Early Occurrence Of Auditory Change Detection In The Human Brain

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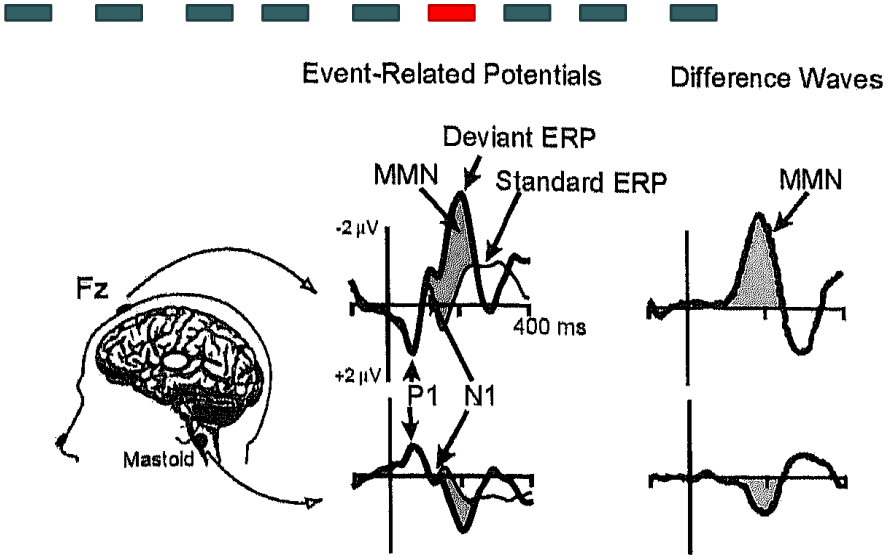
Auditory deviance detection in animals and humans

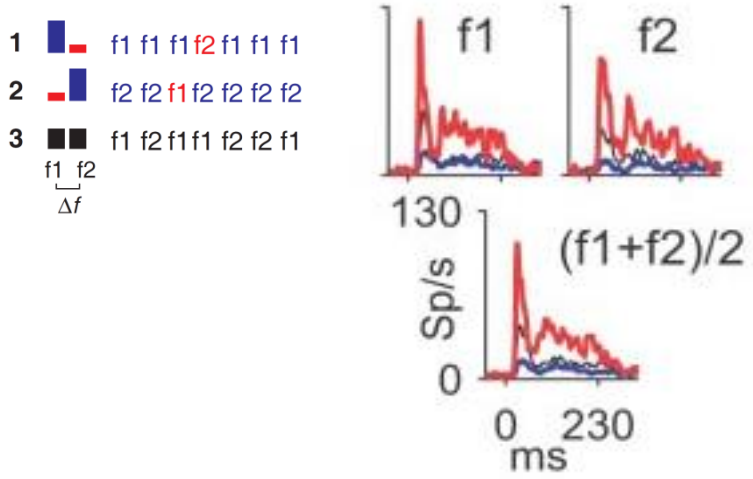
The auditory system constantly scans the acoustic input for regularities and respectively for unexpected, novel events!

Human scalp potential



from: Schröger, 2005

Animal multi-/single-unit responses from A1

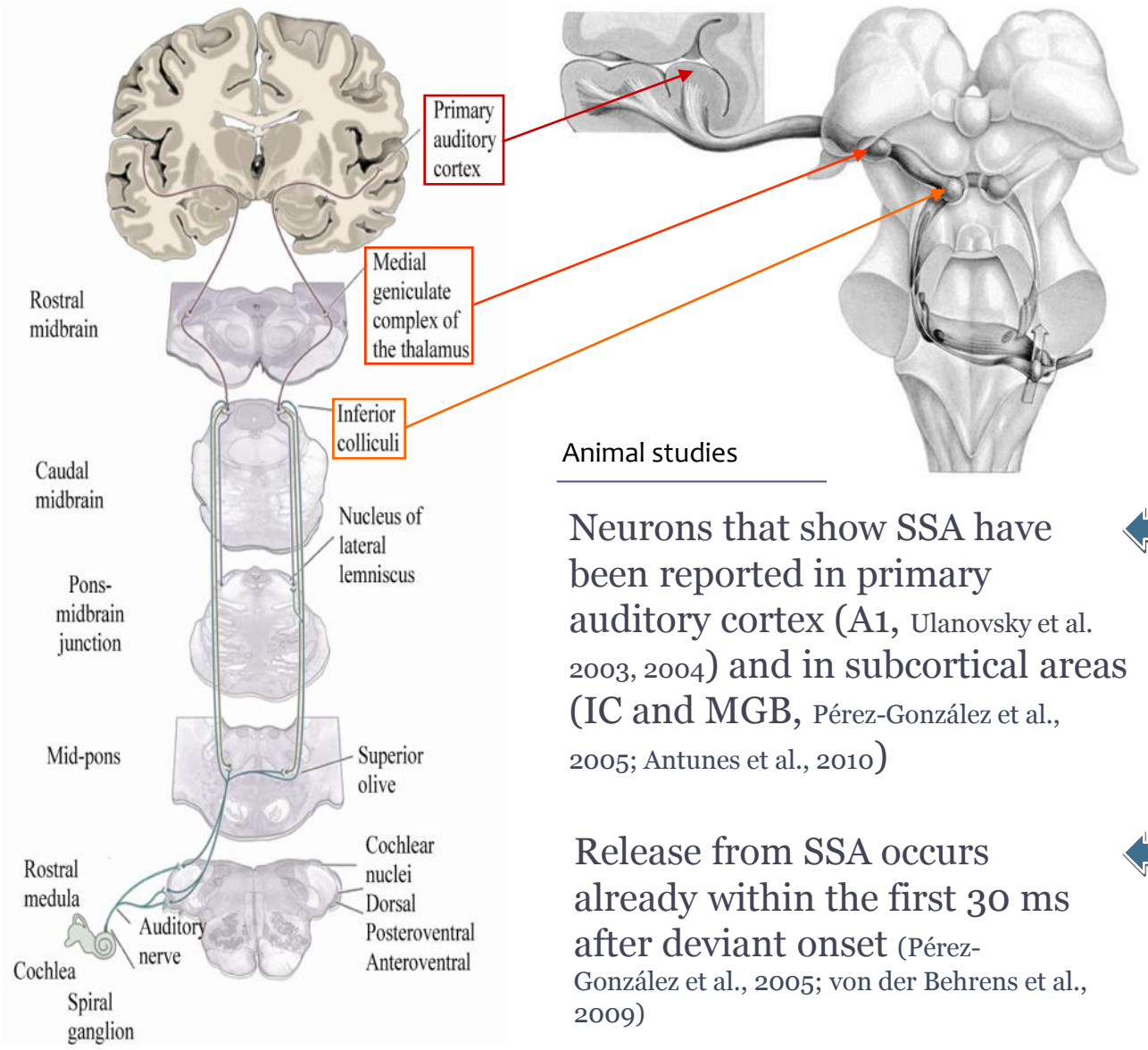


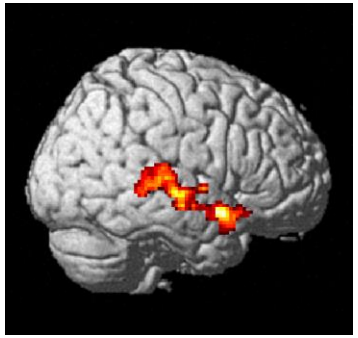
from: Ulanovsky et al. , 2004

Astonishing similarities in their characteristics! (see Nelken et al., 2007)

