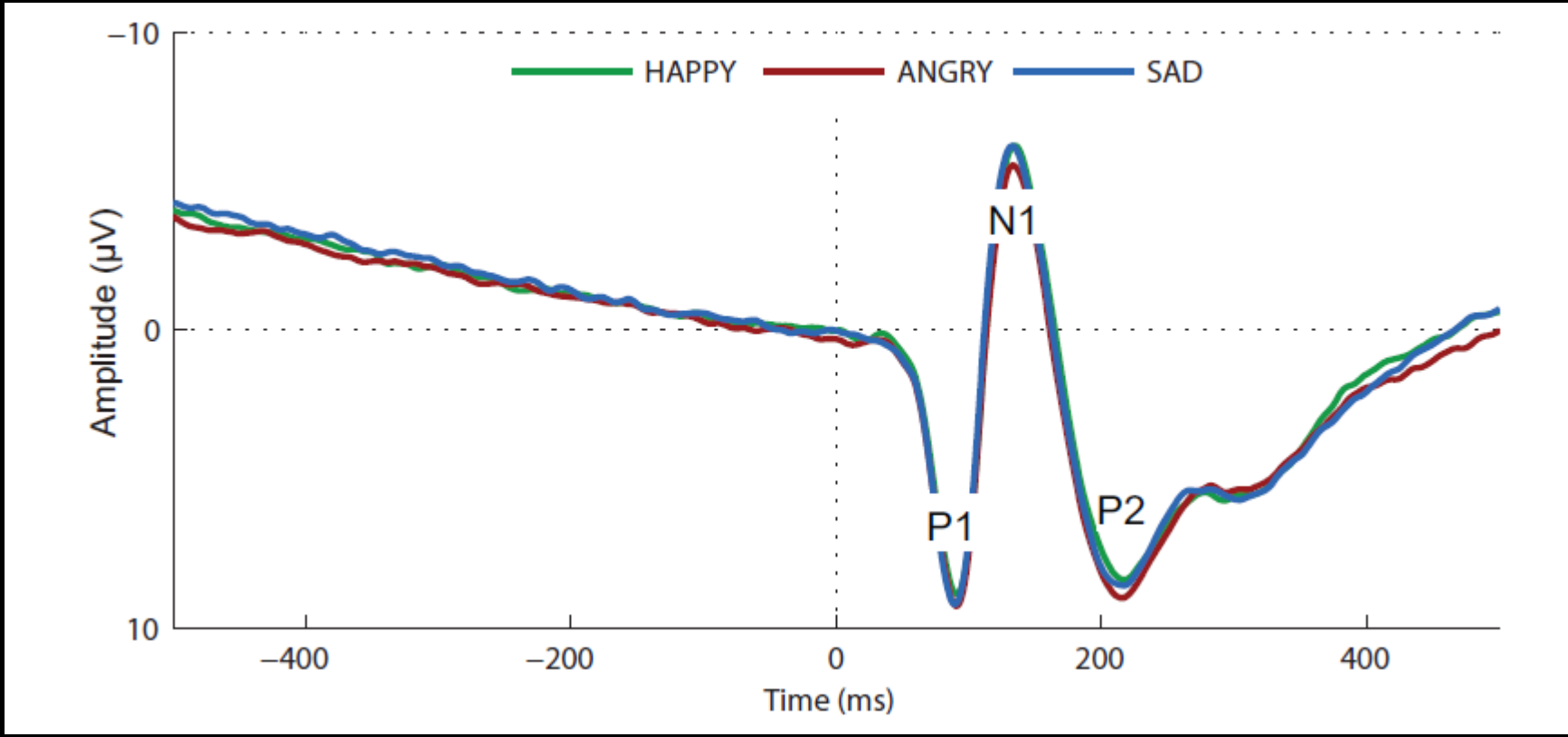


Time-frequency (TF) analysis and ERPs

Time-frequency analyses may help to improve our understanding of ERPs:

- Can certain ERP components be related to basic frequencies, and if so, what are the implications (Van der Lubbe et al., 2016)?
- They may test models concerning the origin of ERPs
- They may lead to a more balanced interpretation of observed effects in the frequency and the time domain

Relating early ERP components to basic frequencies



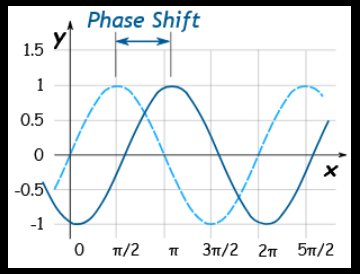
The P1 component; maybe an inhibitory component? (see also Klimesch, 2011)

Block window	variable	Happy EP (s.e.)	c_i (s.e.)
80-100 ms	ERP	8.3 (0.6)	
P1	constant		-5.9* (2.0)
	θ_1	1.57 (0.06)	-2.7** (0.8)
	θ_2	1.82 (0.05)	
	θ_3	2.07 (0.05)	
	α_1	2.15 (0.04)	
	α_2	2.02 (0.04)	9.2** (1.0)
	β_1	1.74 (0.04)	
	β_2	1.29 (0.05)	

Models concerning the origin of ERPs
Van der Lubbe et al. (2016)

The “evoked model”: ERPs are unique responses to stimuli in involved brain areas that are superimposed on the background EEG (e.g., Luck, 2014).

