Auditory salience in the normal, sleeping and pathological brain

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BENESCO Lectures– October 26th 2018

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Auditory, Speech and Language Neuroscience

campus biotech

Salience: the primary condition for detection

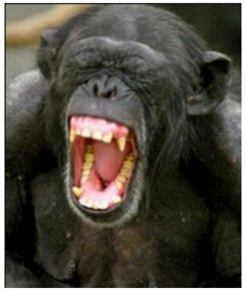
✓ Detection is vital

✓ Vision is limited (sleep)

✓ Hearing is very sensitive:
- despite distance and obstruction
- works even during sleep

A new approach to understand *salience* :
⇒ studying communication signals that aim at capturing attention.

A vital vocalization: screaming

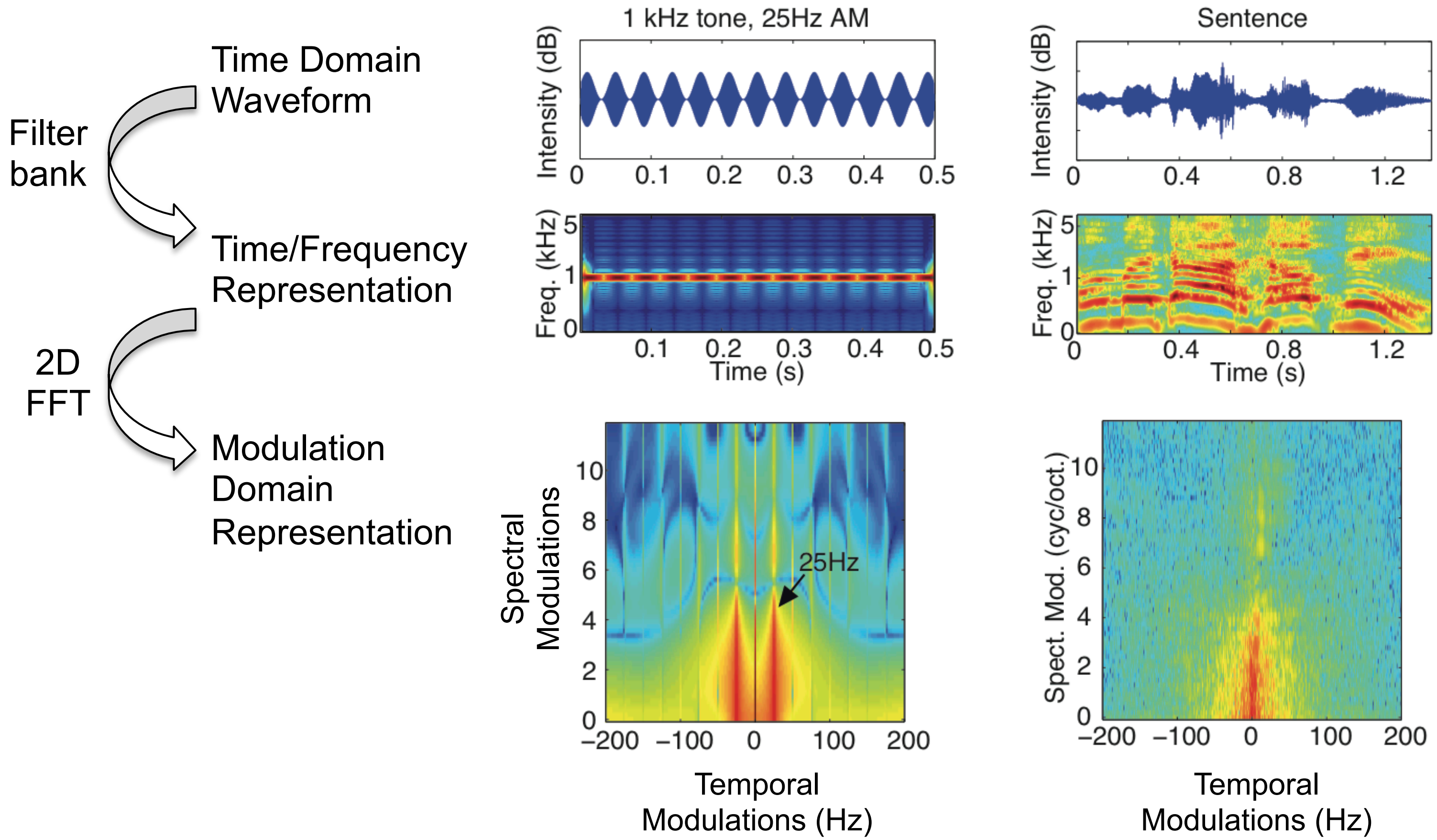
<u>screaming</u>**:**

- *essential* to promote survival (e.g. newborns).
- propagate *fast*, cannot be interrupted or ignored.
- *Innate* and *shared* between many mammals

To be efficiently and exclusively processed as alarm signals, screams must:

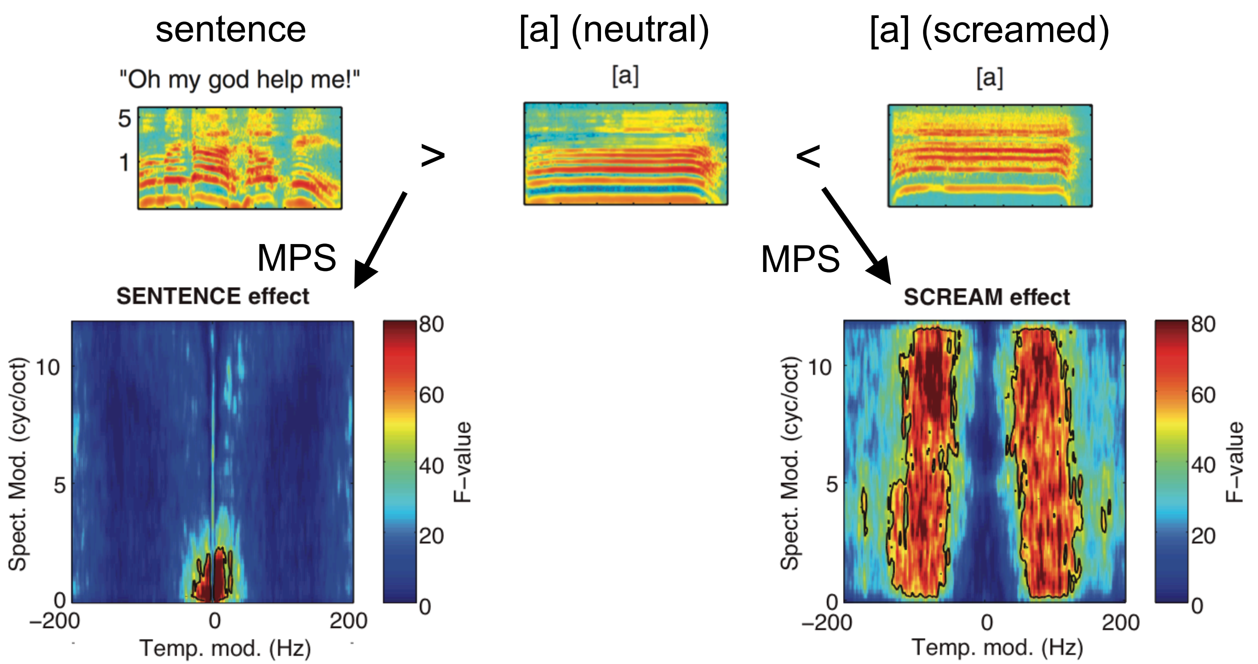
- be distinguishable from other signals by using specific acoustic features
- be processed in an efficient (and unconditional) manner by the receivers' brain.

The Modulation Power Spectrum (MPS)



Temporal modulations in speech *vs.* screams

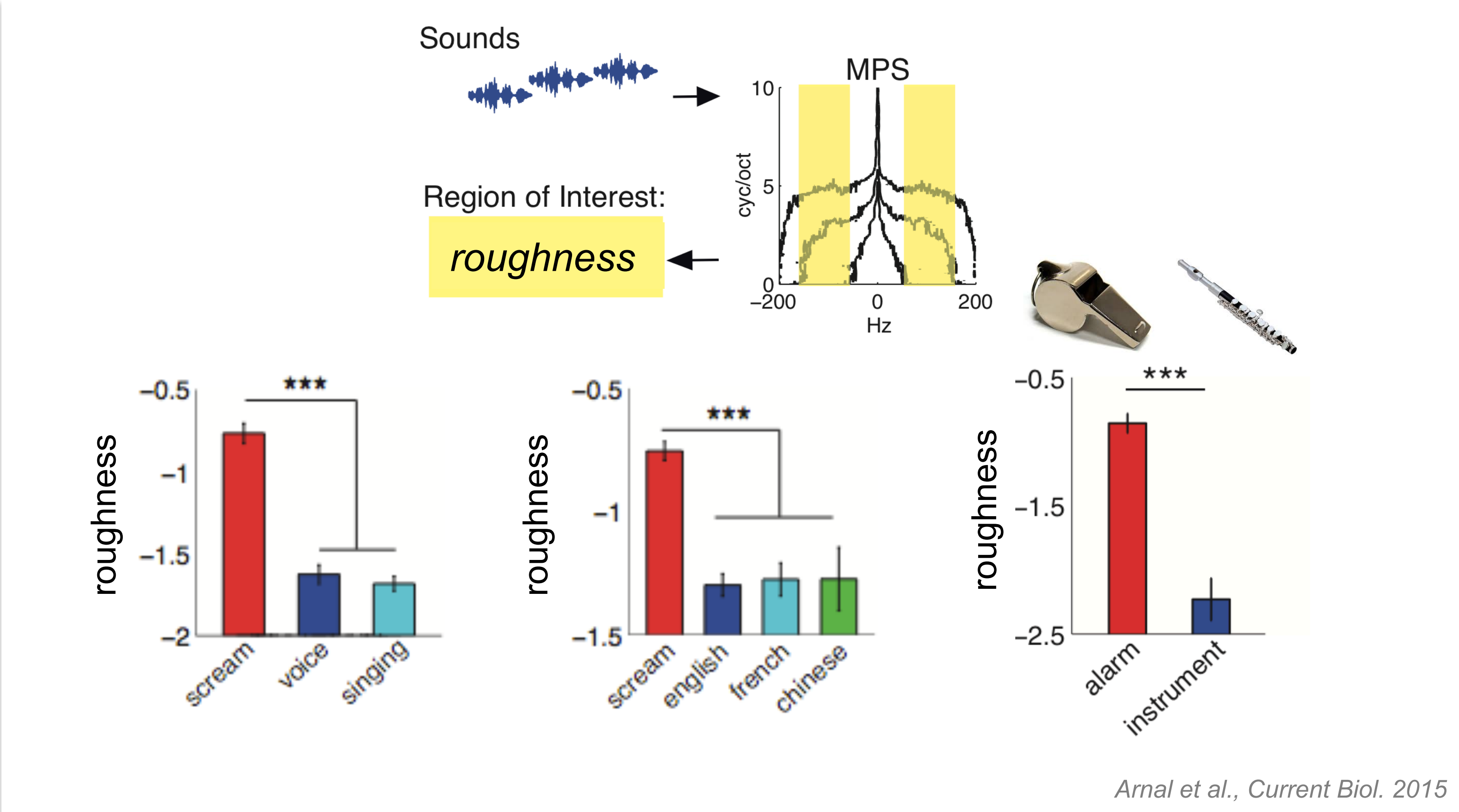
Hypothesis 1: screams must be distinguishable from other signals by using specific acoustic features



