The deep links between auditory perception and memory

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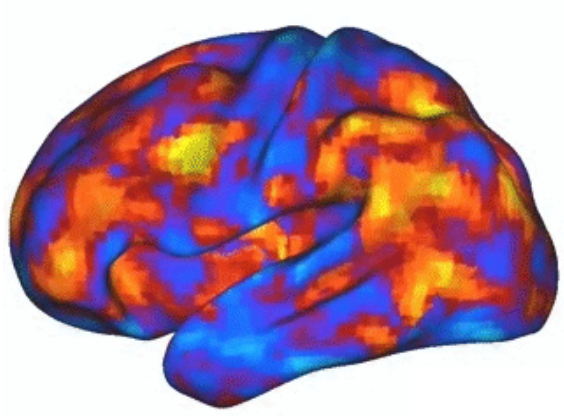
Introduction

Perception



"A tumbled entanglement of the most different kinds of motion, complicated beyond conception". H. Helmholtz (1877)

- Auditory perception and memory are deeply intertwined
- Illusions are a unique window on these links
- Musicians knew all this all along...

Perception and Memory

- Prelude: “*Laurel*” and “*Yanny*”
- Auditory memory acquisition
- Prior knowledge and auditory scene analysis
- Prior context and basic auditory features

Perception and Memory

- Prelude: “*Laurel*” and “*Yanny*”
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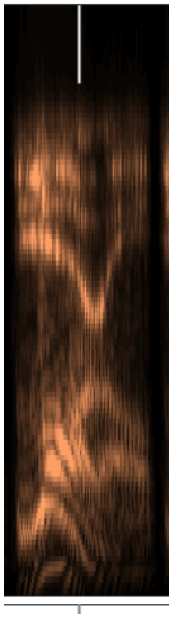
Laurel/Yanny



Do you hear *“Laurel”* or *“Yanny” ?*

Laurel/Yanny

christine teigen
@chrissyteigen

Follow

it's so clearly laurel. I can't even figure out how one would hear yanny.

4:09 PM - 15 May 2018

26,082 Retweets **135,864** Likes

'Laurel' or 'Yanny'? People can't decide

By Chris Bell
BBC UGC and Social News

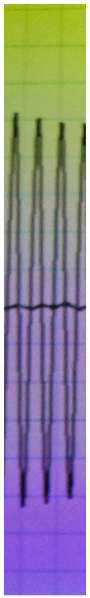
16 May 2018

Share

"It's definitely Yanny, Laurel."

This is the way the world ends. Not with a bang but a "laurel". Or a "yanny". No one can decide.

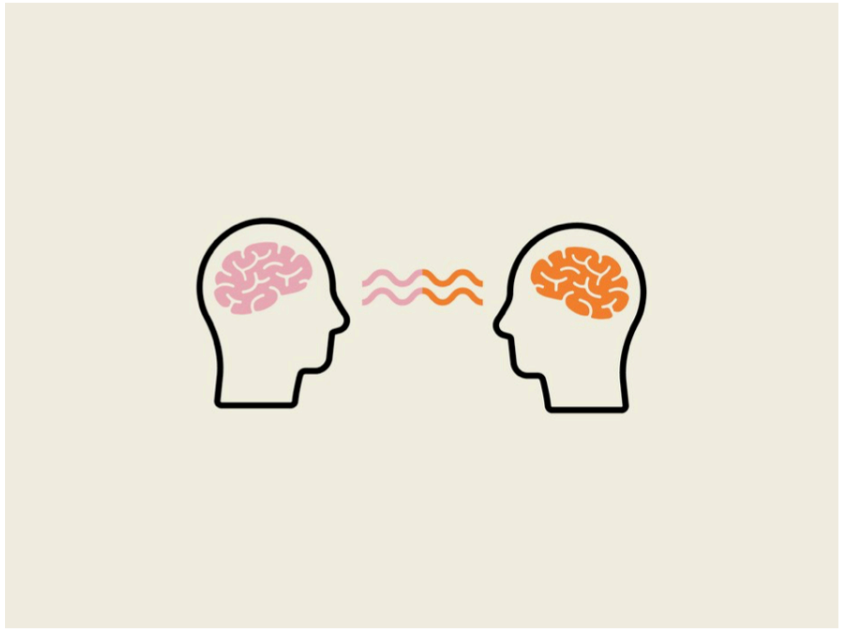
Yanny
ound



l waves a

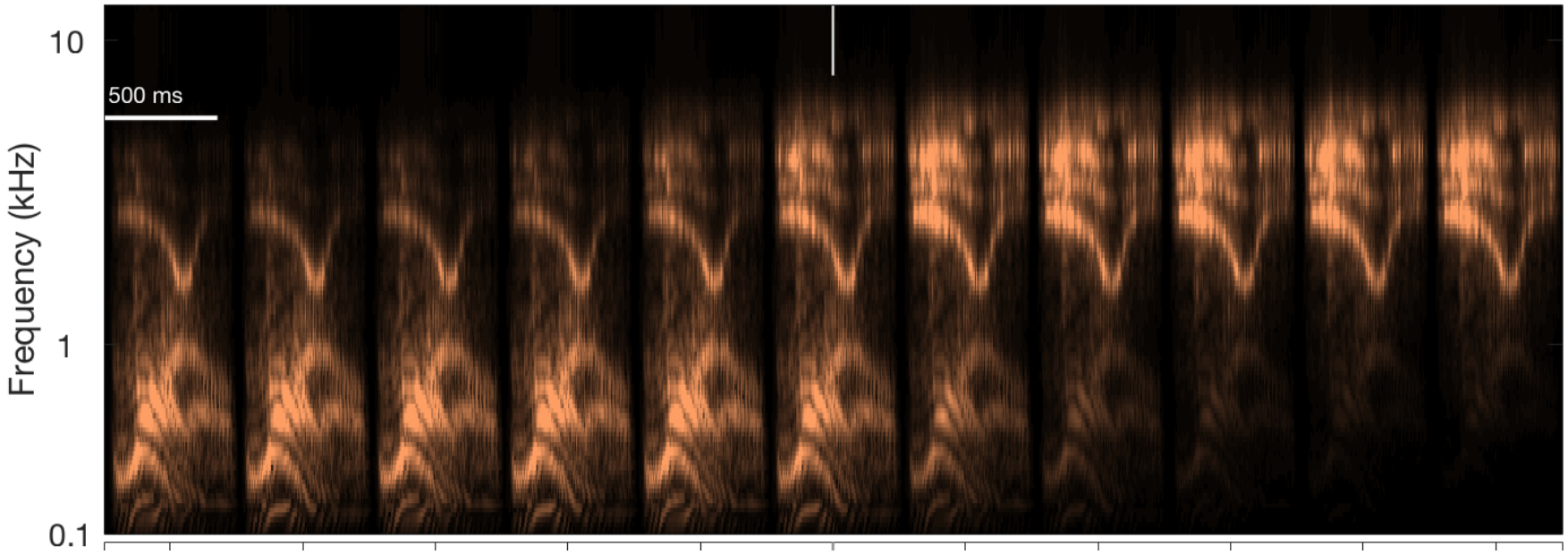
ADAM ROGERS SCIENCE 05.16.18 07:47 PM

THE FUNDAMENTAL NIHILISM OF YANNY VS. LAUREL



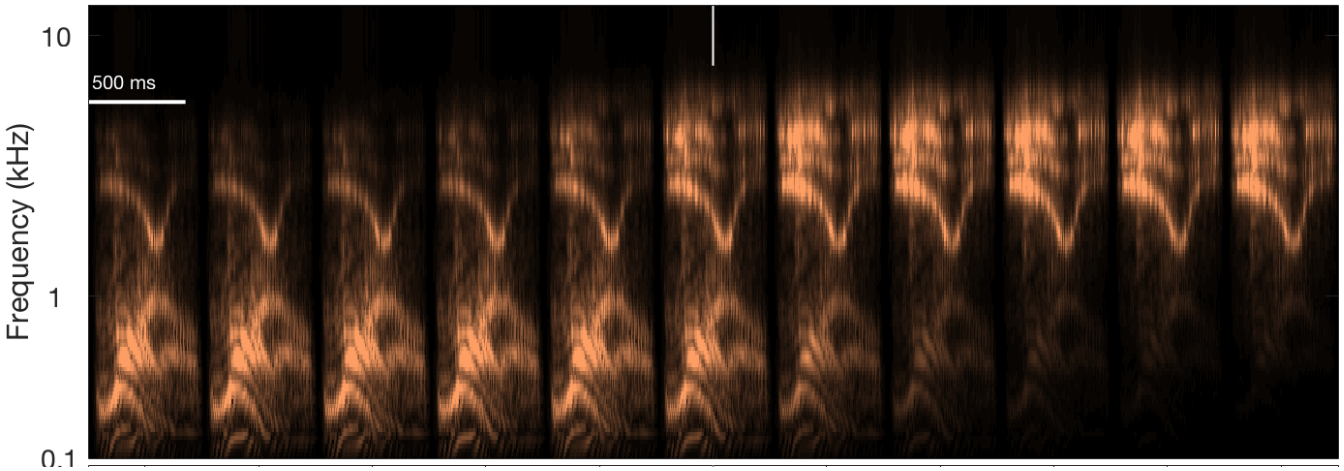
When everyone's brain makes a little world out of sensory input, and everyone's world is just a little bit different, can you really *know* anyone? ALYSSA FOOTE

Laurel/Yanny



- “Laurel” in low frequencies, “Yanny” in high frequencies
- Online experiment, “Do you hear *Laurel* or *Yanny*?”
- How confident are you?