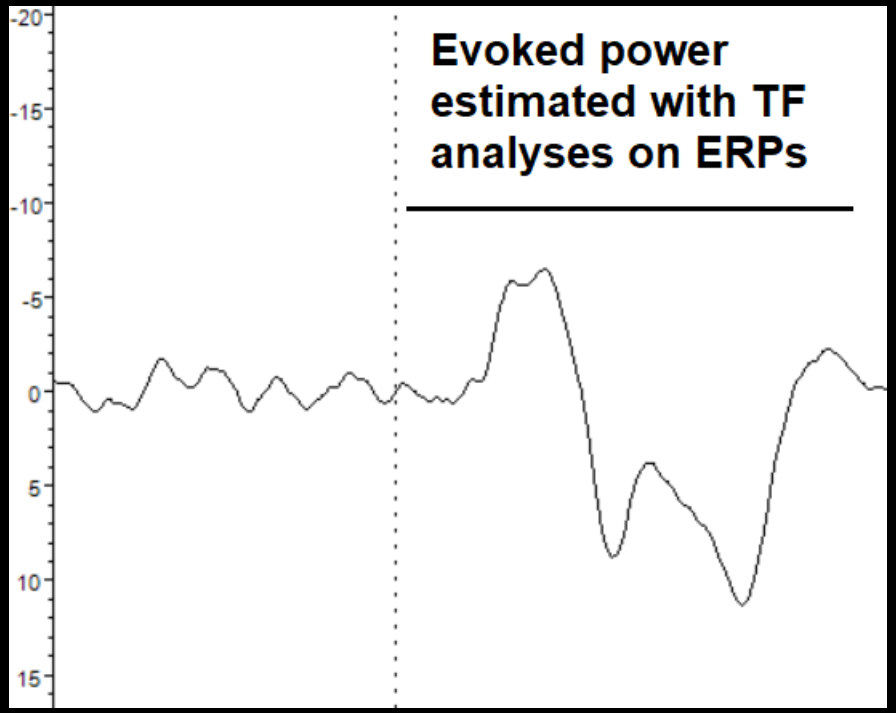
The “phase reset model”: ERPs are due to a (partial) phase reset of ongoing oscillations (Başar, 1999).



The “resonance model”: ERPs are dynamic and show unique nonlinear changes in ongoing oscillations

Distinguishing between different types of activity

Evoked power (EP) = the constant invariant activity generated by a specific event (can be derived from TF analyses on ERPs).



Distinguishing between different types of activity

Baseline power (BP) = the background activity (can be derived from TF analyses on the baseline of single trials, and then averaged).

Total power (TP) = all activity after an event (can be derived from TF analyses on single trials, and then averaged).

Induced power (IP) = the additional activity (random and/or interactive component) related to an event (can be estimated as residual).

Predictions on the relation between Evoked Power and Baseline Power

Evoked model:	EP unrelated to BP
Phase reset model:	EP strongly related to BP
Resonance model:	EP partly related to BP

Evoked Power in the P1 window is related to Baseline Power (disfavors the evoked model)

80-100 ms					
Band	BP	EP	d_i	CP	R^2
α_2	2.42 (0.03)	2.02 (0.04)	0.47** (0.11)	0.89* (0.28)	.12

EP = d * BP + CP

2.02 = 0.47 * 2.42 + 0.89

How can we understand the EEG observed after an event?

The Total Power (TP) after stimulus presentation can be a combination of Evoked Power (EP), Baseline Power (BP), and Induced Power (IP).