Arnal et al., Current Biol. 2015

- Speech temporal modulation (meaning) are mostly visible below 20 Hz
- Screams exhibit *rough* modulations (30-150 Hz), that minimally overlap with speech signals.

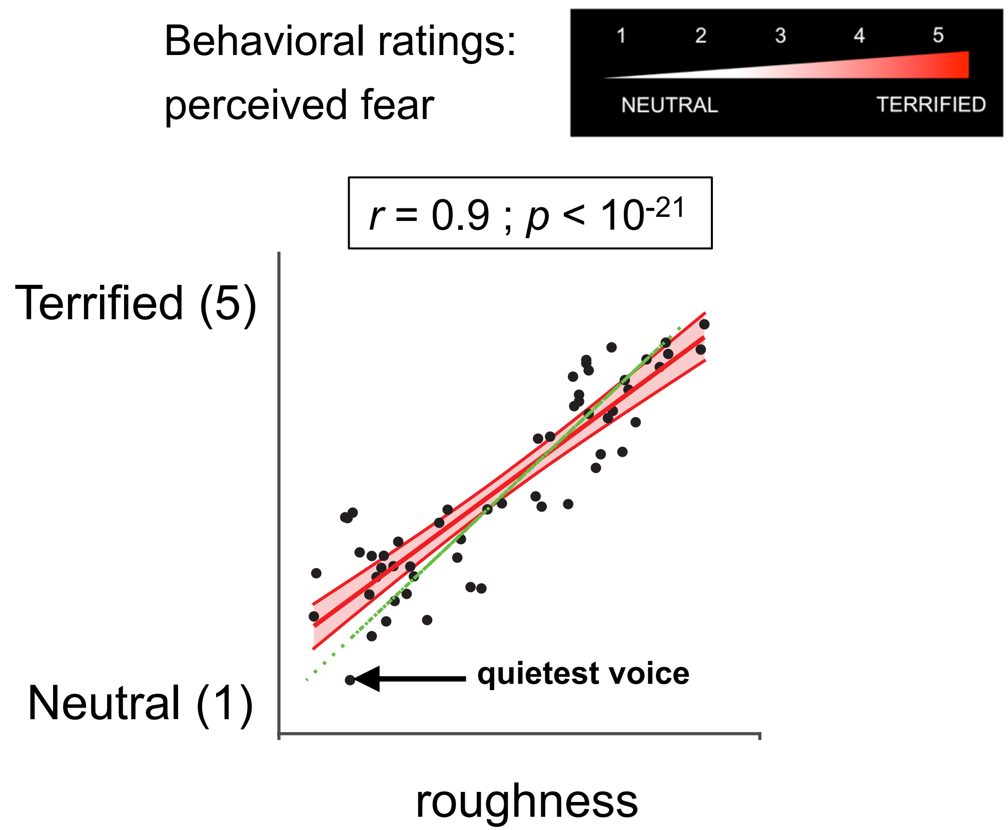
Roughness is selectively used to warn



Roughness is preserved to warn (alarm signals) and not used in neutral contexts:

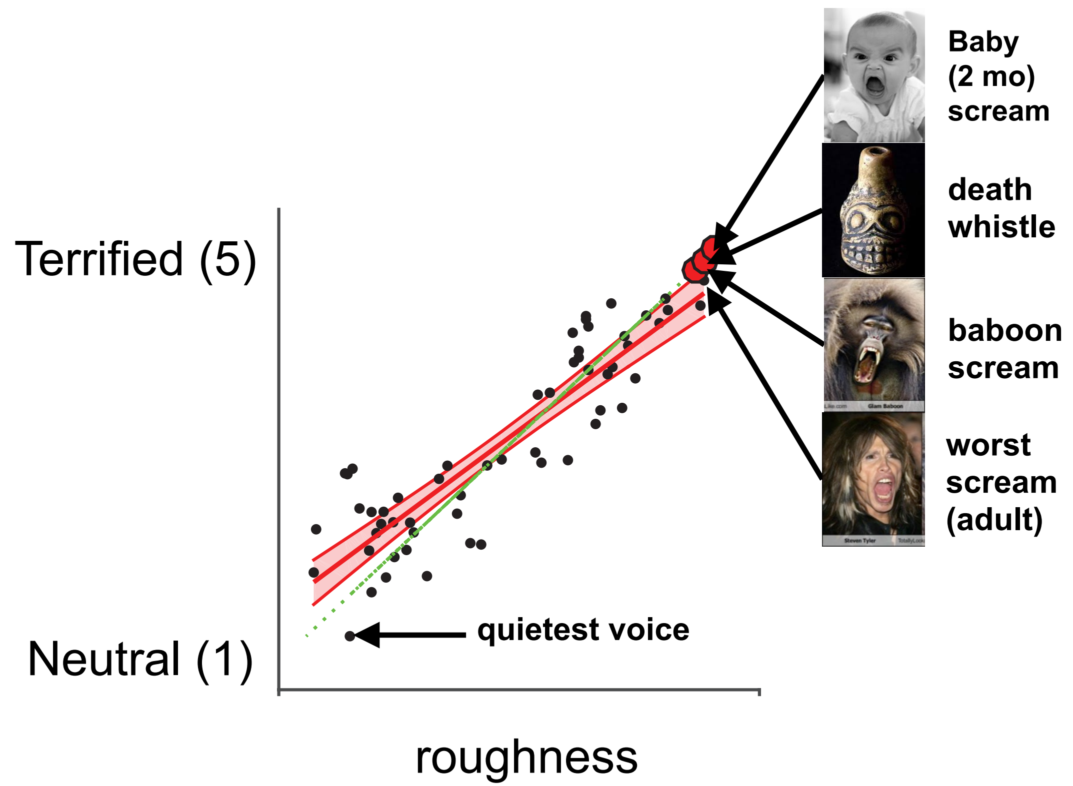
- No roughness in musical or sentential vocalizations or in any of the tested languages.
- Artificial alarms exploit "scream-like" frequencies. (➔ not an epiphenomenon of vocal production)

Rough vocalizations sound 'scared'



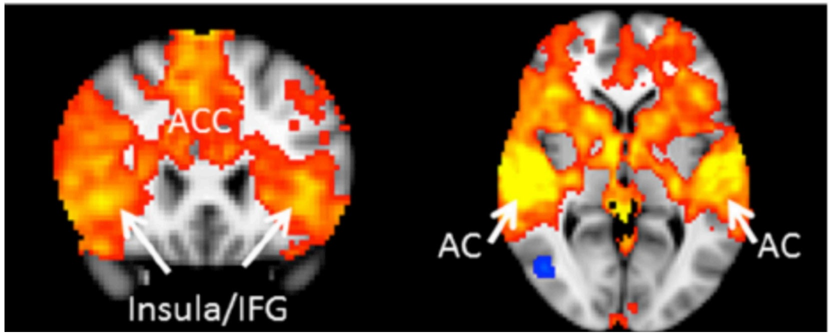
Arnal et al., Current Biol. 2015

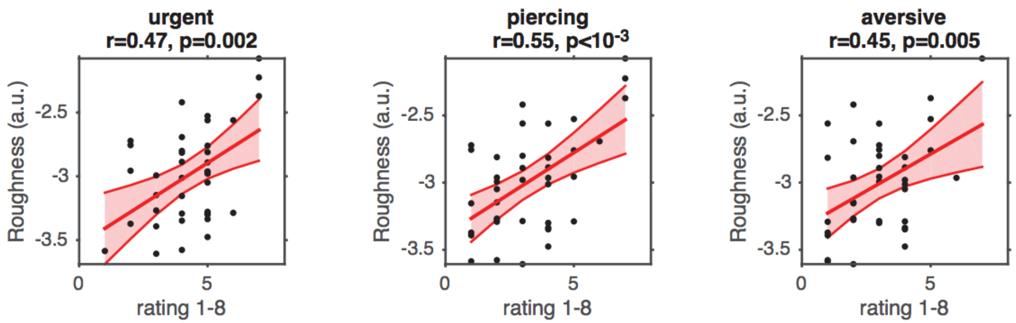
weapons of distraction



Aversiveness of infant cries in young fathers

Shaken Baby Syndrome (Collab. w/ J.K. Rilling, Emory University)



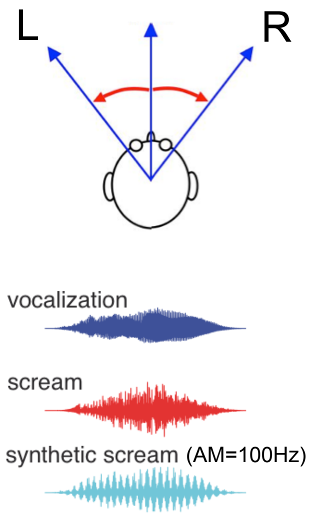


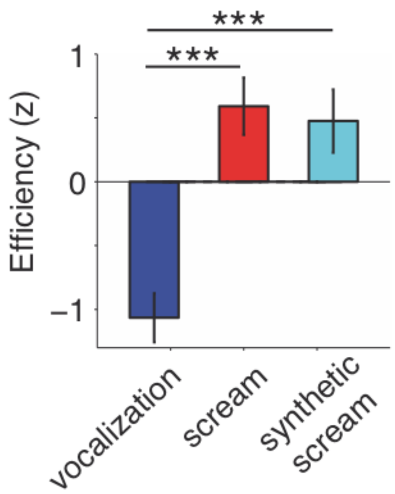
Li et al. Psych. & Behaviour 2018

- Responses to infant crying in both the (dACC) and the anterior insula
- Roughness tracks the aversive quality of infant cries

Rough vocalizations are localized faster

(*ii*) Screams must be processed **efficiently** and unconditionally by the receivers' brain.