Laurel/Yanny



Pressnitzer, Graves, Chambers, de Gardelle, & Egré, Current Biology, 2018

Laurel/Yanny

- The same sound may produce very strong individual percepts
- Correlations with gender, musicianship, English/French…
- A possible interpretation: interaction between acoustics and auditory experience, *i.e.* “memory”

Perception and Memory

- Prelude: “*Laurel*” and “*Yanny*”
- Auditory memory acquisition
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Memory for noise

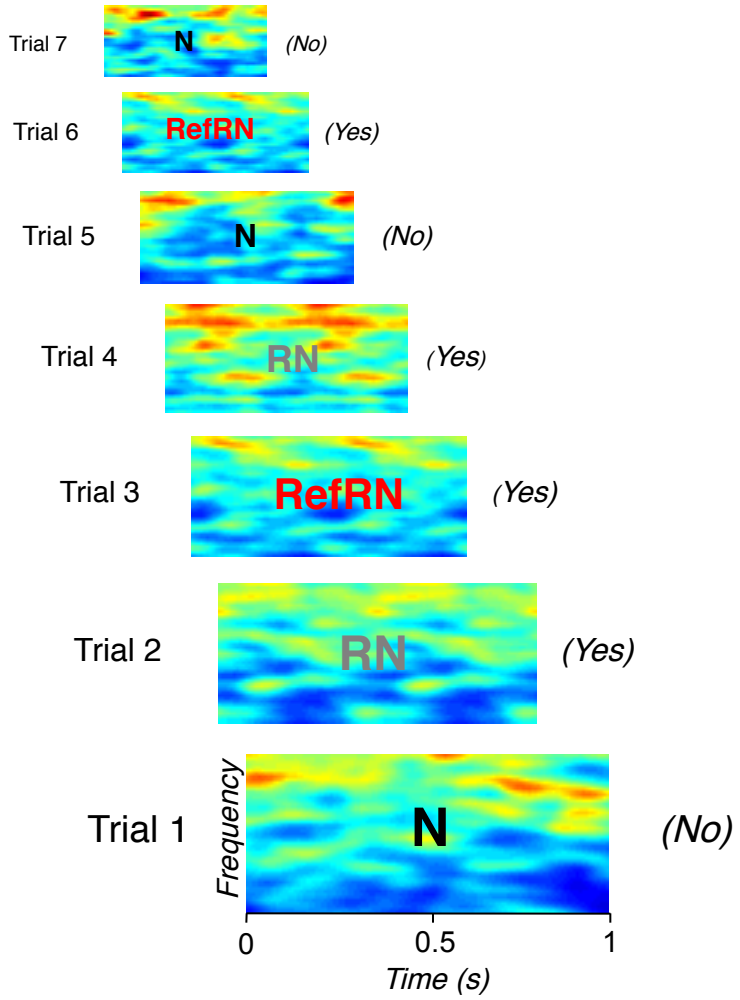
- Noise to observe the time-course of new auditory memories
  - never heard before
  - meaningless
  - unpredictable

Memory for noise

Our task

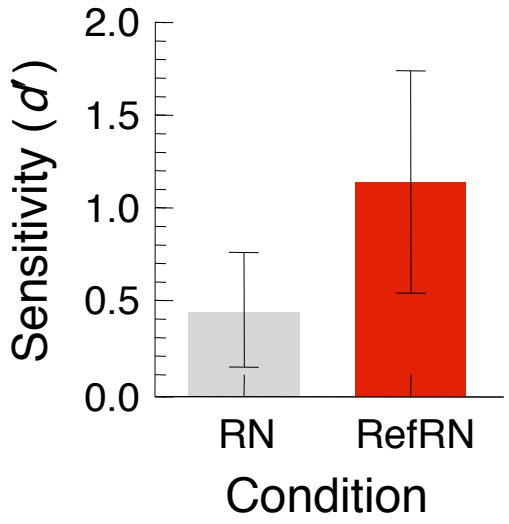
- 1s noise sample
- Repetition detection task
- RefRN identical throughout block