- similar relation to magnitude of change, to probability of deviant events, to the number of standards; similar local effects in 50-50% conditions;

Early occurrence of animal SSA





Animal studies

Human studies

Neurons that show SSA have been reported in primary auditory cortex (A1, Ulanovsky et al. 2003, 2004) and in subcortical areas (IC and MGB, Pérez-González et al., 2005; Antunes et al., 2010)

⟺

Generators of MMN are localized in auditory cortical areas and frontal cortex (Alho, 1995; Huotilainen et al., 1998)

Release from SSA occurs already within the first 30 ms after deviant onset (Pérez-González et al., 2005; von der Behrens et al., 2009)

⟺

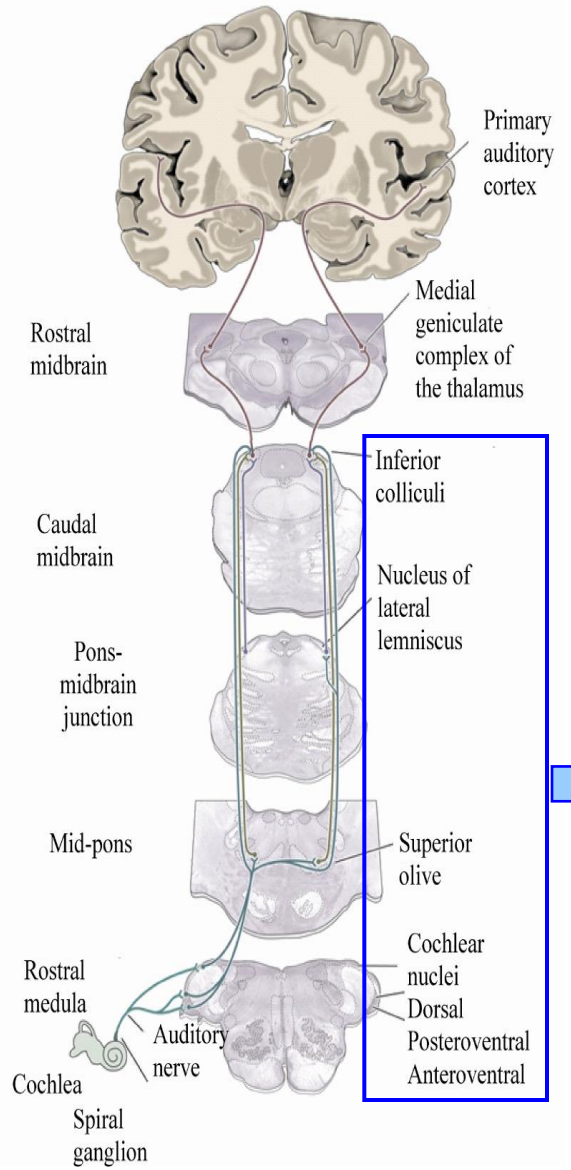
MMN peaks between 100-250 ms

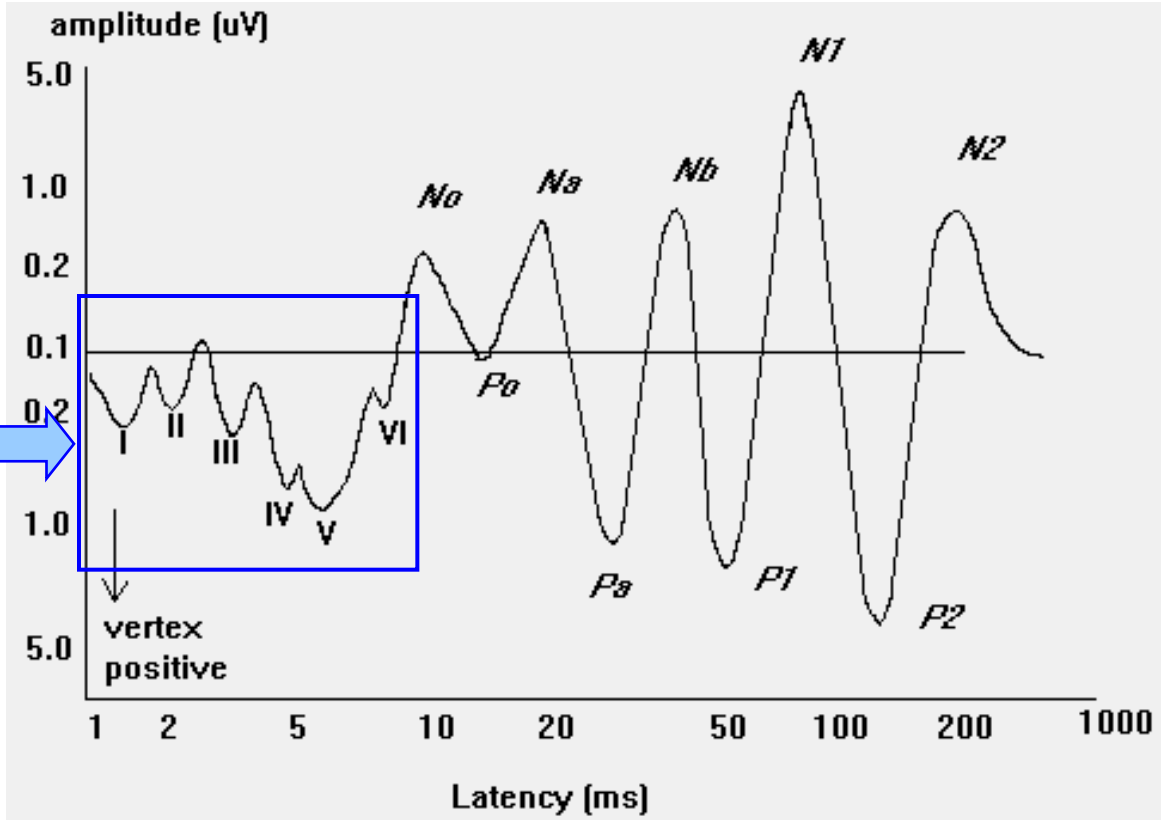
Are there any human correlates of deviance detection at earlier latencies than those of MMN, that could bridge the gap to novelty-related responses recorded in animal studies?

Is human deviance detection a multi-stage process?

In principle, one should be able to use the Auditory Evoked Potential, in its whole complex morphology, to tackle this question.