<u>Efficiency</u>

$$E = \frac{X_A - \mu_A}{\sigma_A} + \frac{X_{RT^{-1}} - \mu_{RT^{-1}}}{\sigma_{RT^{-1}}}$$

A = Localization Accuracy (d-prime)
RT^{-1} = Reaction speed

Arnal et al., Current Biol. 2015

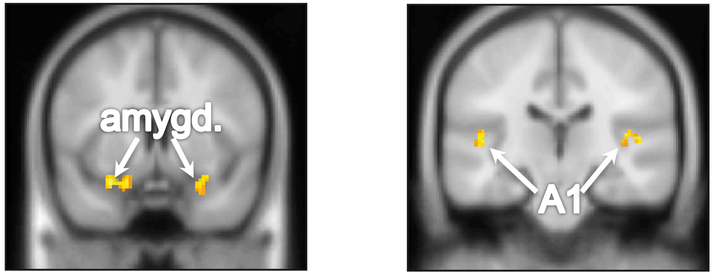
- Localization efficiency is higher for screams than neutral vocalization.
- Adding rough cues (AM = 100 Hz) to normal vocalizations improves localization so that synthetic screams have the same efficiency as screams

Neural routing of rough sounds (1)

<u>fMRI study:</u> 3T, sparse sampling, cardiac gated acquisition

	<u>unpleasant</u>	<u>neutral</u>
<u>natural</u>	screams	vocalizations
<u>artificial</u>	alarm sounds	instruments
<u>interval</u>	dissonant	consonant

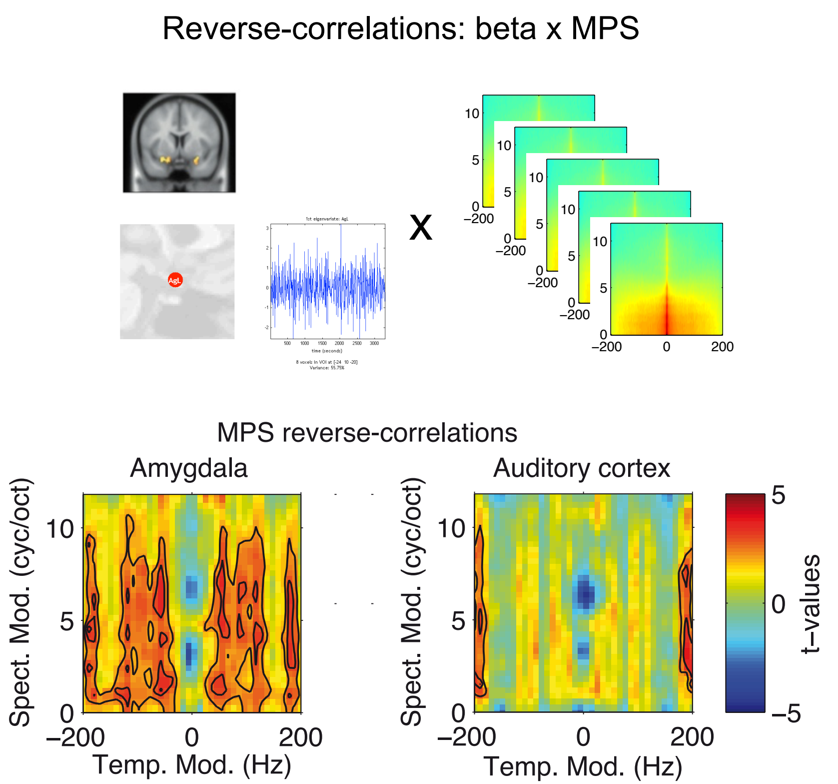
unpleasant *vs.* neutral



Arnal et al. Current Biol. 2015

- The bilateral auditory cortices and amygdala (danger processing) are more activated by unpleasant (rough) than neutral sounds.

Neural routing of rough sounds (2)

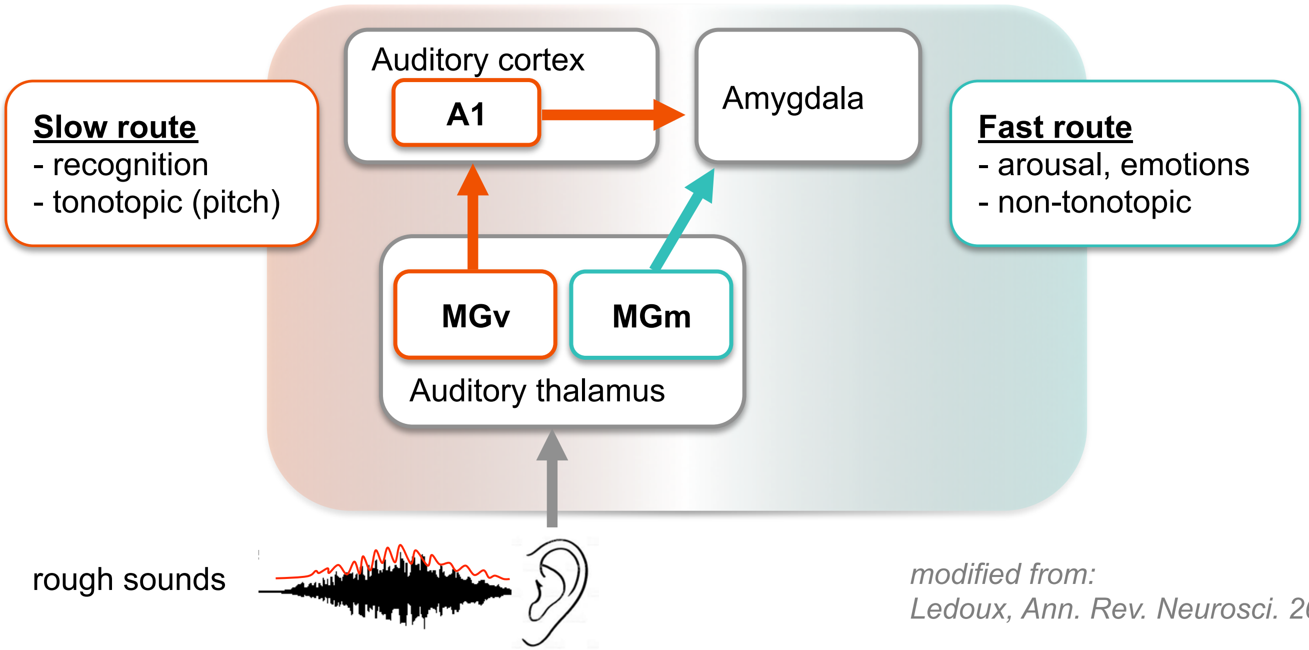


Arnal et al. Current Biol. 2015

- The amygdala (danger processing) is particularly sensitive to rough acoustic cues.
  ⇒ preferential routing of rough sounds (alarm signals) to the amygdala?

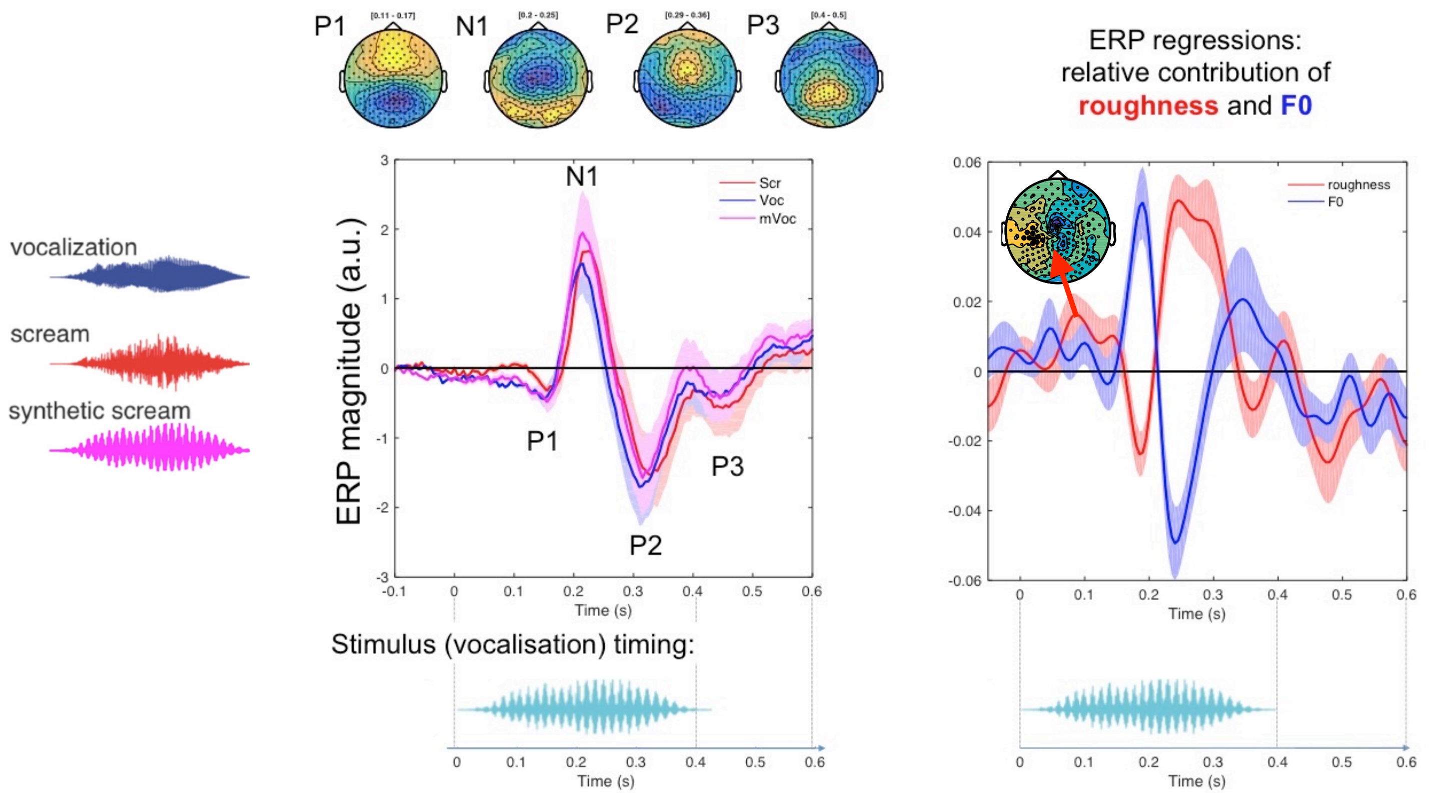
Neural processing of aversive (rough) sounds