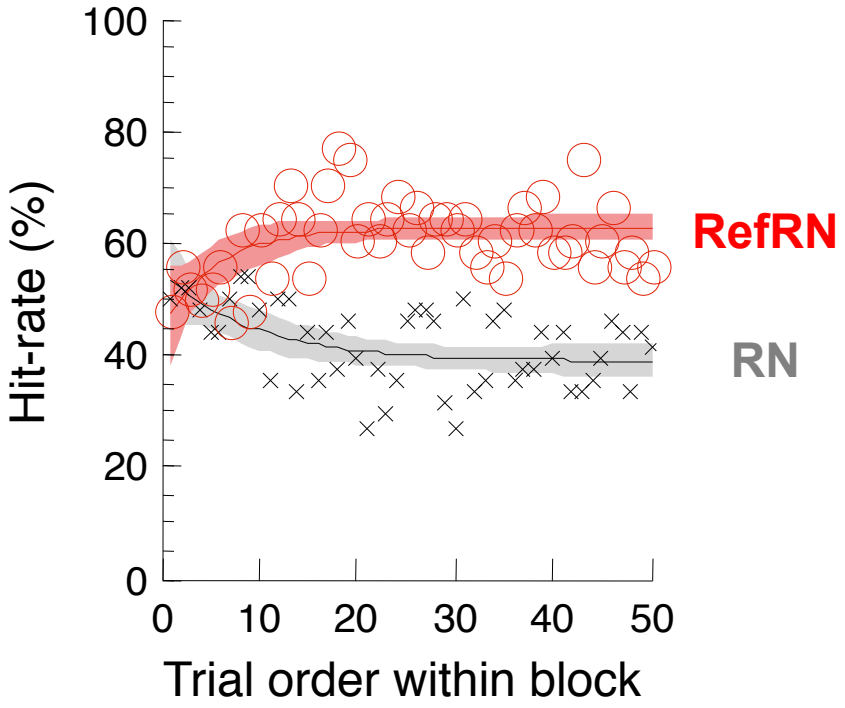
-> Improvement for RefRN=learning



Memory for noise

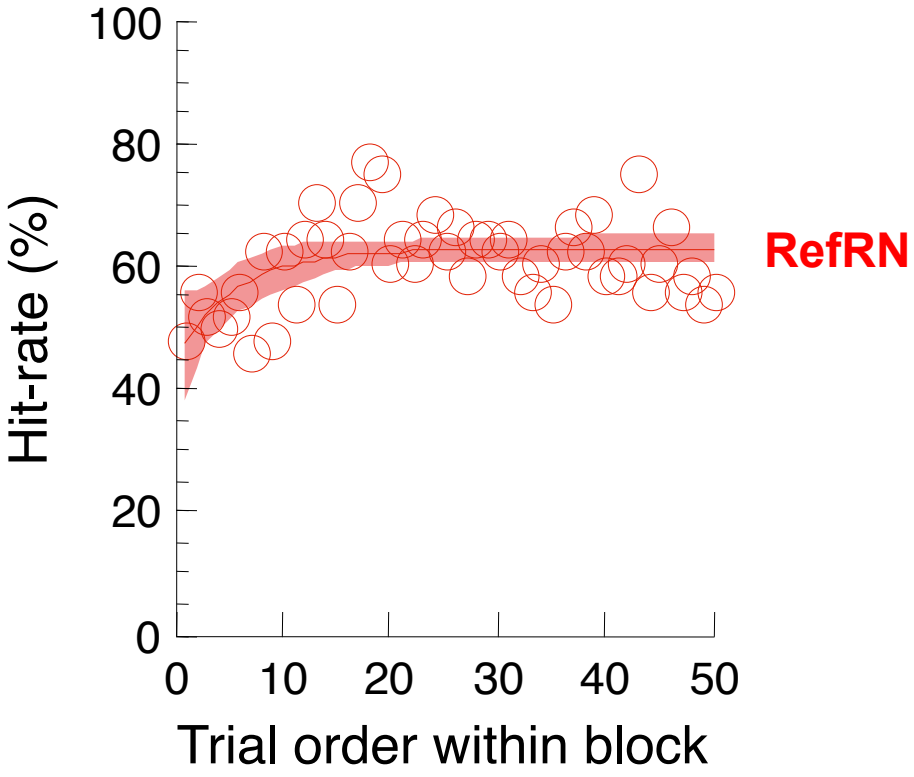
Results





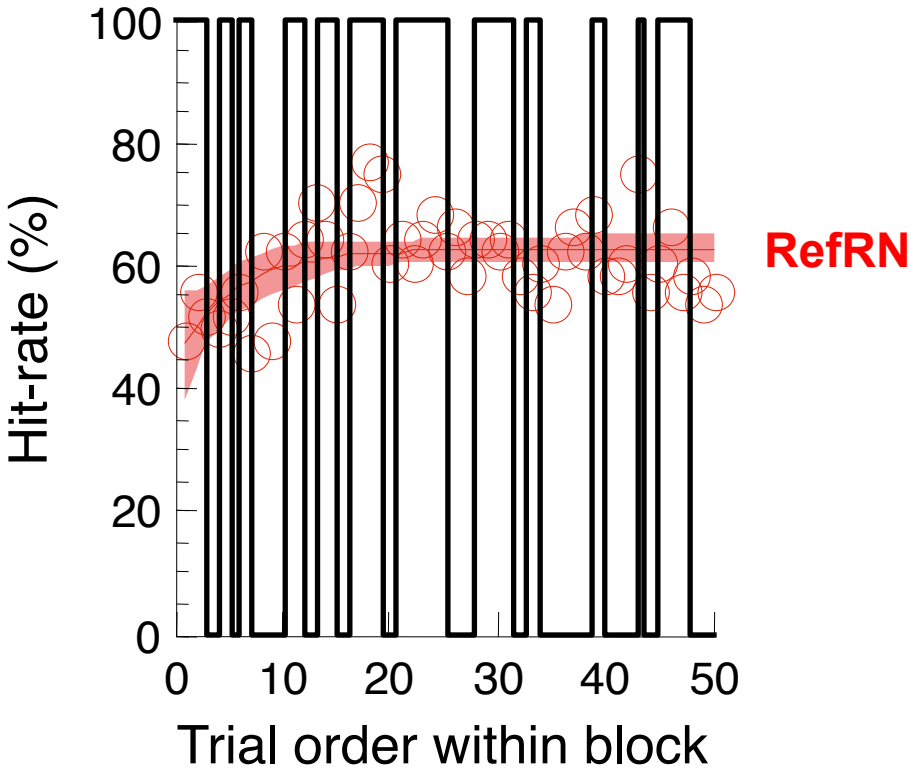
- Performance advantage for reference samples
- Due to an increase in sensitivity during the block
- Decrease for RN: criterion effect

Memory for noise



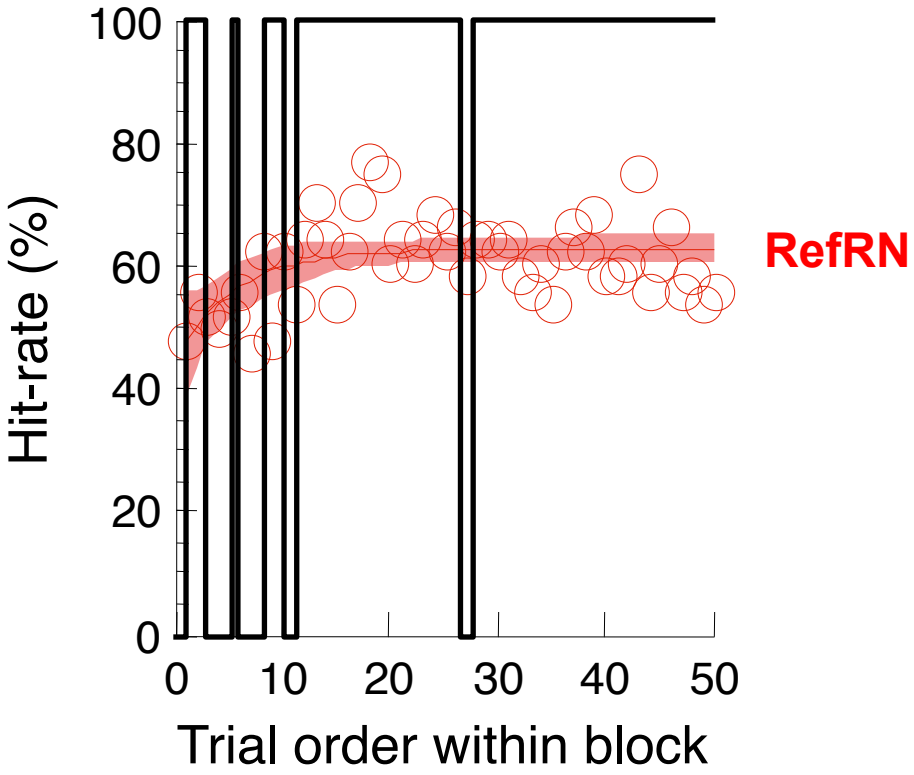
- Modest increase on average
- But inter-blocks variability

Memory for noise



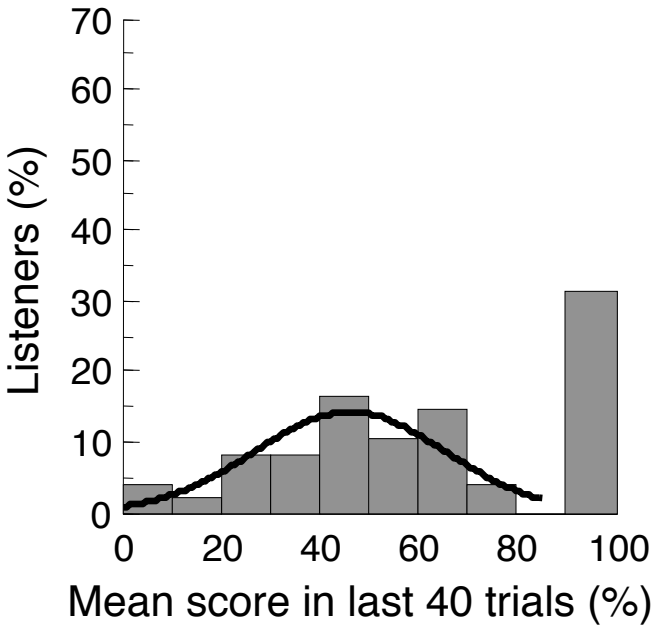
- Modest increase on average
- But inter-blocks variability: no learning

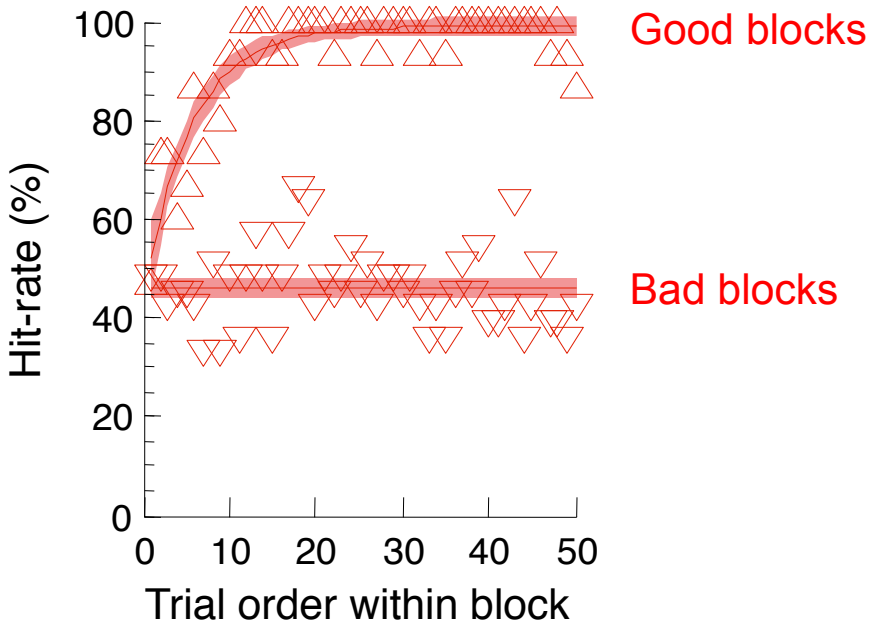
Memory for noise



- Modest increase on average
- But inter-blocks variability: almost perfect learning