1. The Auditory Brainstem Response [ABR].

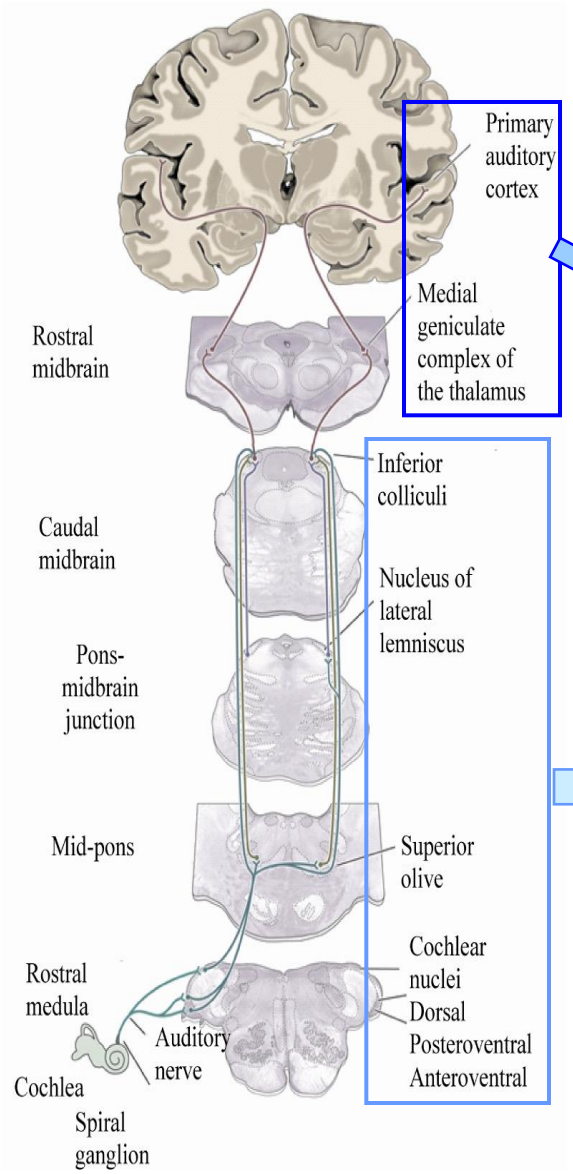


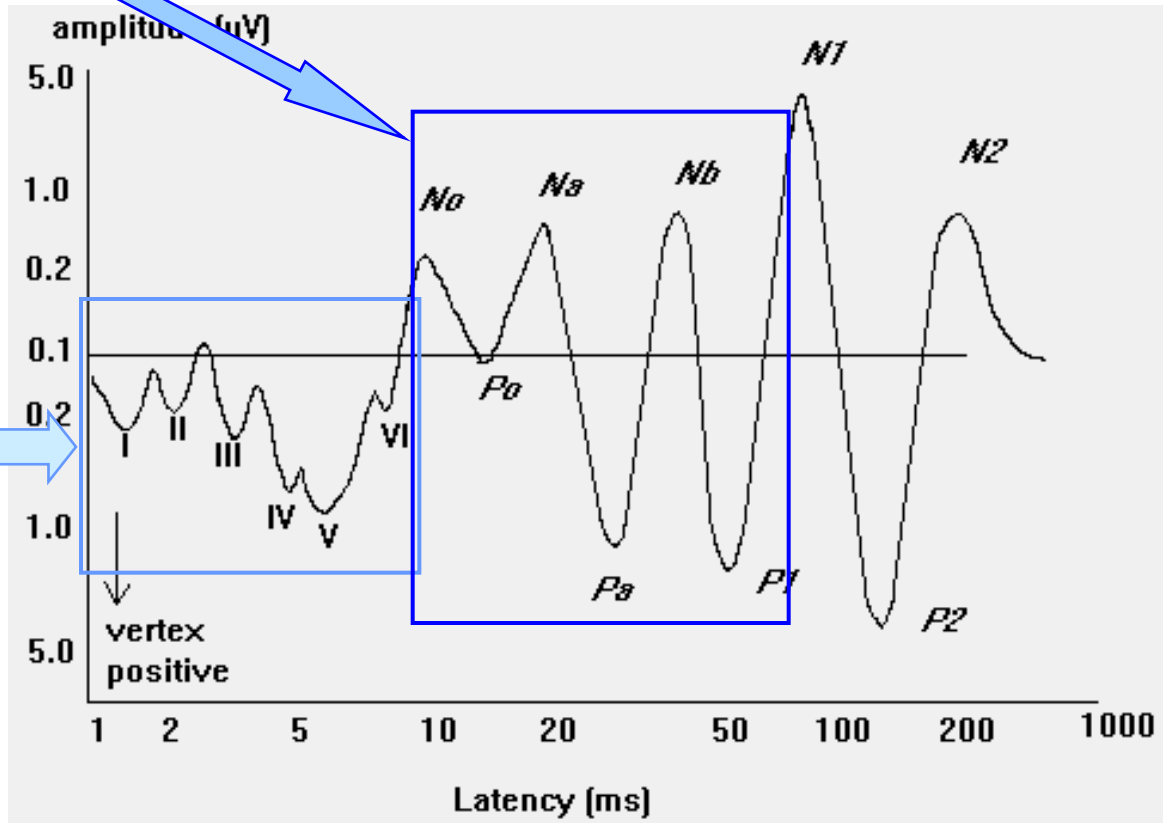


Is human deviance detection a multi-stage process?

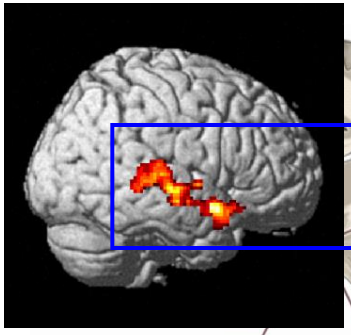
In principle, one should be able to use the Auditory Evoked Potential, in its whole complex morphology, to tackle this question.

1. The Auditory Brainstem Response [ABR].
2. The Middle Latency Response [MLR].



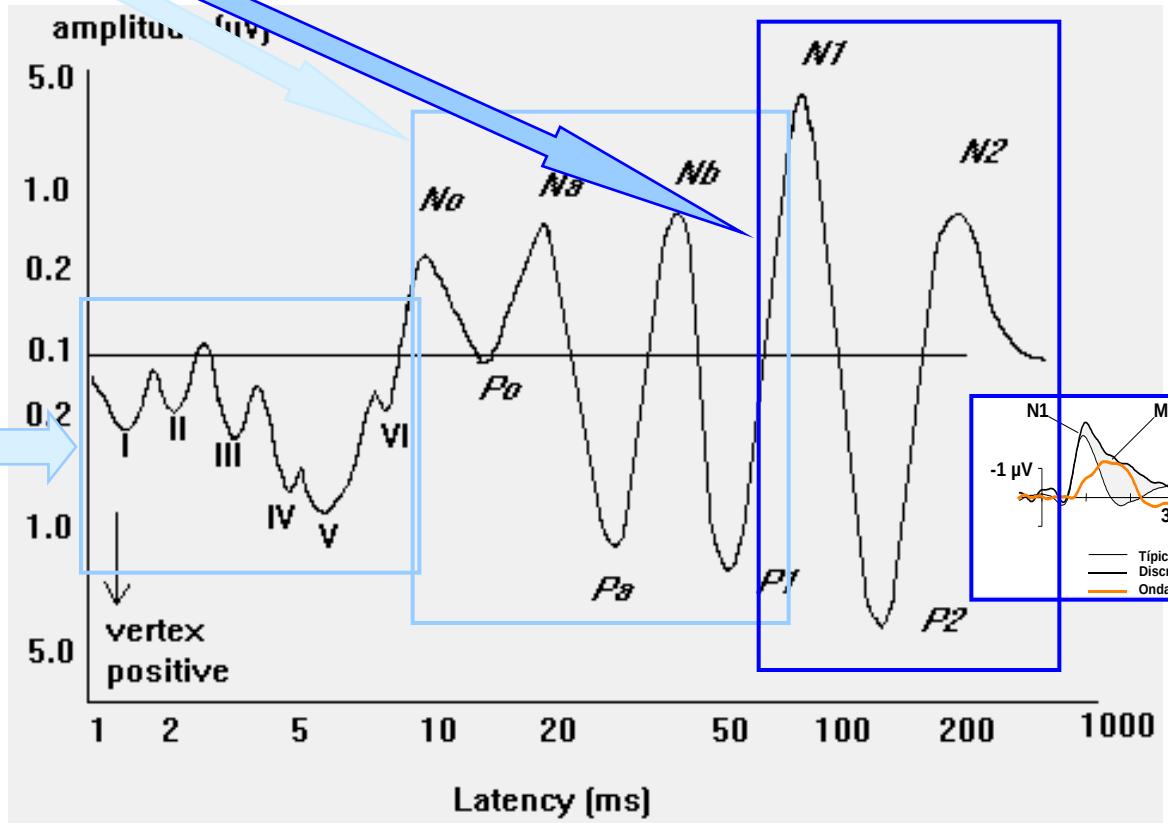


Is human deviance detection a multi-stage process?