Current model



modified from:
Ledoux, Ann. Rev. Neurosci. 2000

Early encoding of roughness

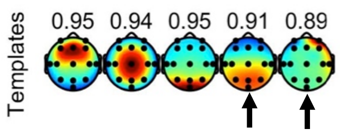


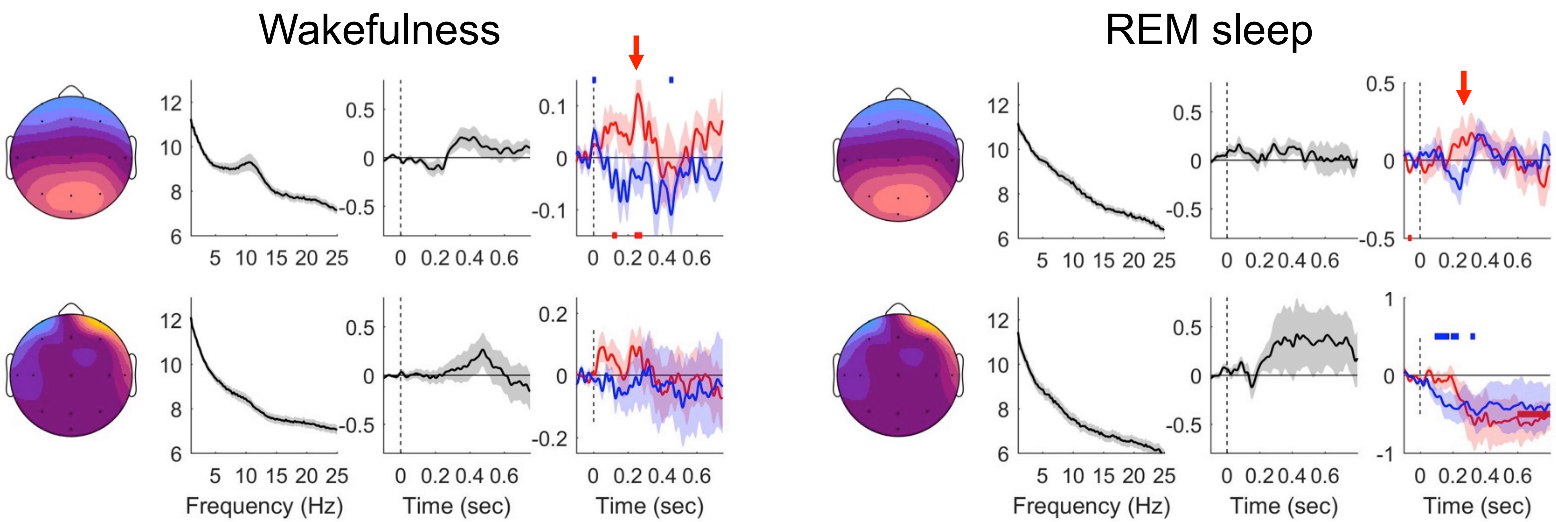
Arnal et al. work in progress

- Early neural signals (P1) encode rough cues.
- Later components (N1/P2) concurrently represent roughness and pitch.

Roughness and pitch encoding during sleep

EEG recordings over 1 night (n=17)
Independent Component Analysis (ICA):



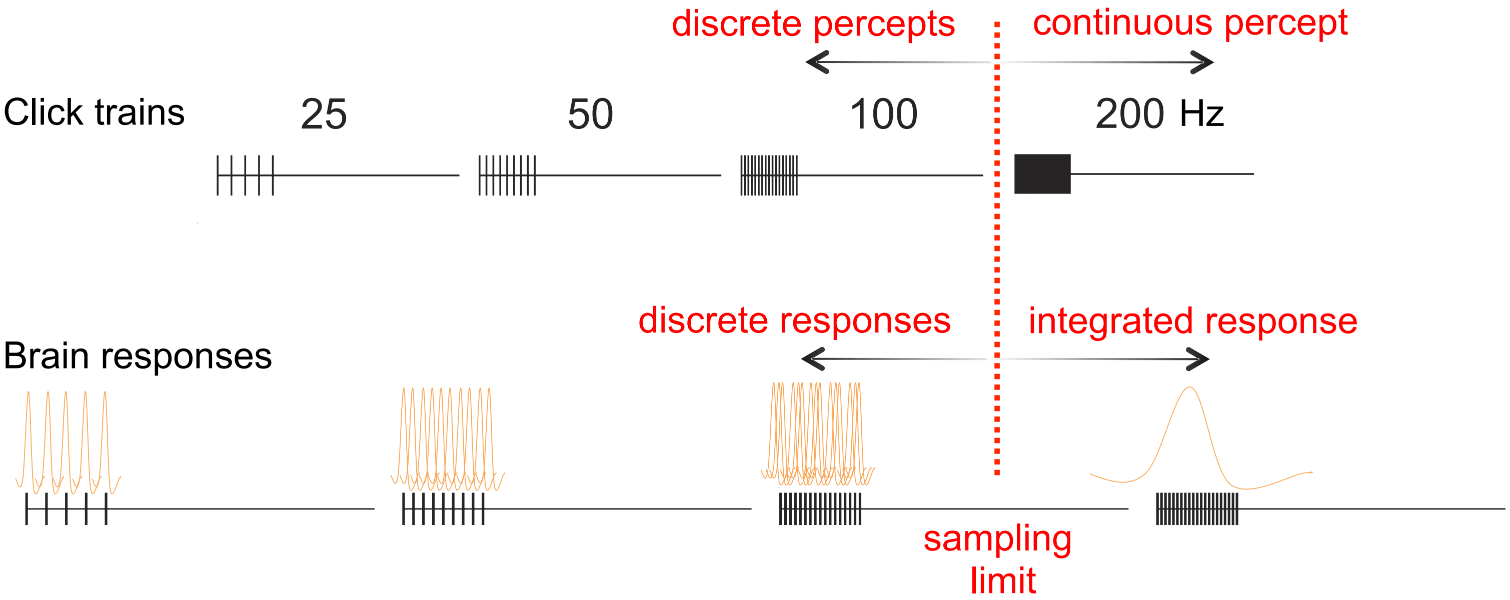


Legendre et al. work in progress

- Differential encoding of roughness and pitch during wakefulness and REM
- Roughness and pitch affect evoked eye movements during REM sleep

The temporal sampling limit

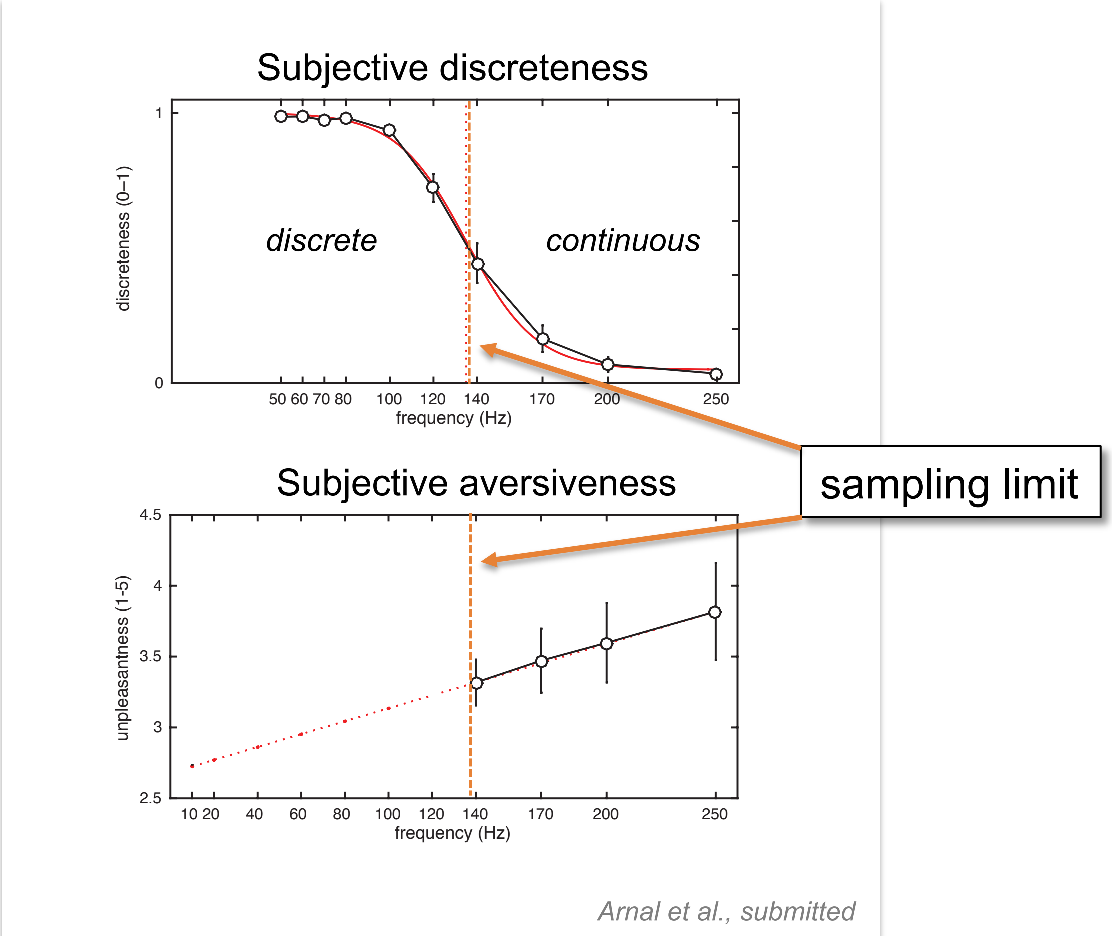
Why do alarm signals specifically exploit rough sounds?