Memory for noise



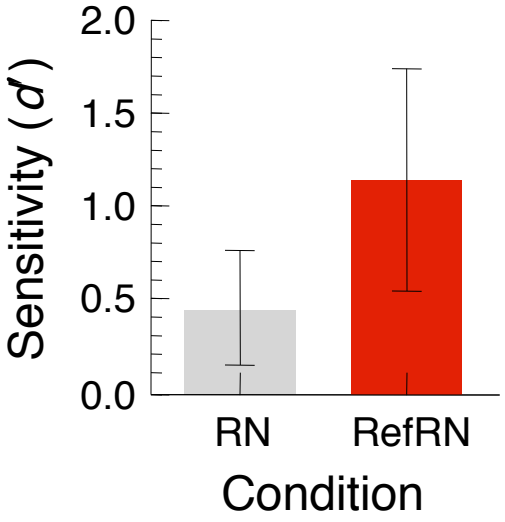


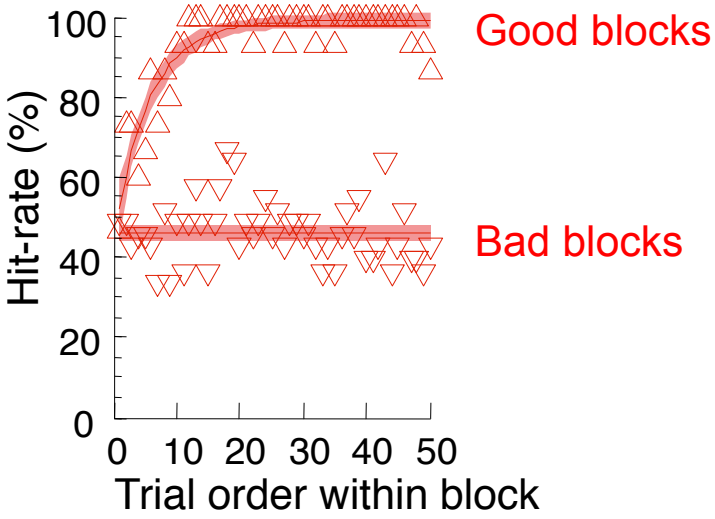
- Learning either absent, or perfect
- When it occurs, extremely fast and long-lasting

Agus, Thorpe, & Pressnitzer, Neuron, 2010

Memory for noise

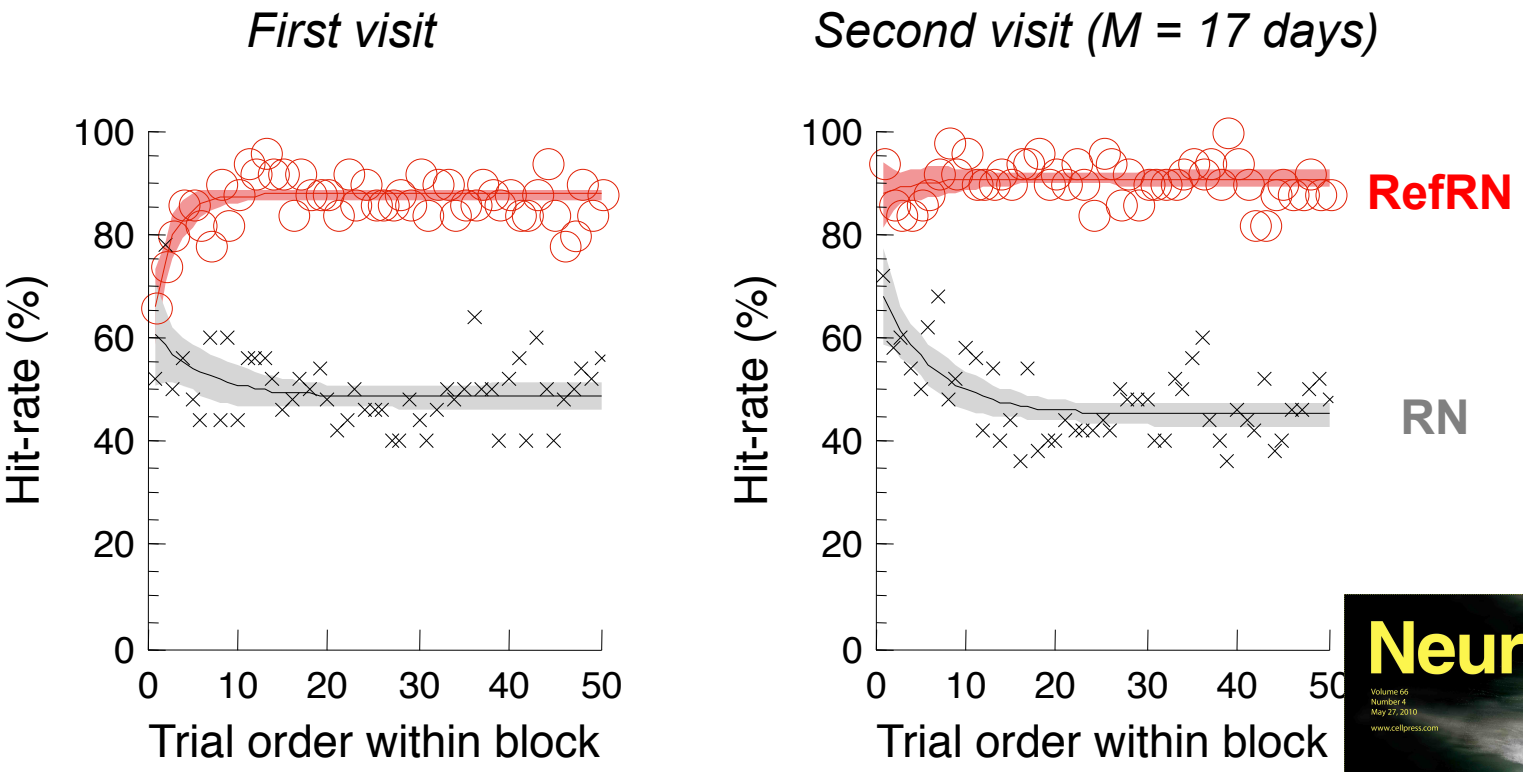
Results



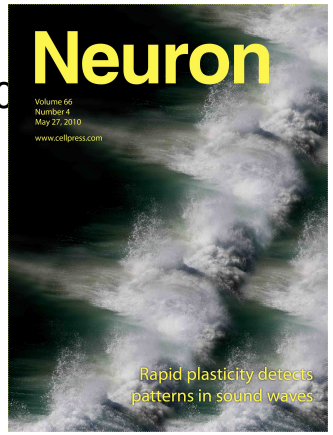


- Performance advantage for RefRN
- Due to a rapid improvement from chance to near perfect