In principle, one should be able to use the Auditory Evoked Potential, in its whole complex morphology, to tackle this question.

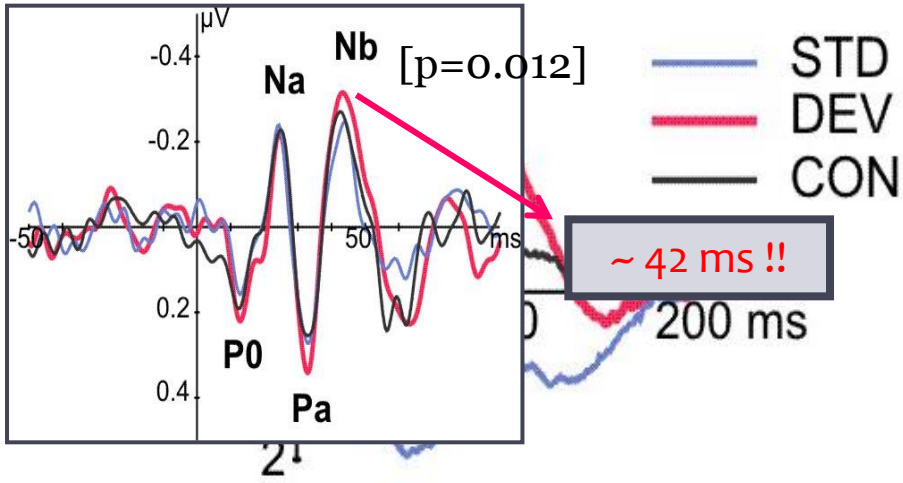
1. The Auditory Brainstem Response [ABR].
2. The Middle Latency Response [MLR].
3. The Long-Latency Auditory Evoked Potential [including the MMN].

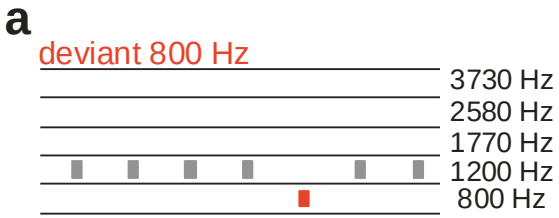


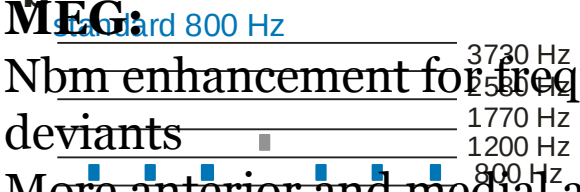
Early EEG correlates of deviance detection

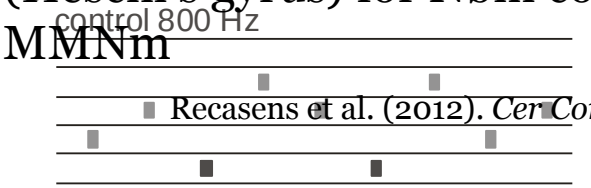
EEG:
Nb enhancement for frequency deviants

Grimm et al. (2011). *Psychophysiology*.







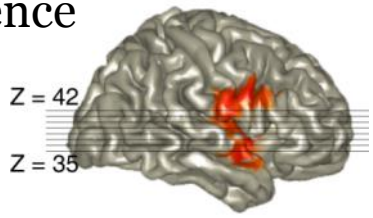


Recasens et al. (2012). *Cer Cortex*.

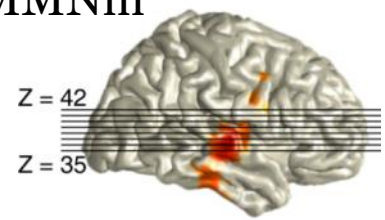
Tone duration: 50 ms SOA: 293 ms

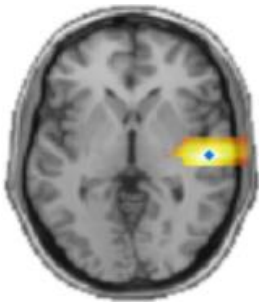
MEG:
Nbm enhancement for frequency deviants
More anterior and medial activations (Heschl's gyrus) for Nbm compared to MMNm

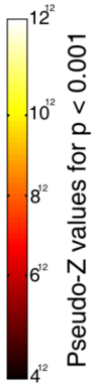
Nbm difference



MMNm



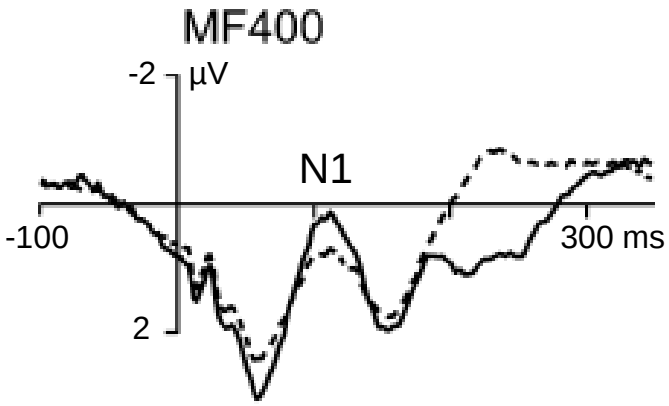




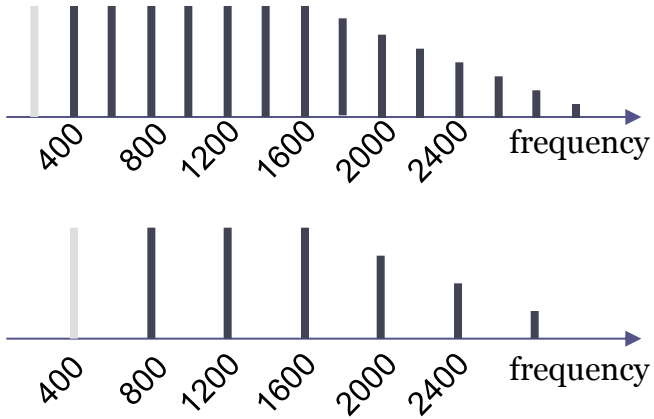
Early EEG correlates of deviance detection

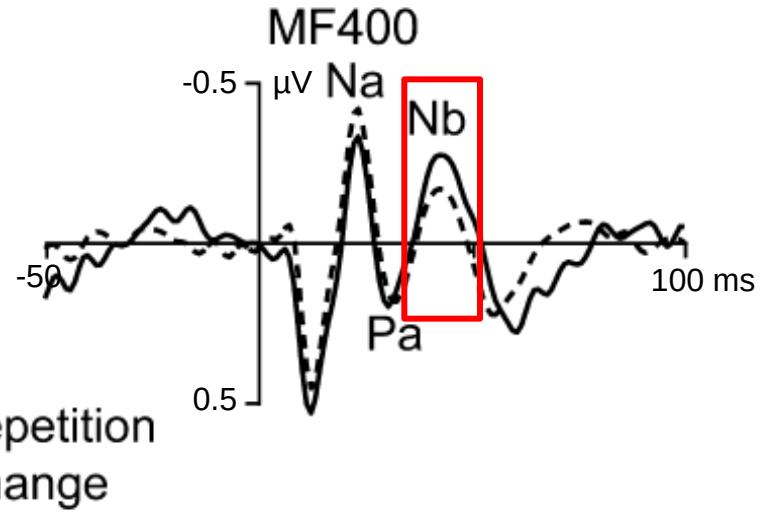
EEG:
Nb enhancement for MF pitch changes