Hypotheses:

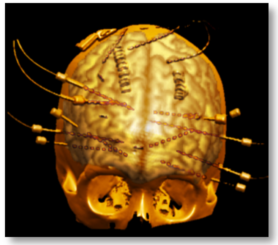
- Stimulating below the sampling limit ***temporally saturates*** the auditory system and maximizes neural responses/time unit.
- This induces unpleasant percepts (analogous to strobe lights in vision) and possibly enhances perception by increasing sensory salience per time unit ⇒ ***Temporal Salience***

Perception around the *sampling limit*

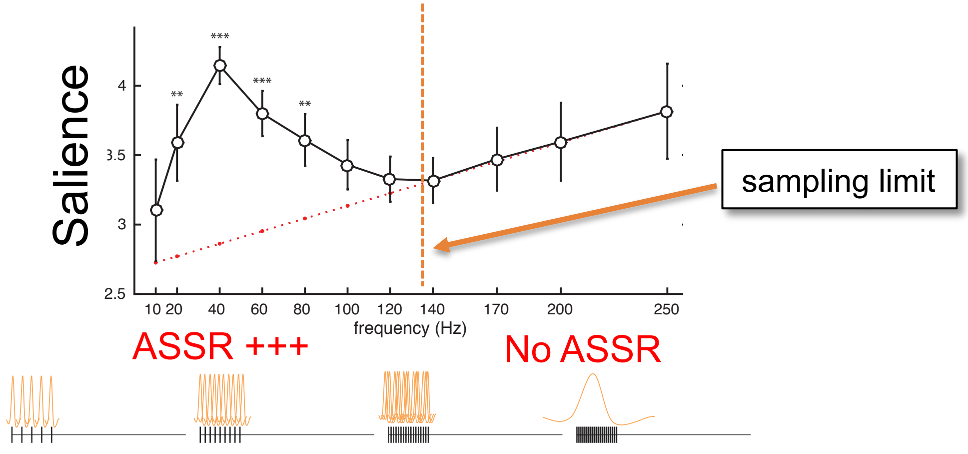


- The roughness/pitch transition occurs at ~130 Hz
- Aversiveness (Salience) is a linear function of sound energy in the pitch range
- Non-linear effect below, ***temporal salience*** is maximal in the roughness range

Back in the ASSR (Auditory Steady-State Responses)



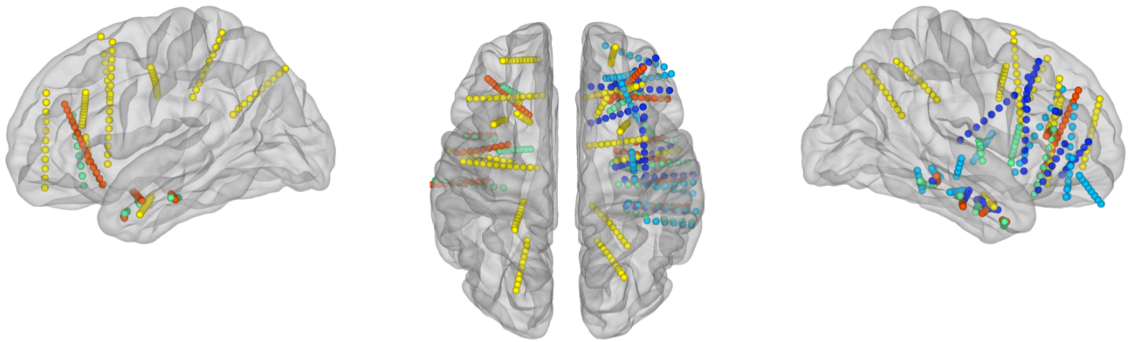
Hypothesis: Exogenous attention (salience) is imposed by exogenous Steady-State entrainment



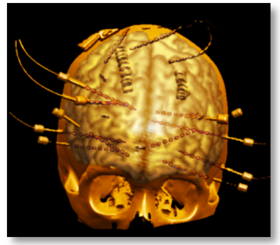
Below the sampling limit
⇒ Roughness: ASSR +++

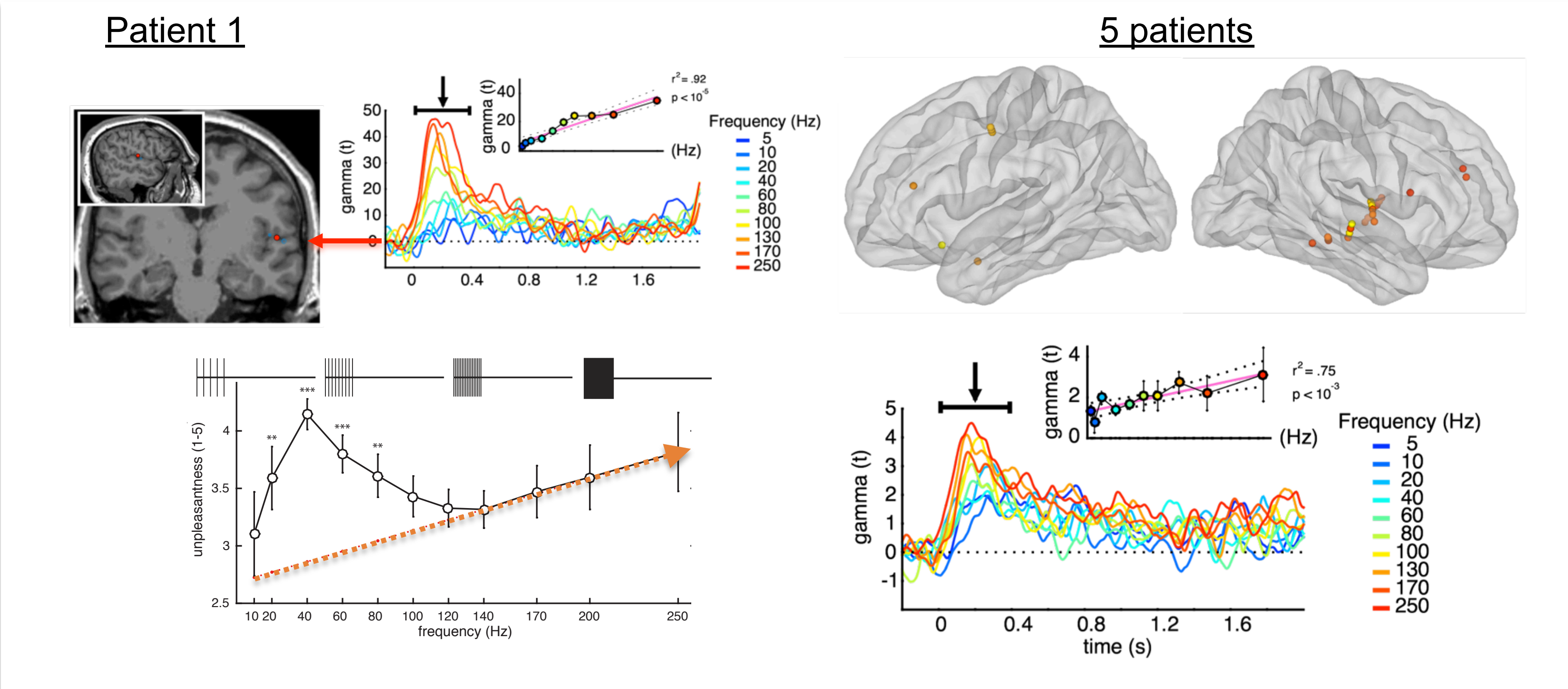
Above the sampling limit:
⇒ Pitch: No ASSR

Epilepsy monitoring (n=5, Phase 2: before surgery)



Neural (gamma-band) responses to click trains

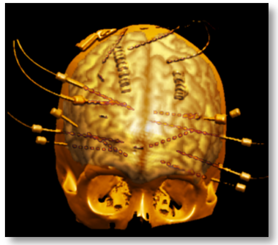




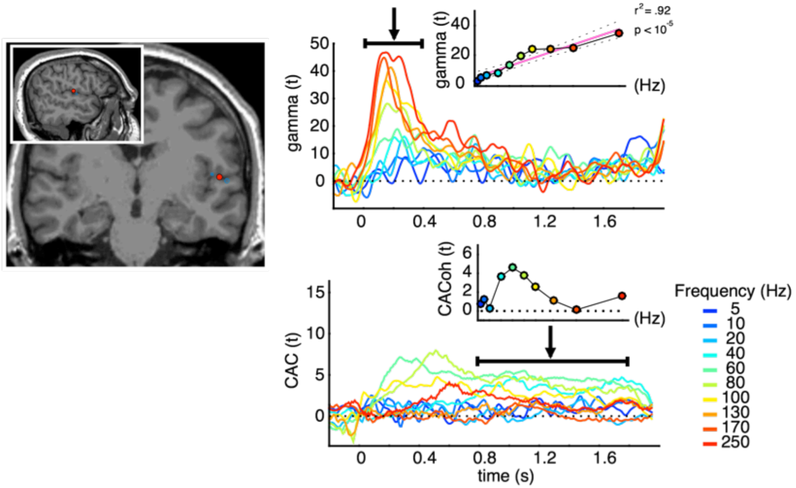
- Onset gamma power correlates with stimulus energy (*r^2=0.75*), but not salience (r^2=0.03)
- Onset gamma responses are mostly localized in early auditory areas

⇒ Hypothesis: temporal salience not indexed by gamma but by the ability of stimuli to entrain sustained brain responses across time.