Long-term memories

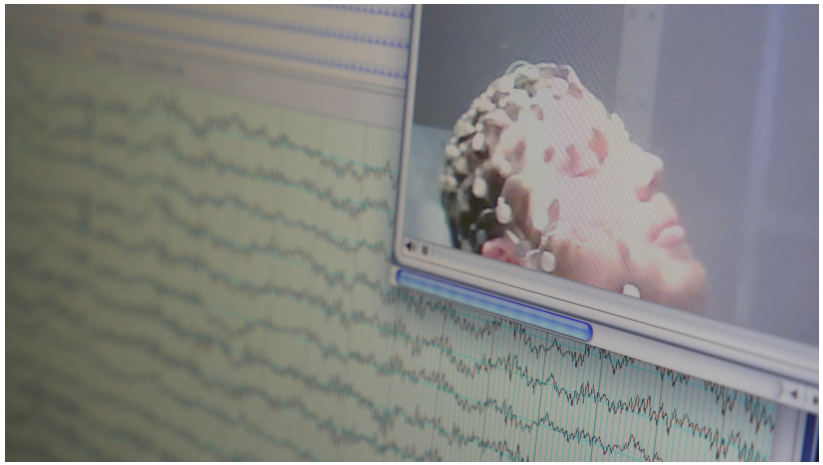


- Memories for noises retained over weeks

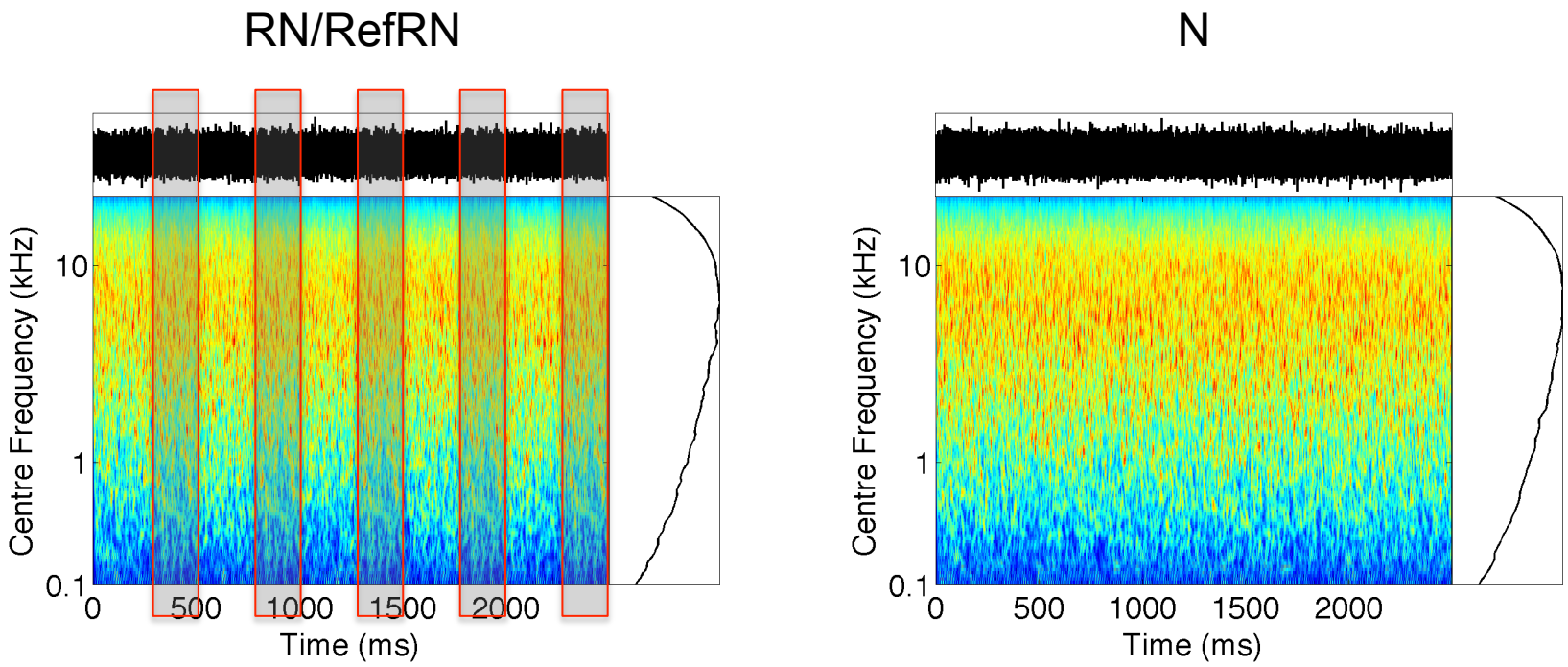


Agus, Thorpe, & Pressnitzer, Neuron, 2010
Agus & Pressnitzer, J. Acoust. Soc. Am., 2013
Kang, Agus, & Pressnitzer, J. Acoust. Soc. Am., 2017

Neural correlates of memory

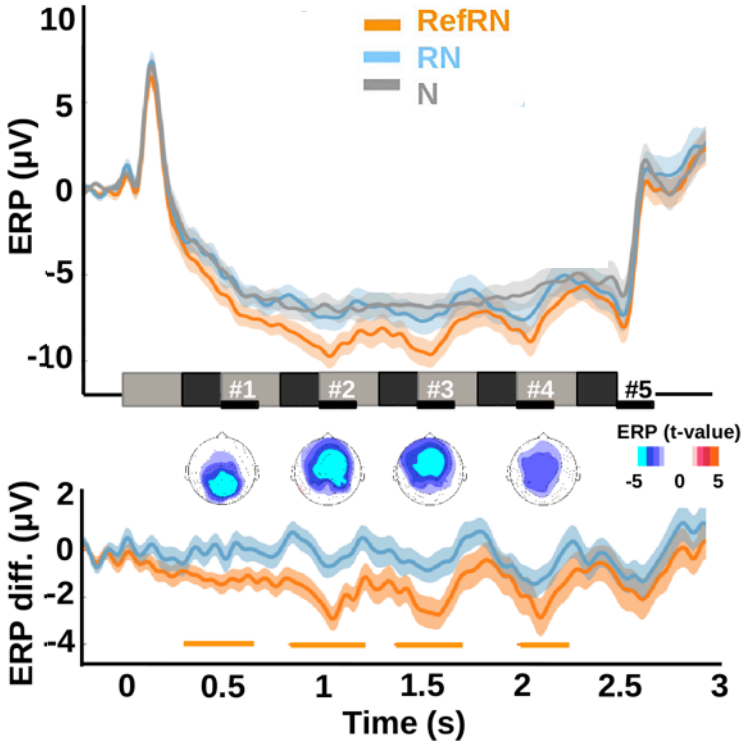


Neural correlates of memory



- No obvious acoustic landmarks
- Noise exemplar becomes salient through learning

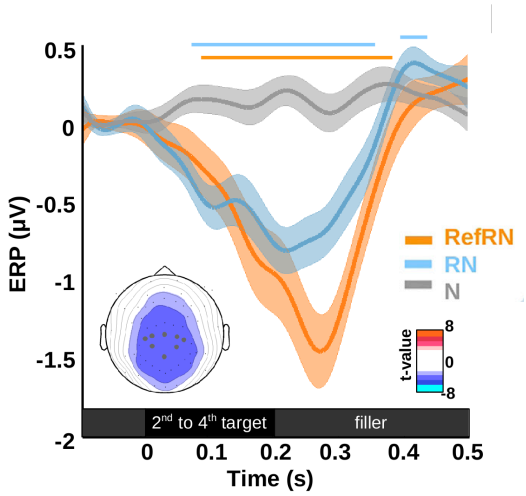
Neural correlates of memory

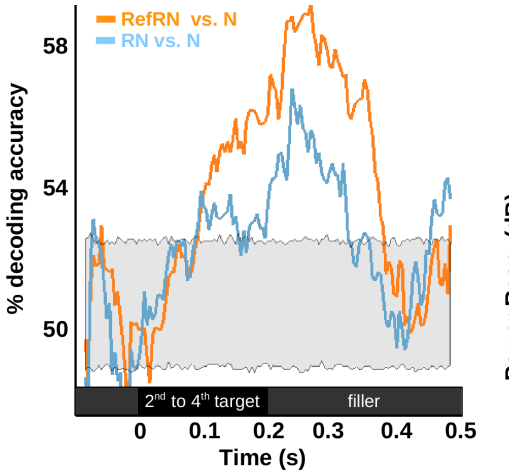


- Event-related potentials after learning

Neural correlates of memory

“Memory-evoked” potentials



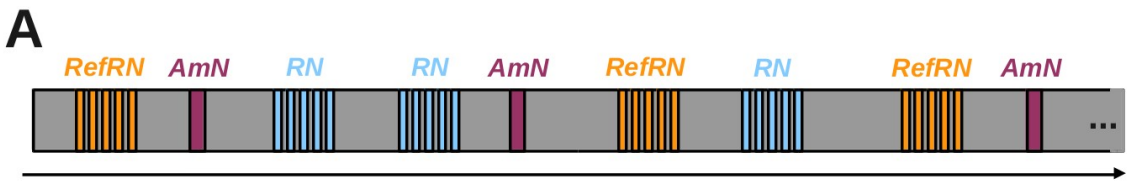


- Early latency and topography suggest sensory origin
- Can be decoded in single trials