Evoked model:

$$TP = EP + BP$$

(Partial) Phase reset model:

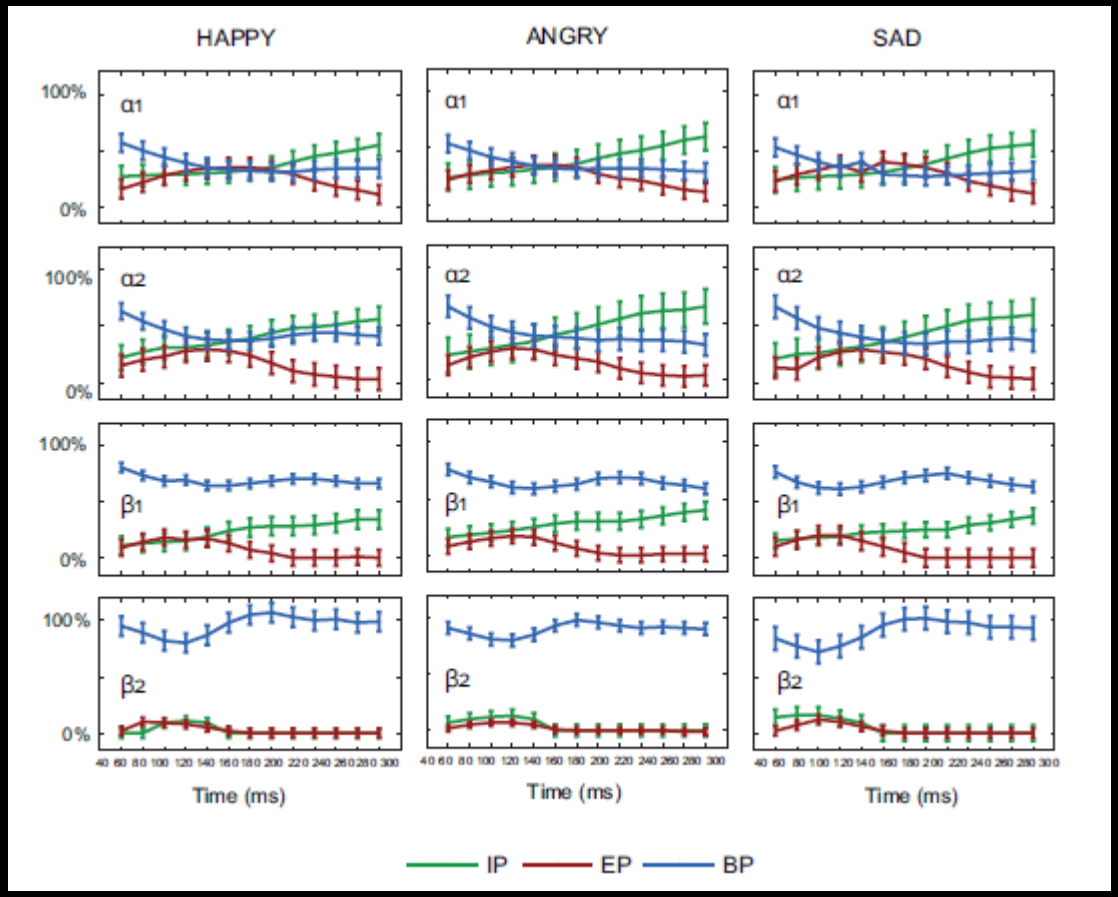
$$TP = BP = EP$$

Resonance model:

$$TP = EP + BP + IP$$

Individual differences in TP predicted by individual differences in BP, EP, and IP

Van der Lubbe et al., 2016



TP = IP + BP + EP

TP = IP + BP (+ EP)

TP = IP + BP (+ EP)