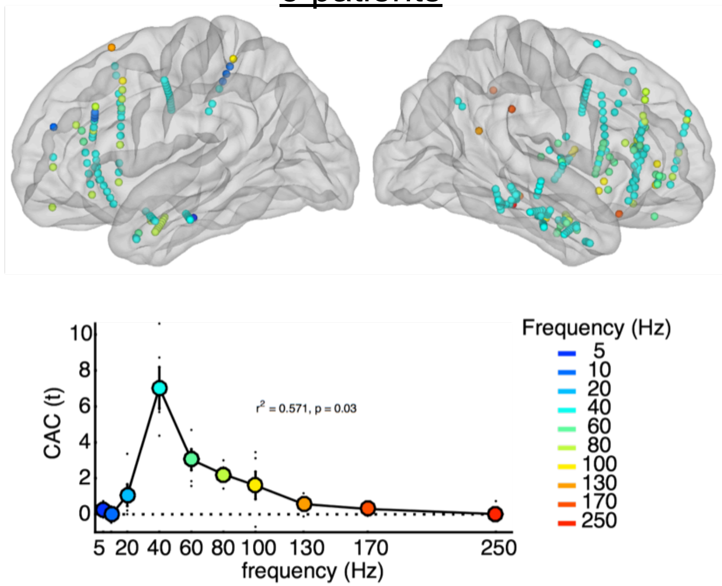
Entrained/sustained responses (ASSR strength)



Patient 1



5 patients

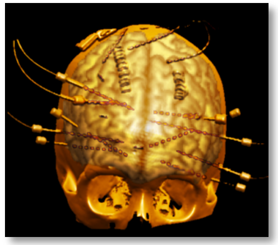


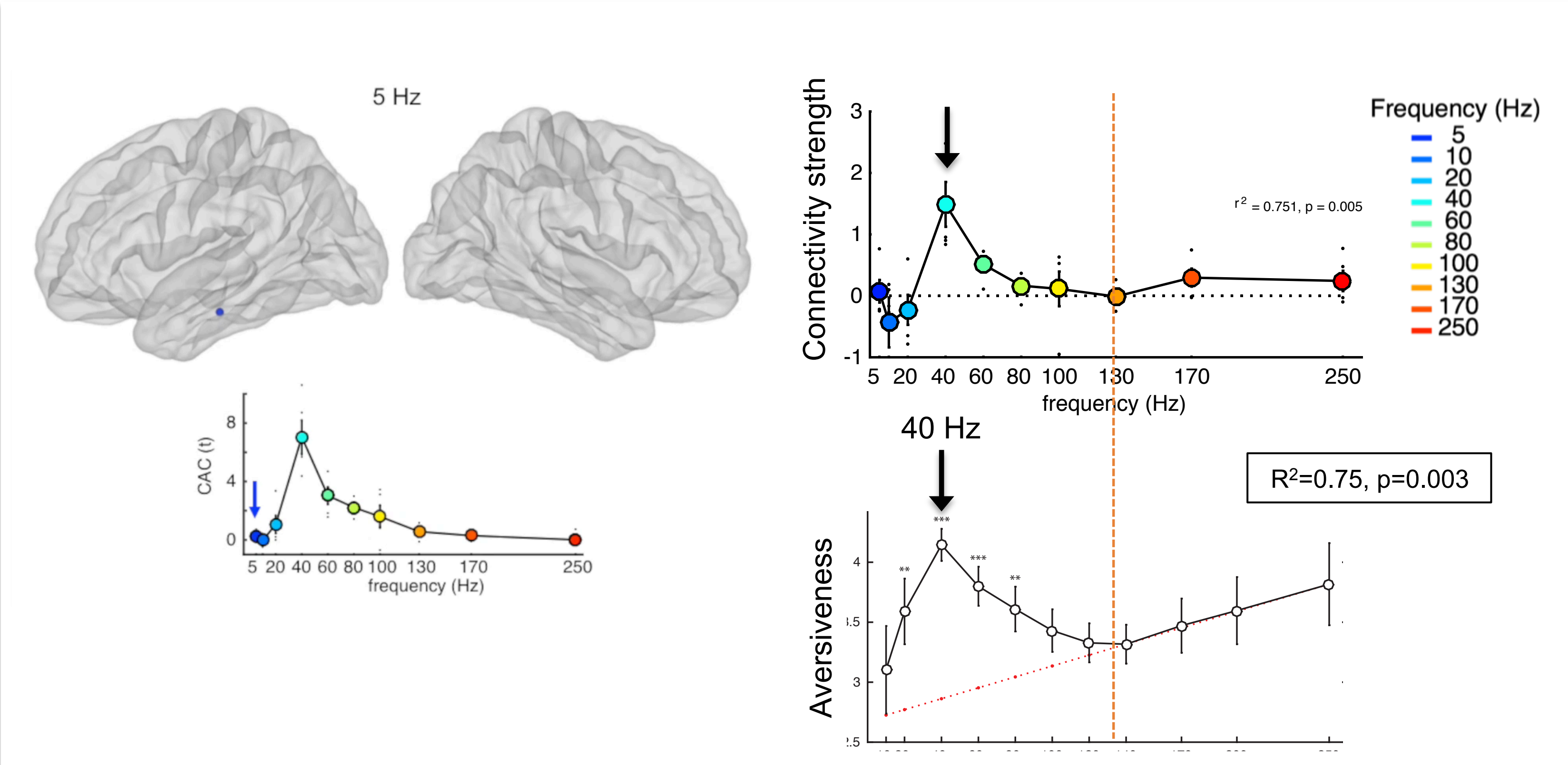
ASSR strength (CAC) = stimulus-brain coherence

The coherence between the stimulus and brain responses (ASSR):

- correlates with salience (r^2=*0.57*) but not energy (r^2=*0.06*) in late sustained responses
- synchronizes electrodes in widespread auditory and non-auditory regions.

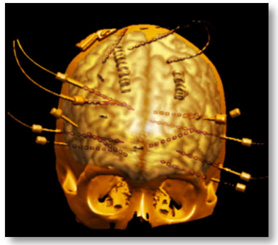
ASSR spatial spread and long-range synchrony

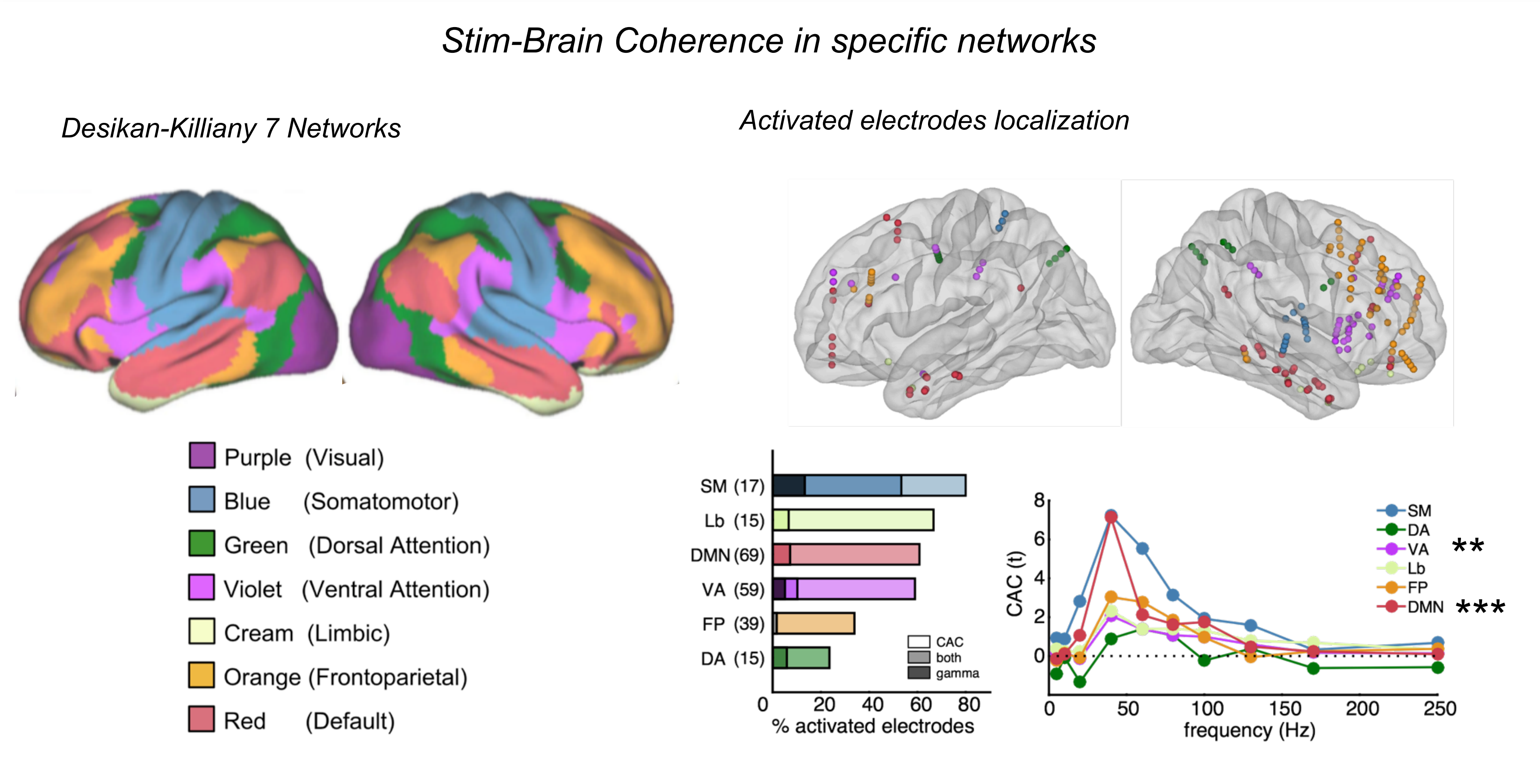




- Temporally salient click trains massively entrain and synchronize activity in auditory but also –mostly– non-auditory electrodes.
- Long-range synchrony/connectivity patterns best account for subjective ratings.