Andrillon, Kouider, Agus, & Pressnitzer, Current Biology, 2015

Neural correlates of memory

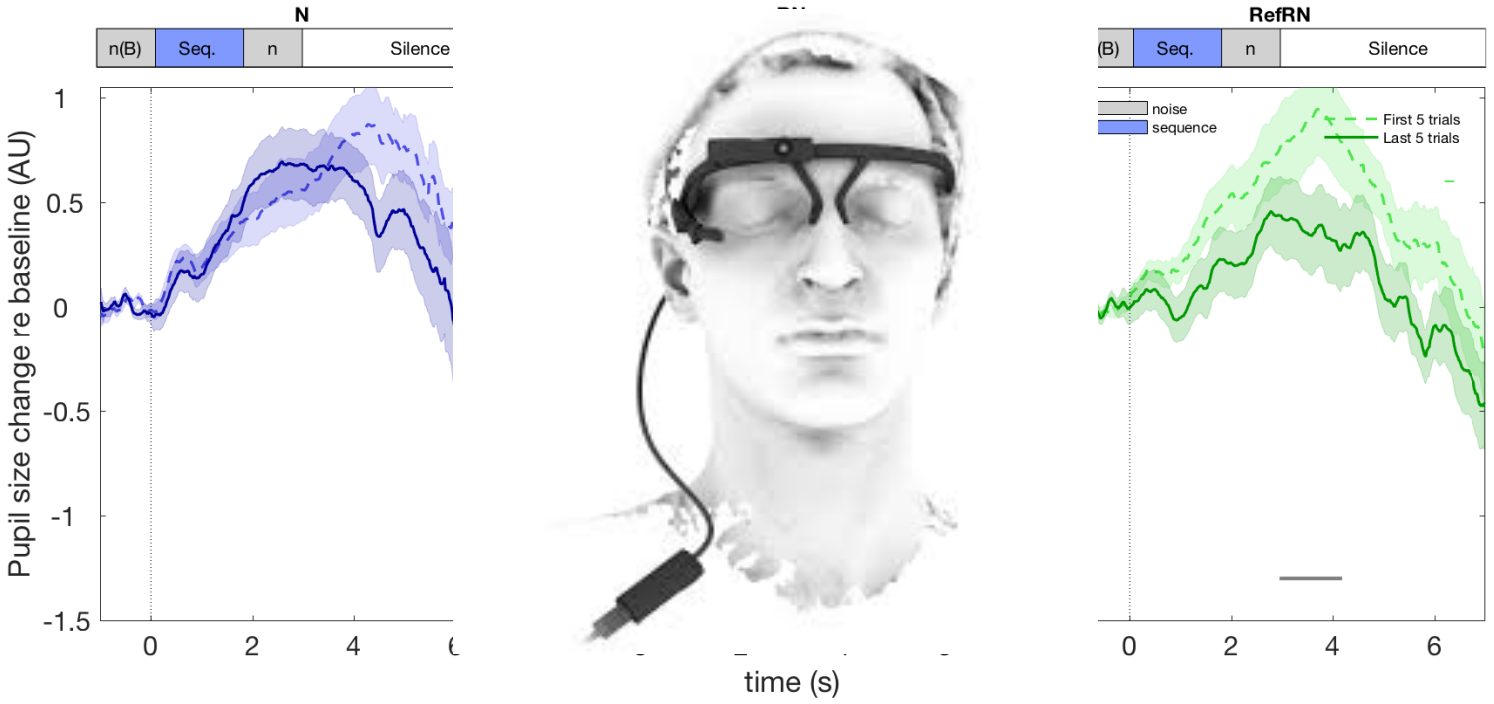
Diverted attention



- No task-directed attention needed

Andrillon, Kouider, Agus, & Pressnitzer, Current Biology, 2015

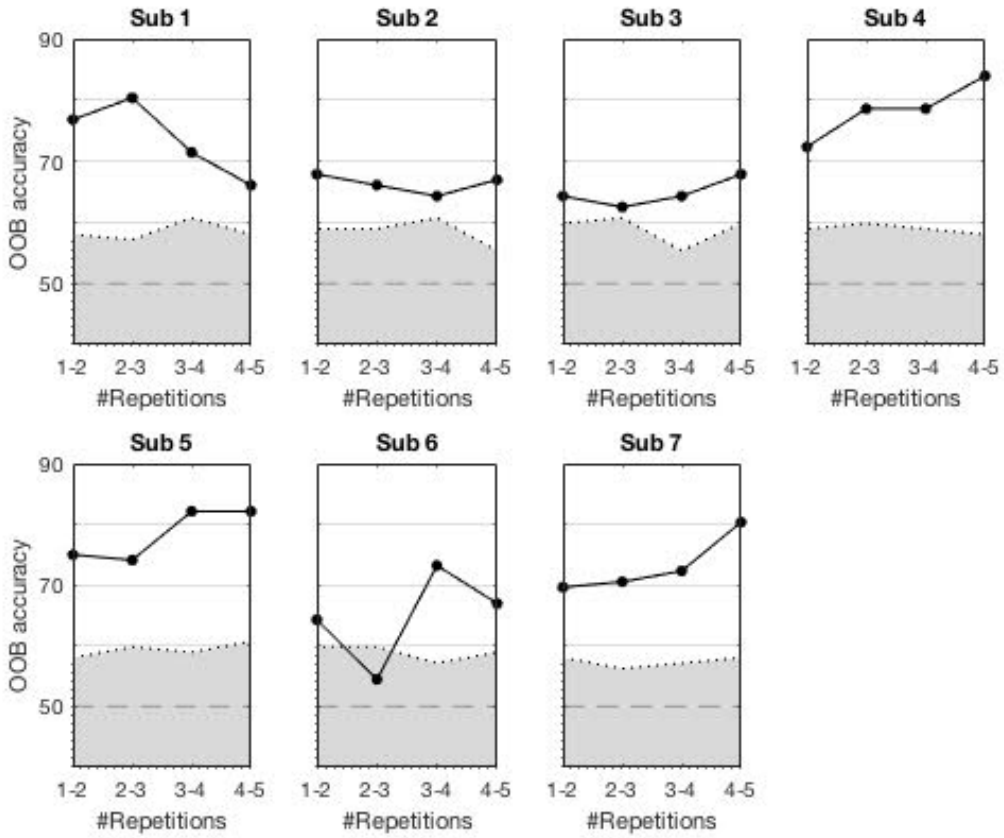
Seeing auditory memory in pupil size



- Pupil size reflects neurotransmitter release, related to memory
- In the active task, memorized sounds induce different pupil sizes

Kang & Pressnitzer

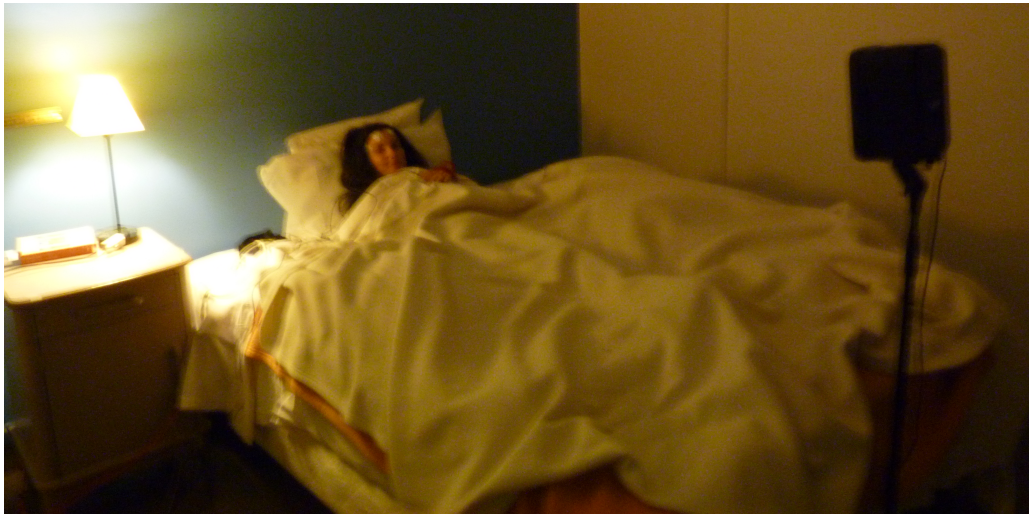
Seeing auditory memory in pupil size



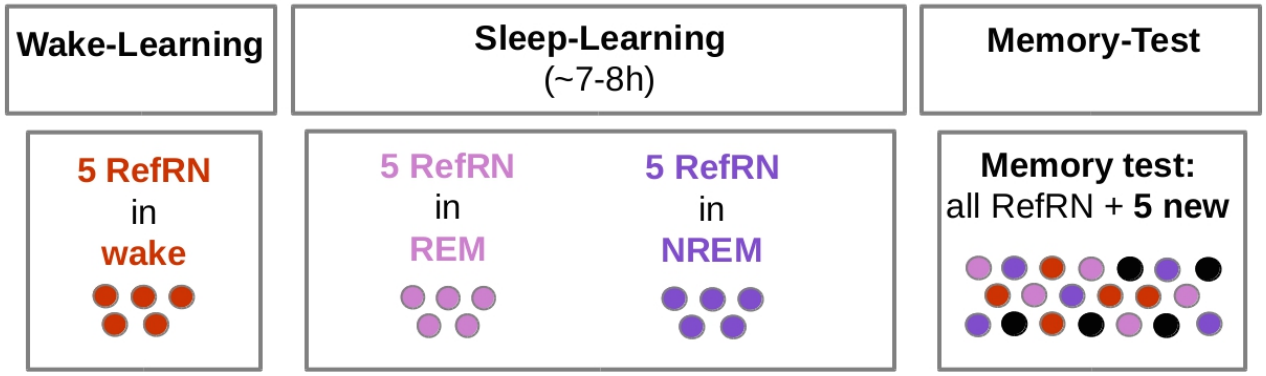
- Passive listening without a task?
- Sounds *being implicitly memorized* decoded from pupil size

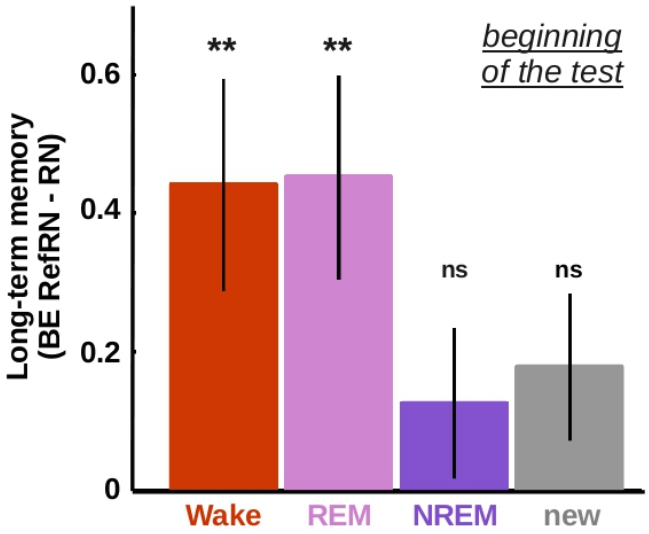
Kang, di Liberto & Pressnitzer

Learn while you sleep!