TP = BP

Support for the resonance model

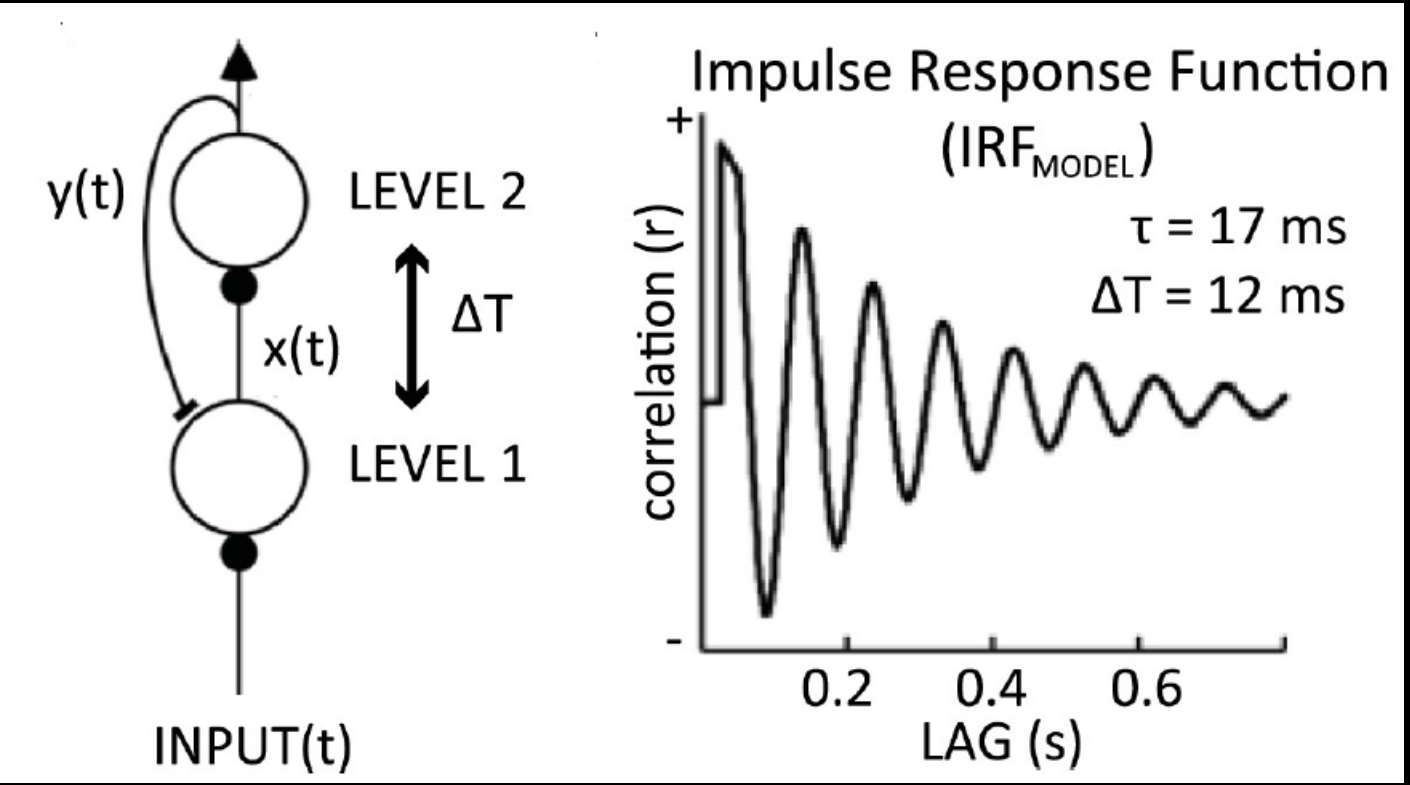
α_1 > resonance model

α_2 > resonance model

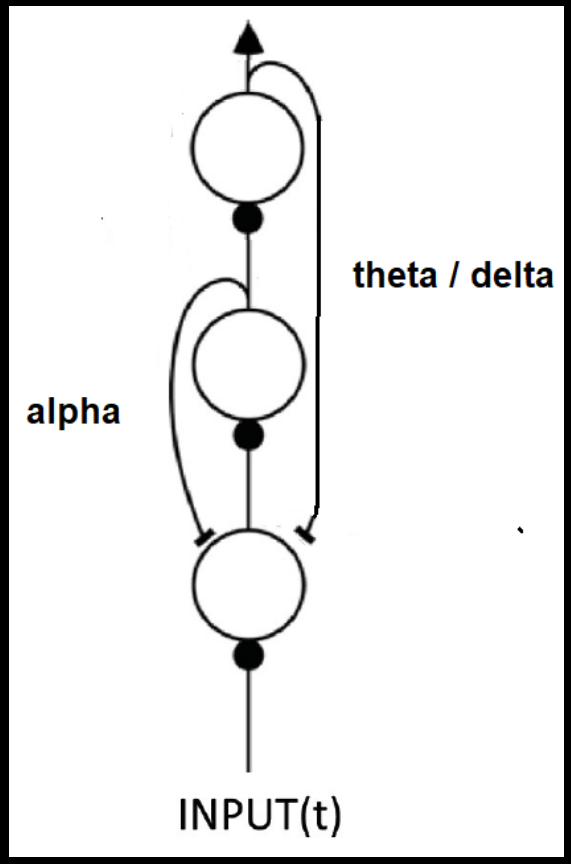
β_1 > resonance model

β_2 > phase reset model

Predictive coding and alpha oscillations (Alamia & Van Rullen, 2019)



A possible implication of recurrent connections crossing multiple levels



Relatively short recurrent connections may result in alpha oscillations (e.g., thalamus-V1), longer recurrent connections may result in theta or even delta oscillations (see also Buzsáki, 2006)

Final conclusions

- We need convincing models concerning the origin of cortical oscillations
- The interpretation of an effect on a certain ERP component or frequency band otherwise remains a bit like a shot in the dark
- Attempts to interpret ERP/FFT/TF effects should
  - become more aware of the logical error in “affirming the consequence”
  - try to relate observed effects to an underlying neurophysiological mechanism
  - try to falsify their theoretical stance

Thank you for your attention!

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