Anatomo-functional selectivity

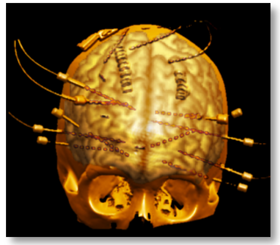




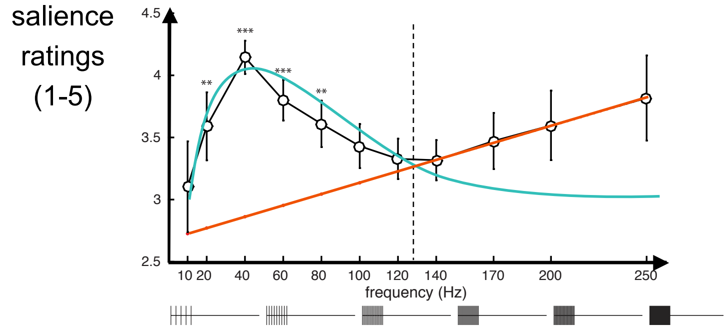
- Temporally salient sounds **synchronize** limbic, medial temporal and frontal regions:

⇒ mix of sensory areas AND “**salience**” networks (aka pain/aversion networks)

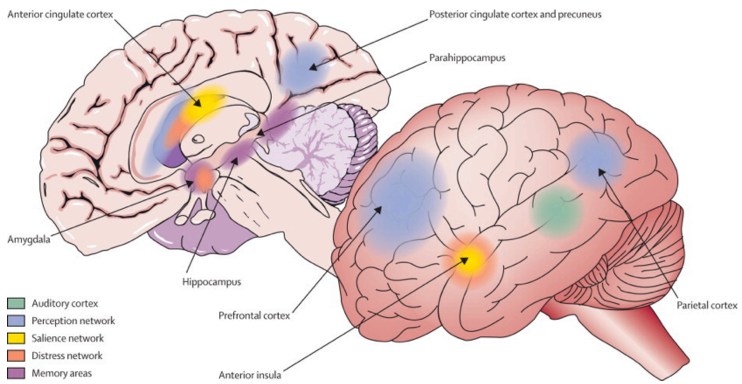
Neural routing of roughness: intracranial recordings



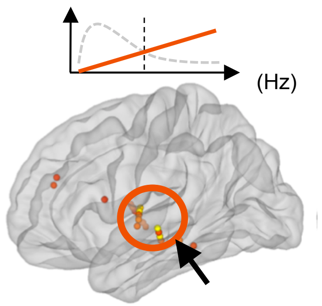
Subjective salience (aversiveness)



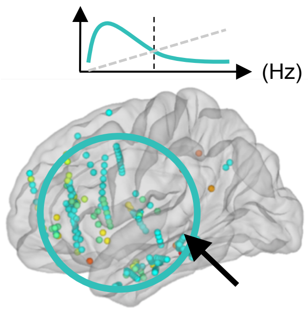
Rough sounds target the Salience Network



Intracranial recordings



auditory cortex



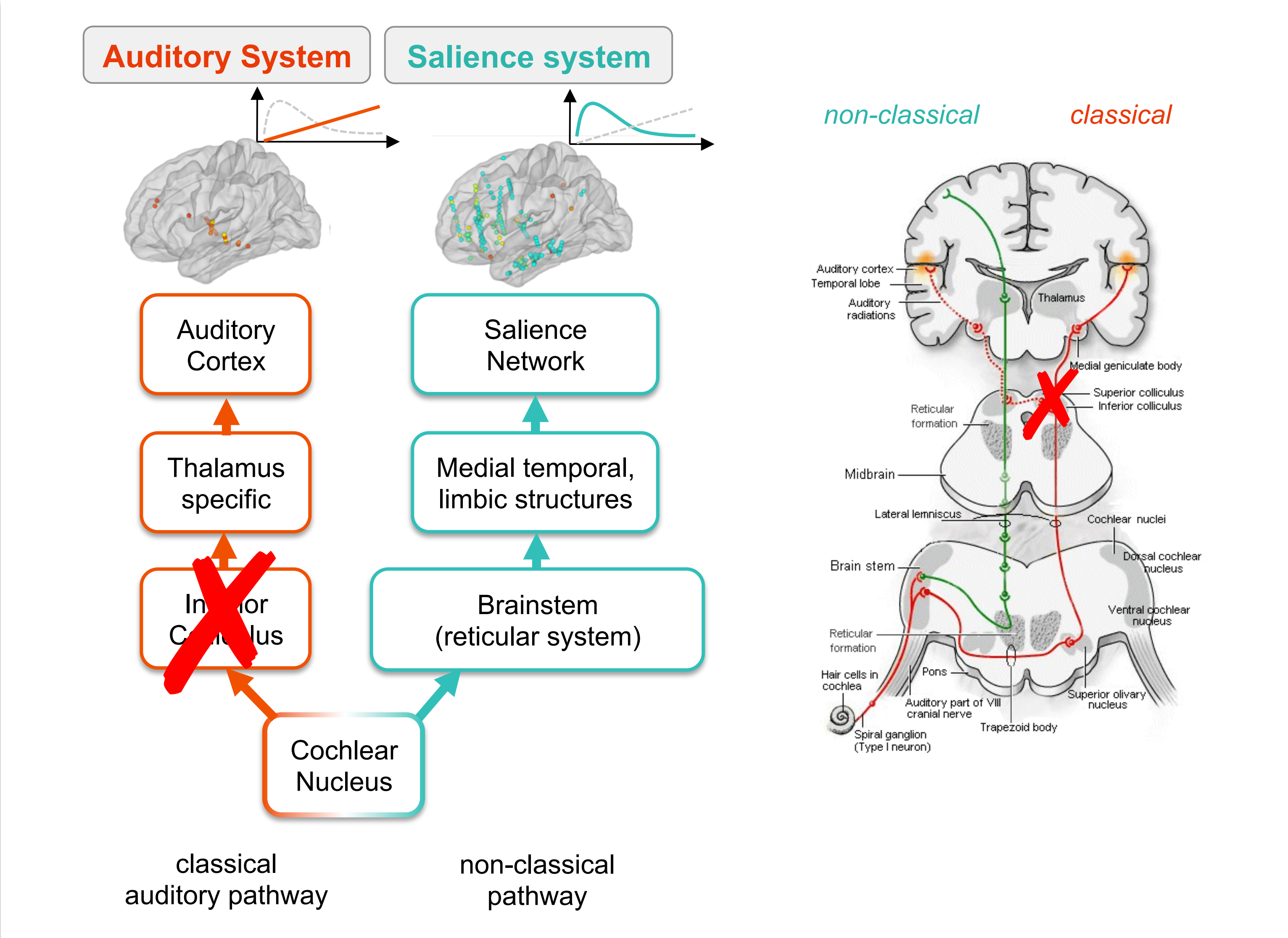
salience network

⇒ Responses reflect pitch processing in the classical *auditory system*

⇒ Responses reflect aversion to roughness in the *salience network*

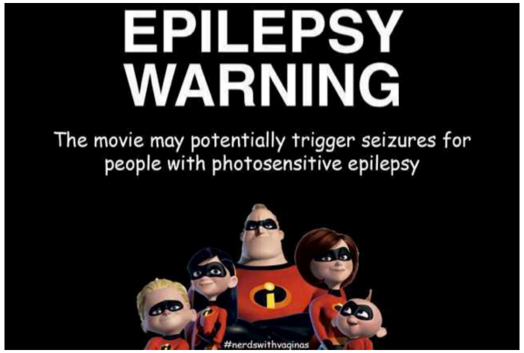
Arnal et al. in revision

Routing of roughness through non-classical pathways?

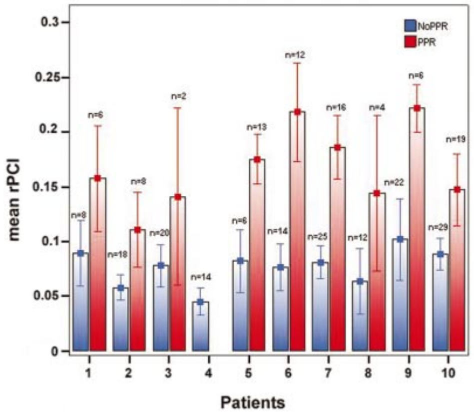


Gamma synchrony in photosensitive epilepsy

Photosensitive epilepsy

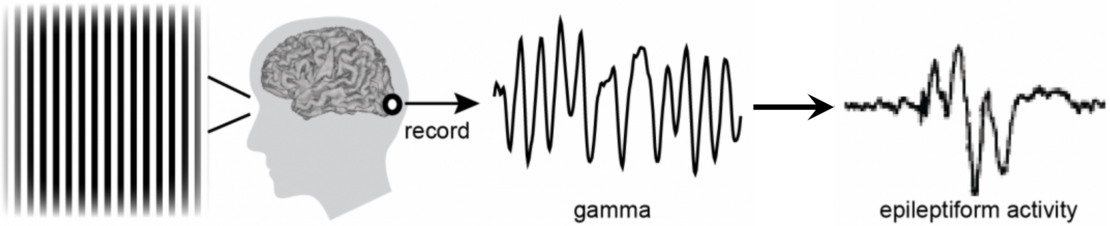


Intermittent Photic Stimulation



Gamma (30–120 Hz) synchrony is larger before epileptic trials (10 patients)