Sleep study





- REM induces learning,

Andrillon, Pressnitzer, Léger, & Kouider, Nature Communications, 2017

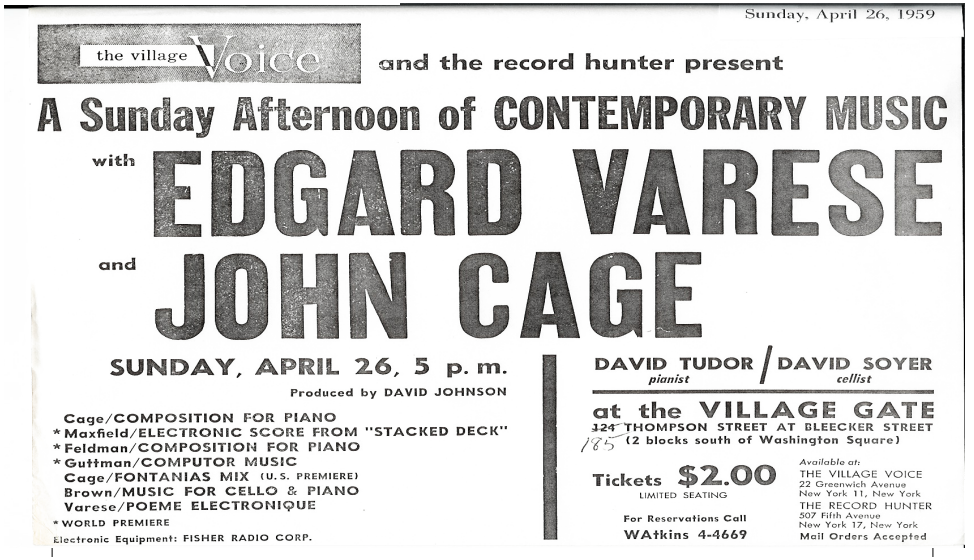
Musical interlude

Lower Limits of Auditory Periodicity Analysis

NEWMAN GUTTMAN AND BELA JULESZ

Bell Telephone Laboratories, Inc., Murray Hill, New Jersey

(Received 10 January 1963)



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the village Voice and the record hunter present

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- The original use of noise to probe auditory memory was from a pioneer of computer music

Musical interlude

Sonata-allegro form-within-a-form

A		B	A’	
Exposition		Development	Recapitulation	
a	b		a	b
1st Theme	2nd Theme		1st Theme	2nd Theme

Christian Fennesz, “Happy Audio”

- Memory is at the core of many classical forms
- In some cases, memory seems the main structural factor

Memory for noise

- Auditory memory is fast and efficient
- Unsupervised/incidental learning without focused attention
- Leaves an instant trace in sensory cortex

-> We probably memorize more about sounds than we “know”

Perception and Memory

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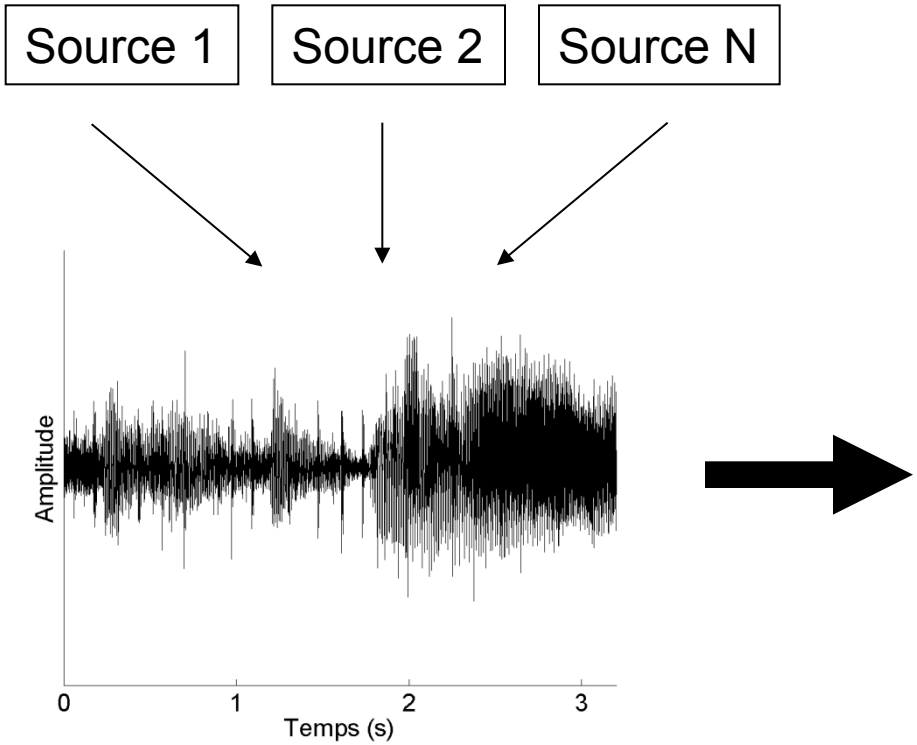
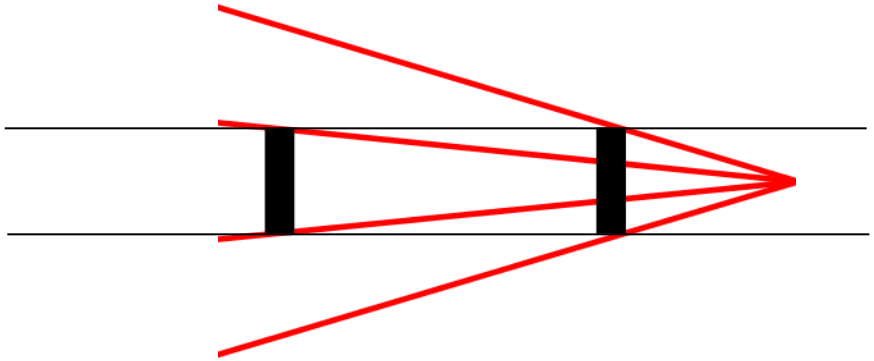
Auditory scene analysis