Alho, Grimm et al. (2012). EJN



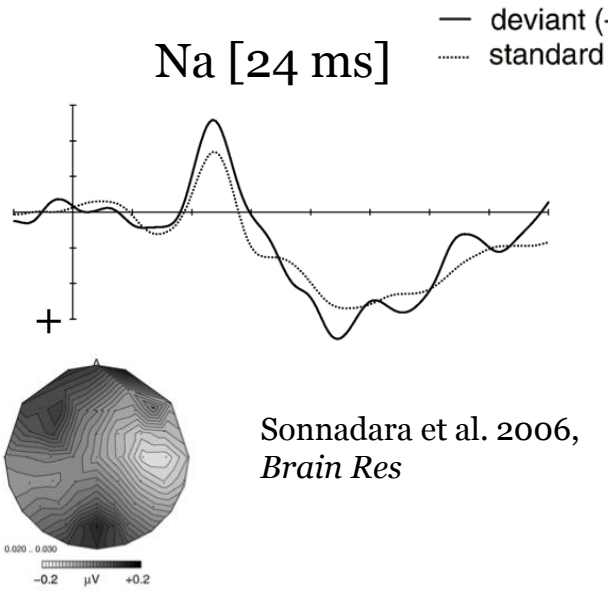
Missing fundamental (MF) stimuli:



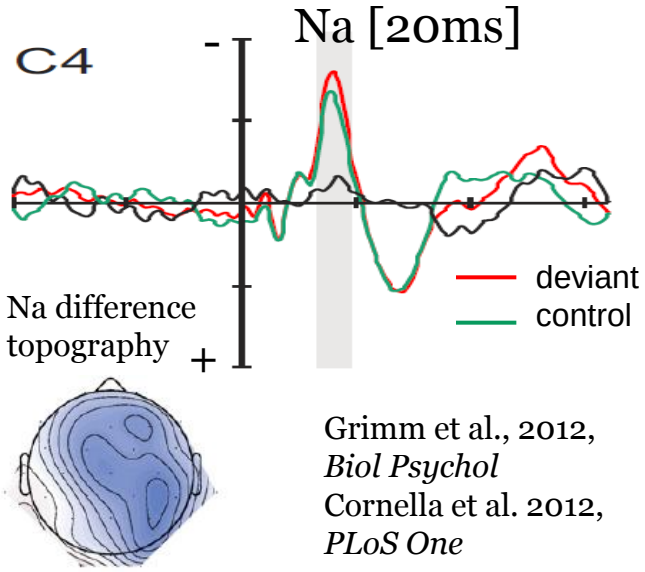


Early EEG correlates of deviance detection

Na enhancement for location deviants



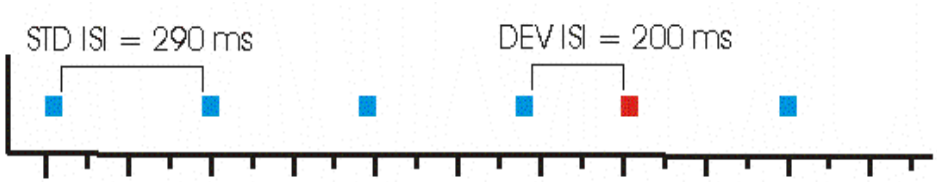
Sonnadara et al. 2006, *Brain Res*

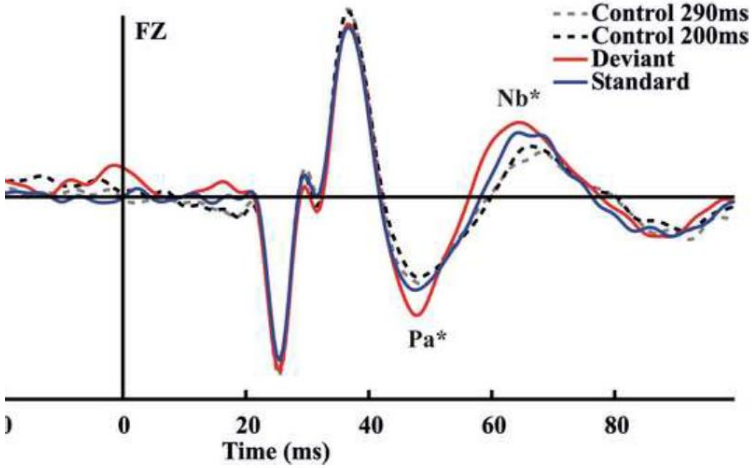


Grimm et al., 2012, *Biol Psychol*
Cornella et al. 2012, *PLoS One*

Pa/Nb enhancement for SOA shortenings

Leung, Recasens, Grimm, Escera, 2013, *Clin Neurophysiol*





So far, so good...

Deviance-related effects occur at multiple latencies including much shorter ones than those of the MMN!!!

- Early deviance effects occur **at different components (Na, Nb: 20-40 ms)** of the Middle Latency Response depending on the stimulus feature:

- Some indication that the early effects reflect an **enhanced deviance processing** rather then repetition suppression (based on experiments controlling for stimulus probability)

- MEG: Nbm effect is localized **near primary auditory cortex** whereas MMNm shows **more posterior and lateral** activations

Functional role of these multiple stages of deviance detection?

* acting in a complementary, hierarchical, interactive, or a redundant manner?