Parra et al. 2003

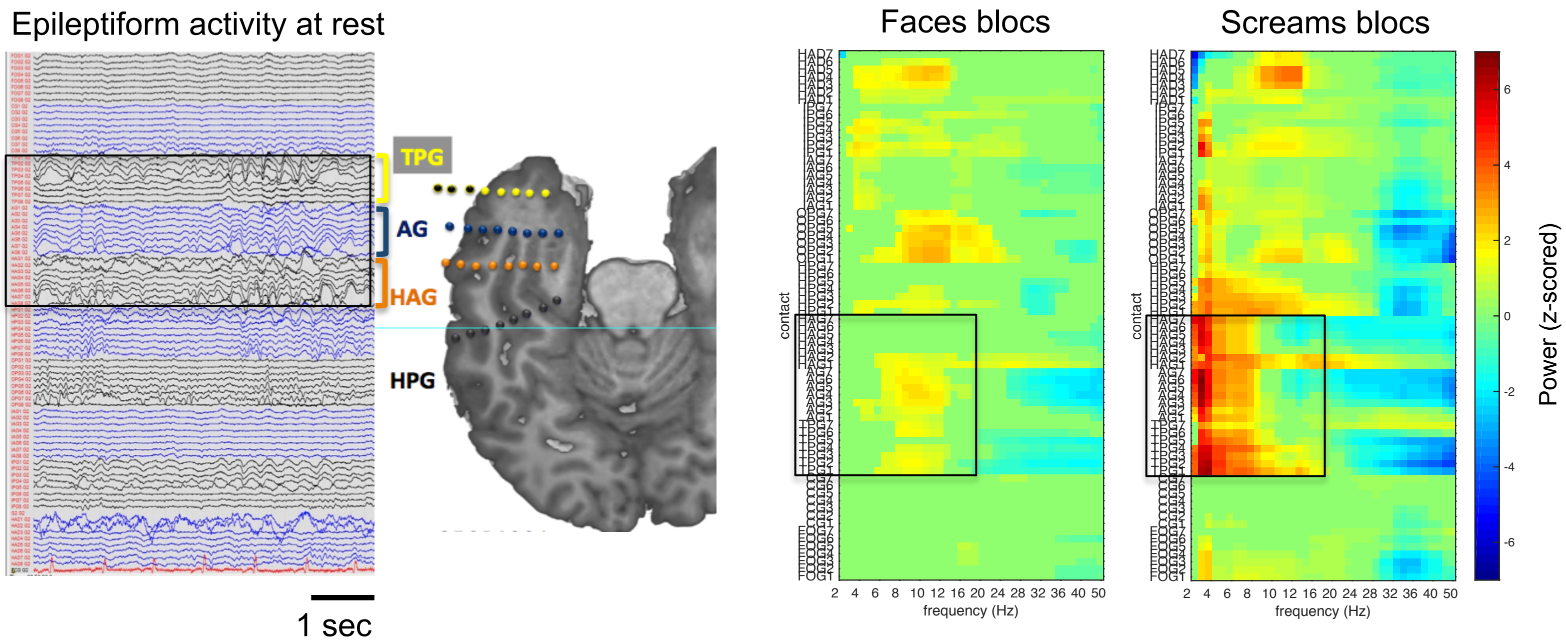


- Prevalence of temporal >> occipital epilepsy (66 *vs.* 3 %).
- Rough sounds (30-150 Hz) entrain gamma rhythms in temporo-limbic networks often affected in temporal lobe epilepsy (TLE).

<u>Hypothesis</u>: rough sounds ⇒ 🡅 gamma ⇒ 🡅 temporal epileptic activity?

Phonosensitive low-frequency activity?

Comparison: visual (emotional faces) *vs.* auditory (screams) protocols
[stimulation *minus* rest, averaging about 40 * 5 seconds chunks, no cleaning]

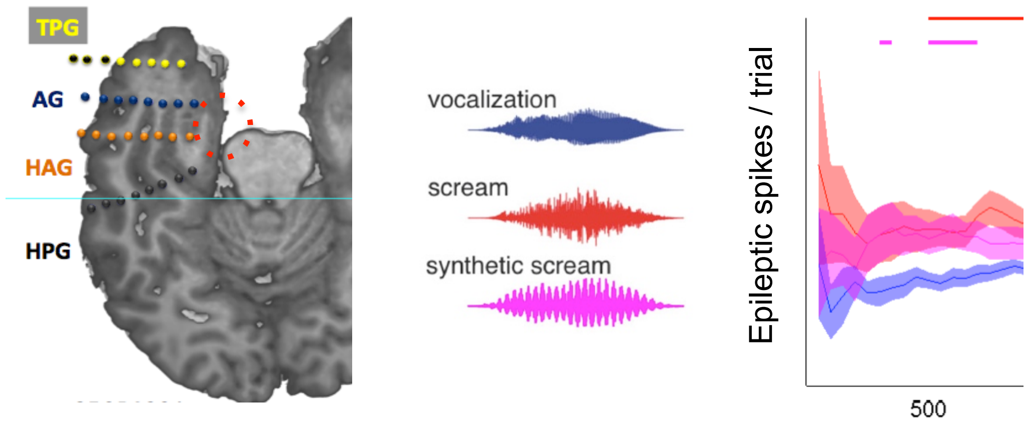


- Fearful voices (screams) induce more ‘epileptiform’ low-frequency activity than fearful visual (faces) stimuli. ⇒ An effect of roughness?

An effect of roughness on epileptic activity ?

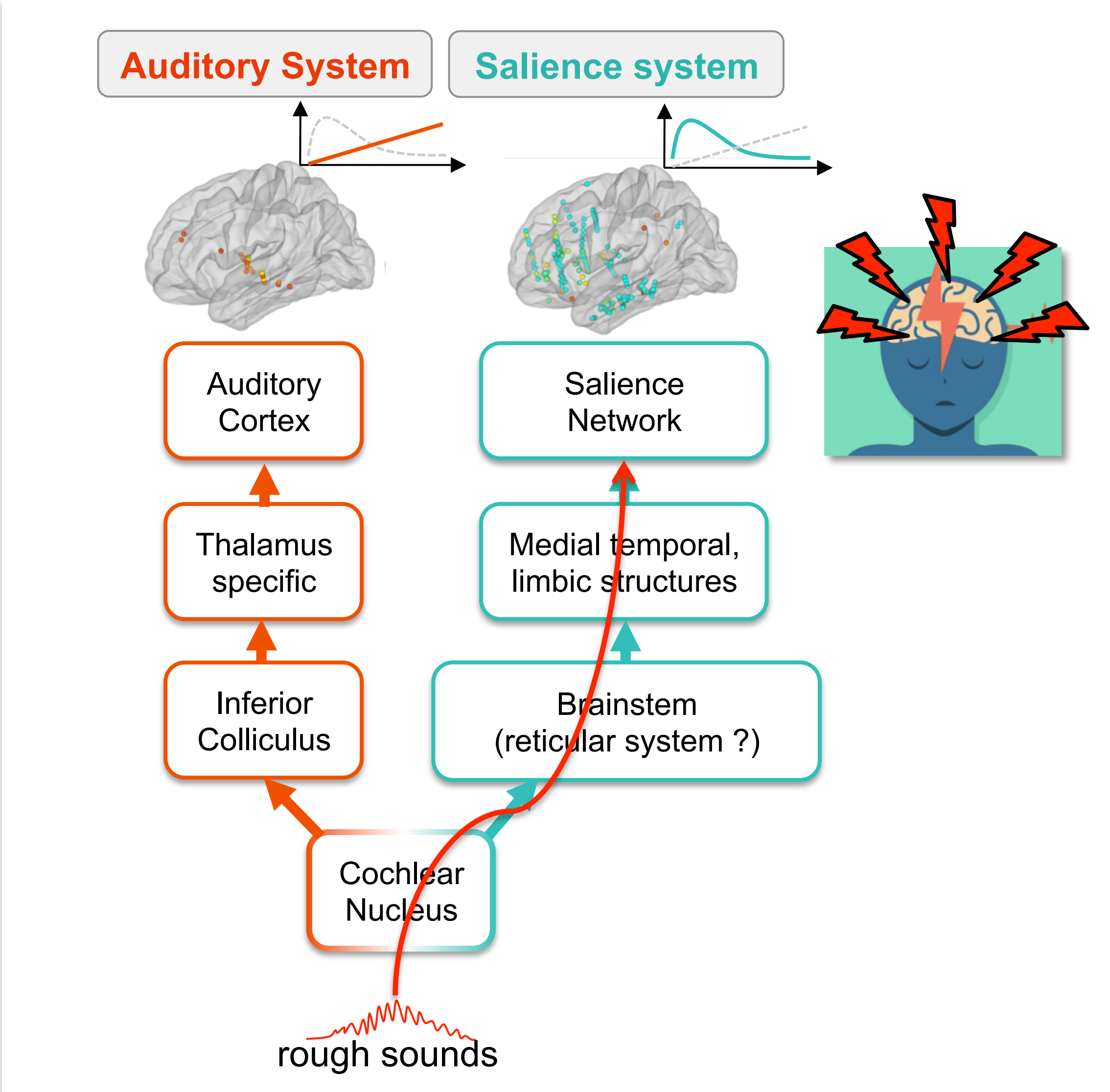
Measuring 'sound-evoked' epileptic spikes in medial temporal contacts:

preliminary data, no clear auditory responses in these contacts.



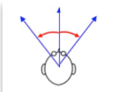
- Rough sounds increase **epileptic** spiking (in those 3 shafts that spike most).
- Rough sounds also increased the spread of spiking across electrodes

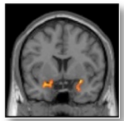
Roughness-induced medial temporal epileptic activity ?

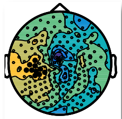


The sound of salience: summary

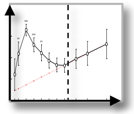

Rough vocalizations sound scared, scary and are salient


Rough cues enhance behavioral (localization) efficiency

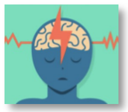

Rough sounds are routed to emotion related limbic areas.


Rough cues are encoded in early EEG responses


Rough cues may be encoded early in EEG responses during REM sleep


Rough sounds (below the ‘sampling limit’) are subjectively salient


Temporally salient (rough) sounds massively recruit the ‘*salience system*’


Rough sounds enhance epileptic activity in temporo-limbic electrodes

thank you

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