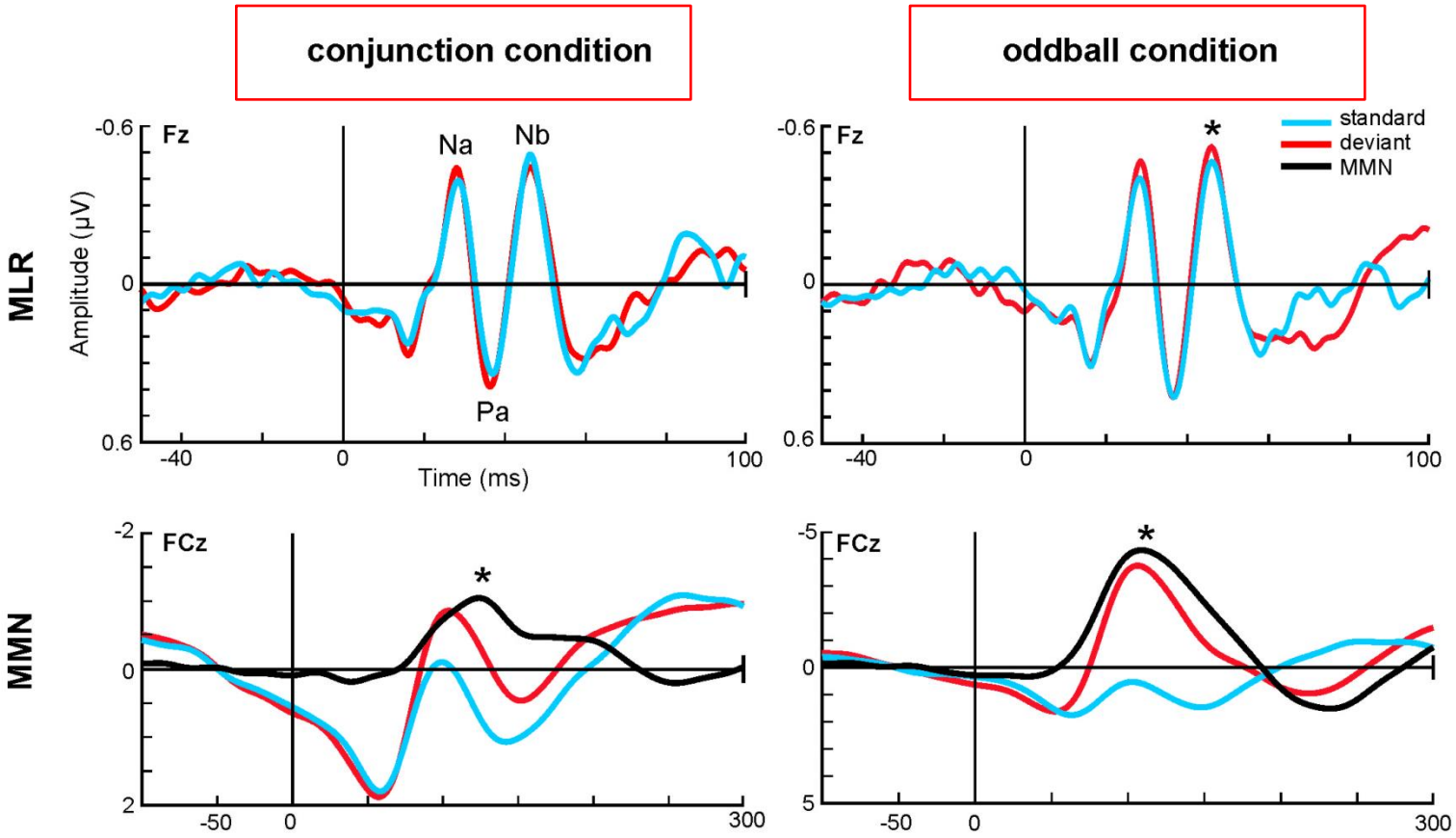
Can the early deviance-related effects be observed in the context of more complex regularities?

Early detection of violation within complex regularities

FEATURE CONJUNCTION DEVIANTS

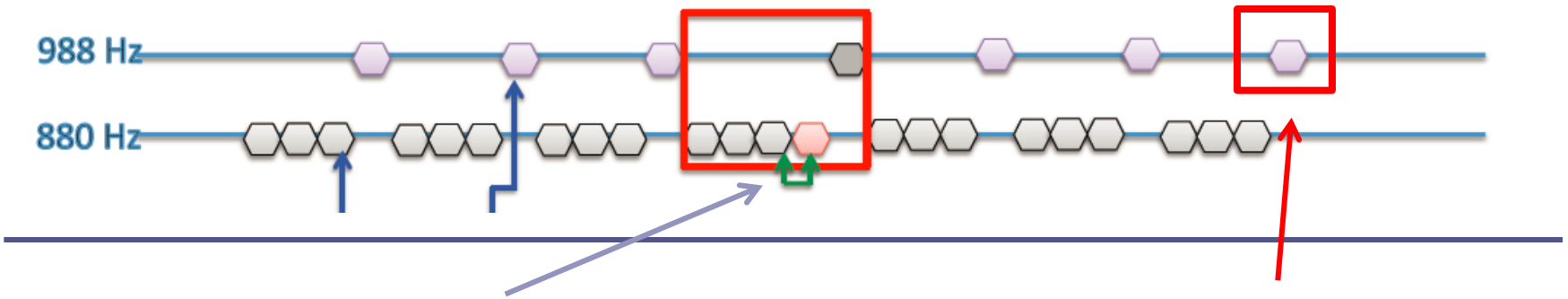
	-90°	90°
800 Hz	45%	5%
1200 Hz	5%	45%

	-90°	90°
800 Hz	45%	45%
1200 Hz	5%	5%



Althen, Grimm, Escera, 2013, EJN

Early detection of violation within pattern regularities



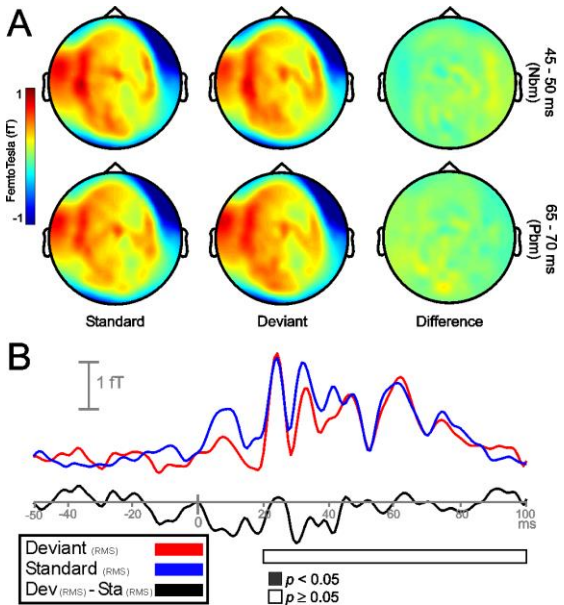
A: Global deviant
confirming local rule of frequency repetition
breaking global pattern rule

B: Local deviant
breaking local rule of frequency repetition
confirming global pattern rule

mMLR

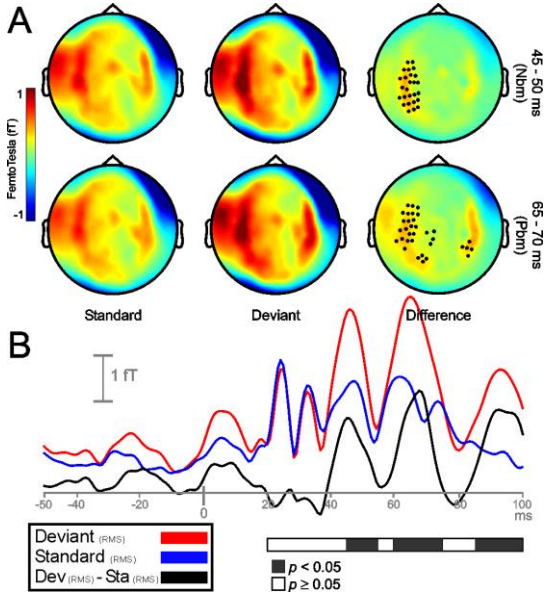
No MLR effect!

A:

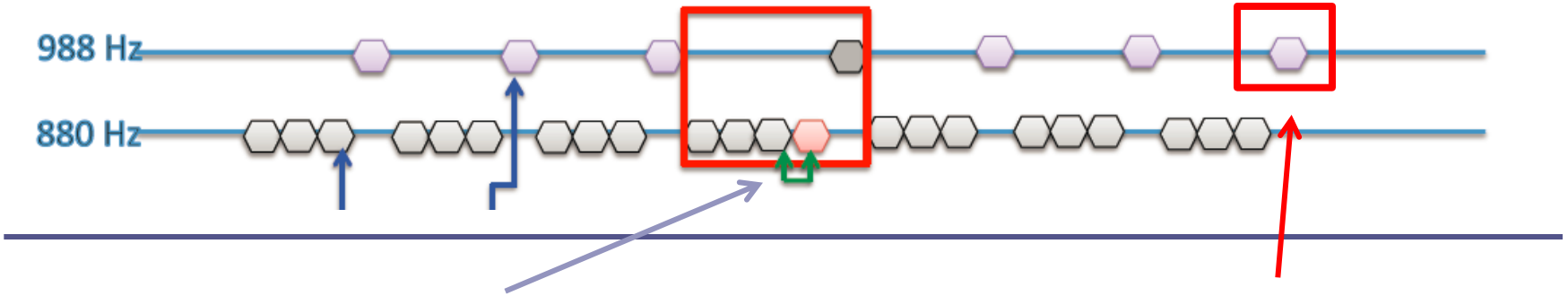


MLR effect! - Nb

B:



Early detection of violation within pattern regularities



A: Global deviant
confirming local rule of frequency repetition
breaking global pattern rule

B: Local deviant
breaking local rule of frequency repetition
confirming global pattern rule

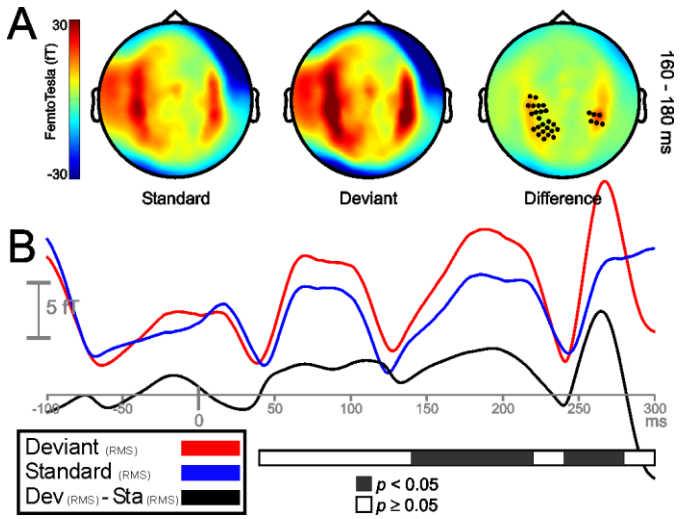
MMN!

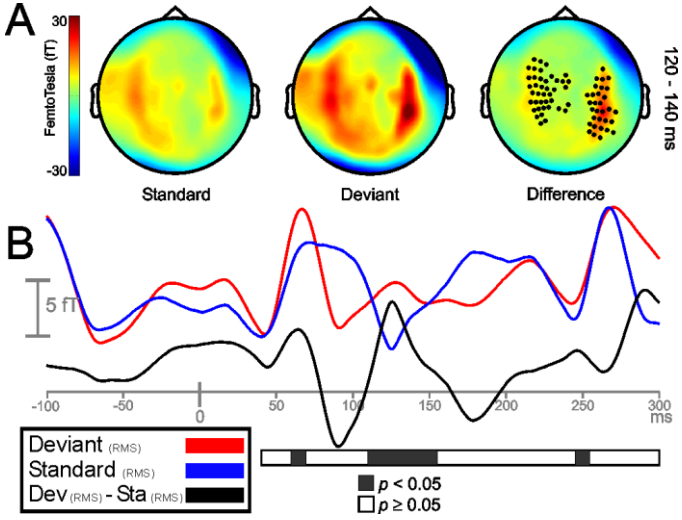
MMN/N1 effect

A:

B:

mMMN





Whereas simple regularities are encoded in the earlier time range, more complex regularities (such as the frequent occurrence of specific patterns or feature combinations) are likely to be encoded only at the higher levels.

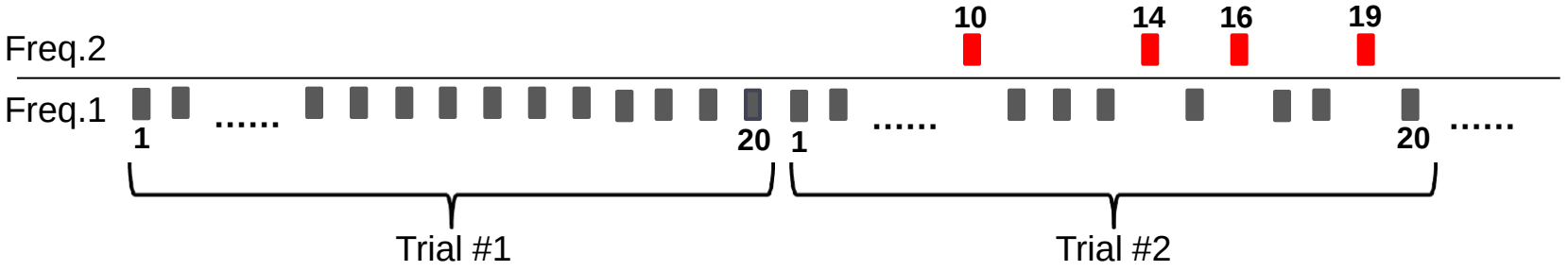
(well, at least deviations of this simple and complex regularities are detected at different time points)

Can we observe deviance-related responses at the human scalp that reflect a processing of stimulus statistics at subcortical levels?

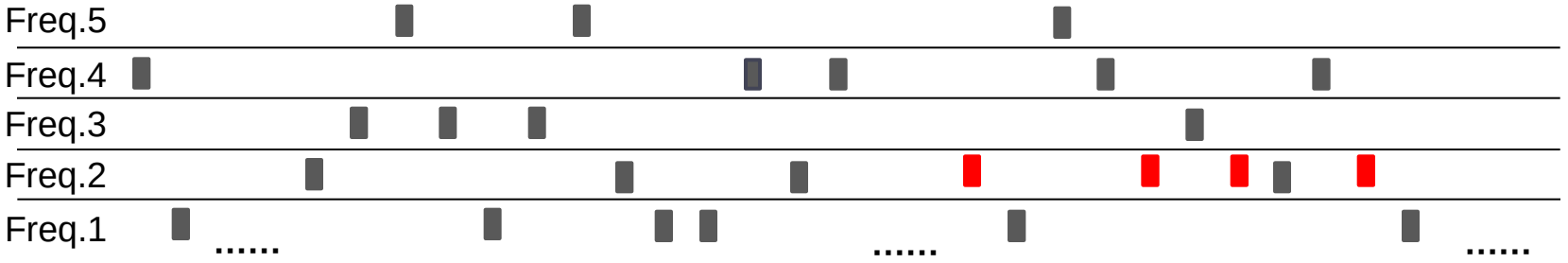
Deviance-related changes at subcortical levels? fMRI

- Stimuli were arranged in 2 different sessions
- Each session: 250 trials; each trial: 20 stimuli (constant SOA = 150ms)
- In total, 5000 stimuli delivered per session
- 12 subjects (age 24-36; 7 females; 4 left-handed)

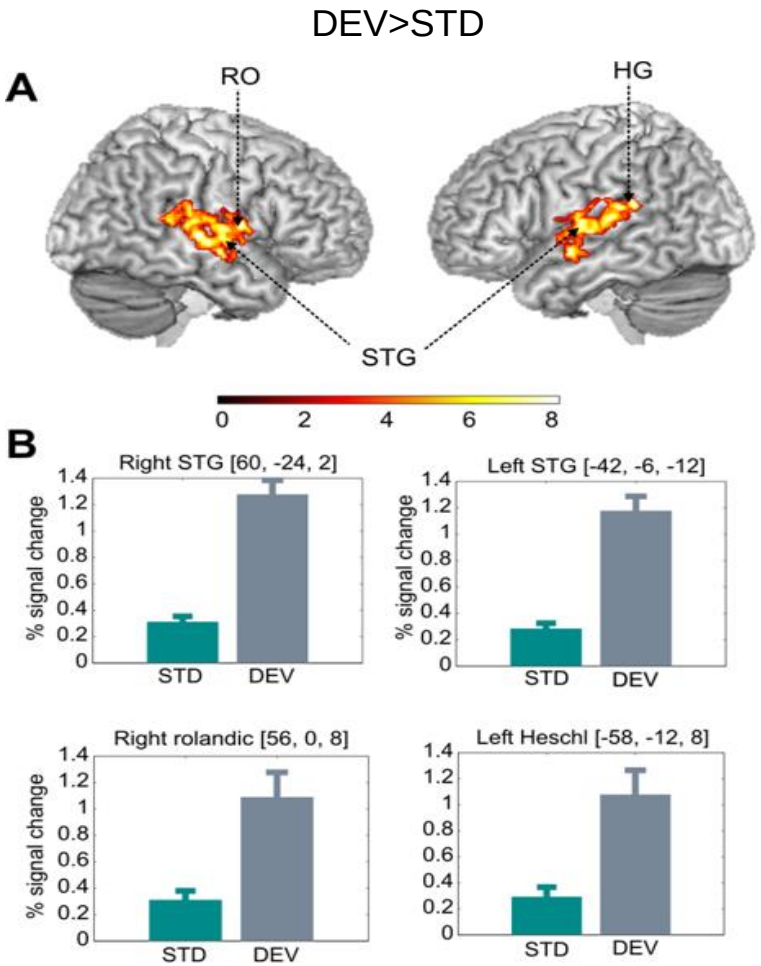
Session #1: 125 standard trials + 125 deviant trials

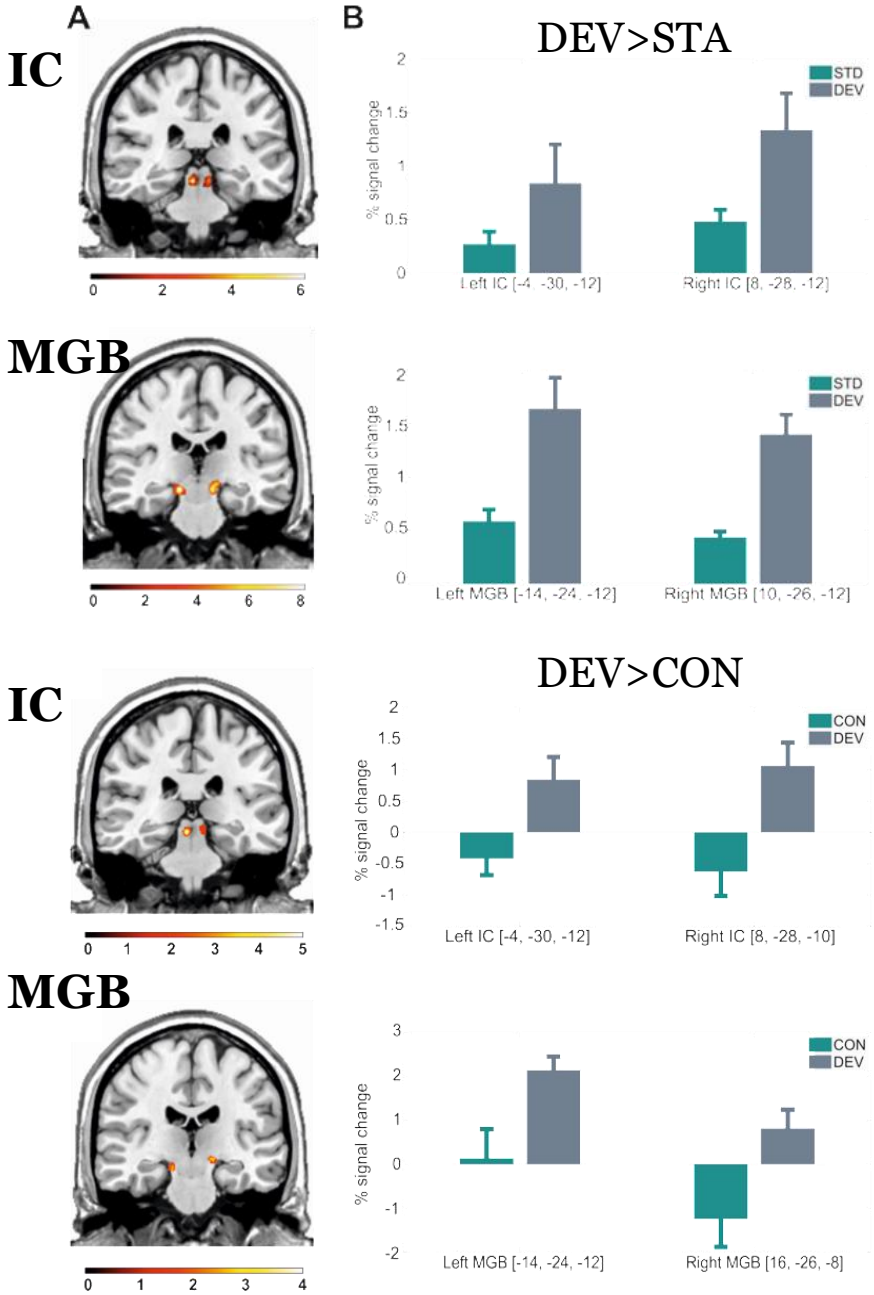


Session #2: 125 control trials + 125 silent trials (baseline)



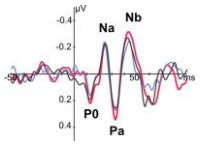
Deviance-related changes at subcortical levels? fMRI



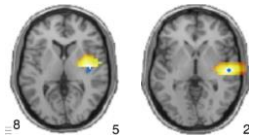


Cacciaglia et al., in preparation

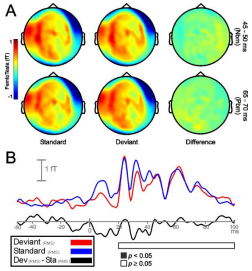
Summary



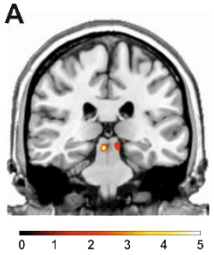
- deviance-related activity can be observed at multiple time scales



- sources of these deviance-related activities are organized in spatially distinct areas of the Human Auditory Cortex



- whereas deviance-related MLR effects indicate the early processing of simple feature changes, more complex regularity violations are only reflected in the MMN time range



- already at the level of the inferior colliculus, the statistical status of a sound is processed as reflected by an enhanced BOLD response to deviants

Summary

Deviance detection, based on regularity encoding, is a **key principle** of the **functional organization of the auditory system**, spanning from **lower levels in the auditory brainstem** to **higher order areas of the cerebral cortex**.

At higher levels in the auditory system deviant responses become stronger (in terms of amplitude) and functional complexity of deviant processing increases.

Thank you for your attention

Thanks to the members of the Group for Cognitive Neuroscience at the University Barcelona:

and to our collaborators:

Kimmo Alho, Torsten Baldeweg, Manolo Malmierca, Israel Nelken, Minna Huotilainen, Erich Schröger, Istvan Winkler et al.

Important announcement:

at the University of Leipzig, Germany