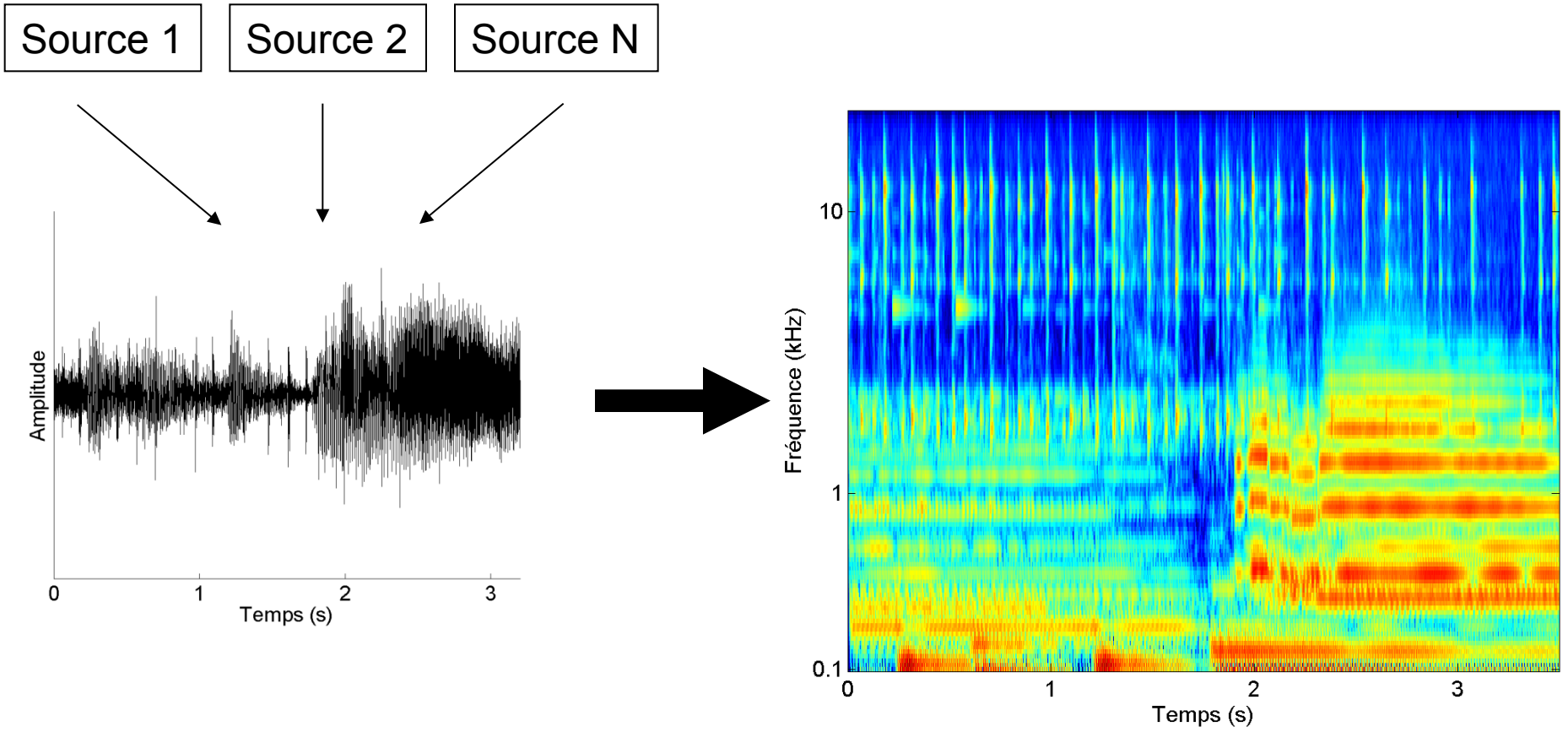
- Ill-posed problem, impossible to solve as is
- Memory to internalize prior knowledge as additional cues

Auditory scene analysis



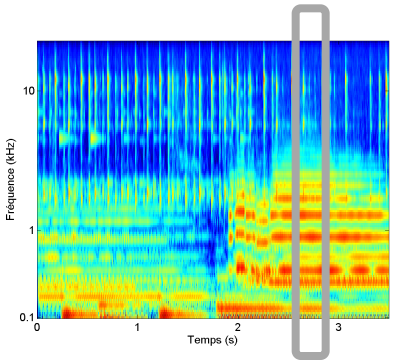
- Illusions can reveal how internal knowledge shapes perception

Auditory scene analysis



Indices d'organisation

Organisation verticale



- Sources "complexes"
  - regrouper ce qui appartient à une source

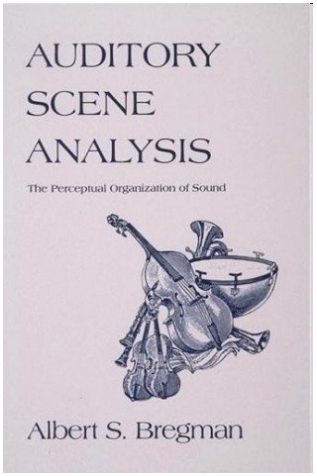
- Sources "transparentes"
  - séparer ce qui appartient à des sources distinctes

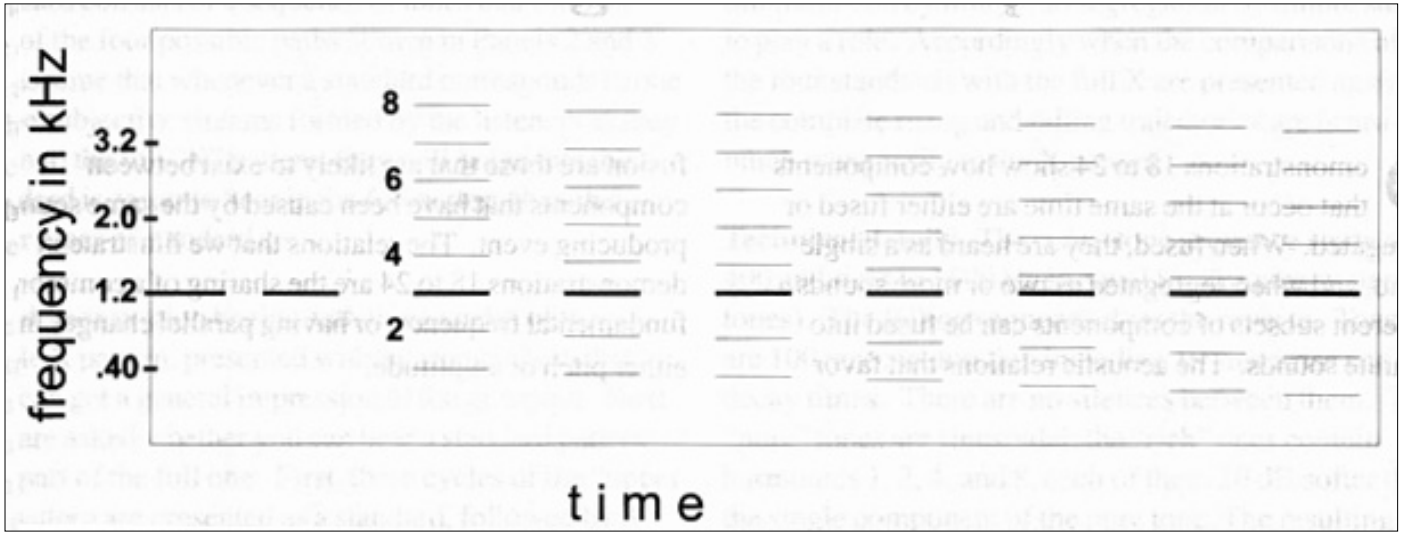
Indices possibles:

- Localisation
- Synchronie
- Harmonicité

Indices d'organisation

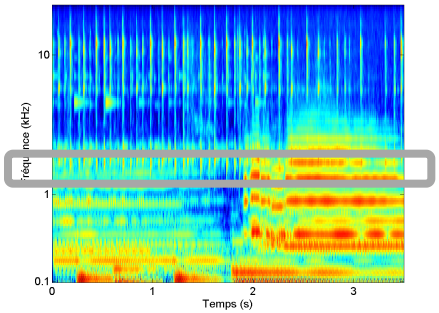
Organisation verticale: Harmonicité





Indices d’organisation

Organisation horizontale



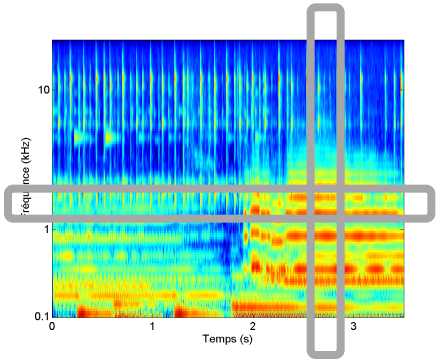
- Sources étendues dans le temps
  - suivre une source en dépit d’interruptions potentielles

Indices possibles:

- Localisation
- Proximité en fréquence
- Proximité en temps
- Timbre

Indices d’organisation

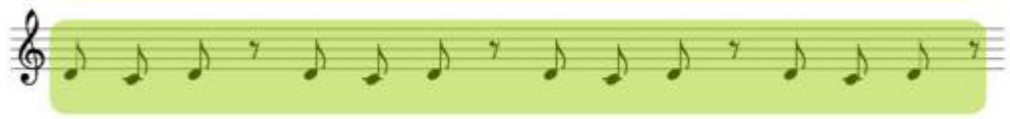
Organisation horizontale et verticale



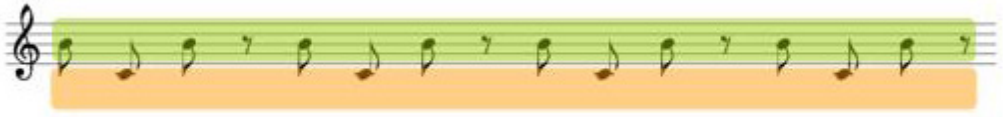
- Une grande variété d’indices
- Concordants ou non

L’organisation auditive est une “prise de décision” qui combine de multiples sources d’information

Auditory scene analysis



One stream



Two streams

Illusory switches

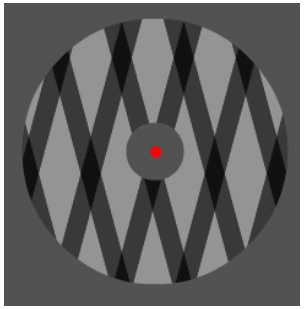
- A useful rule: similar sounds tend to come from a same source

Pressnitzer & Hupé, *Current Biology* 2006

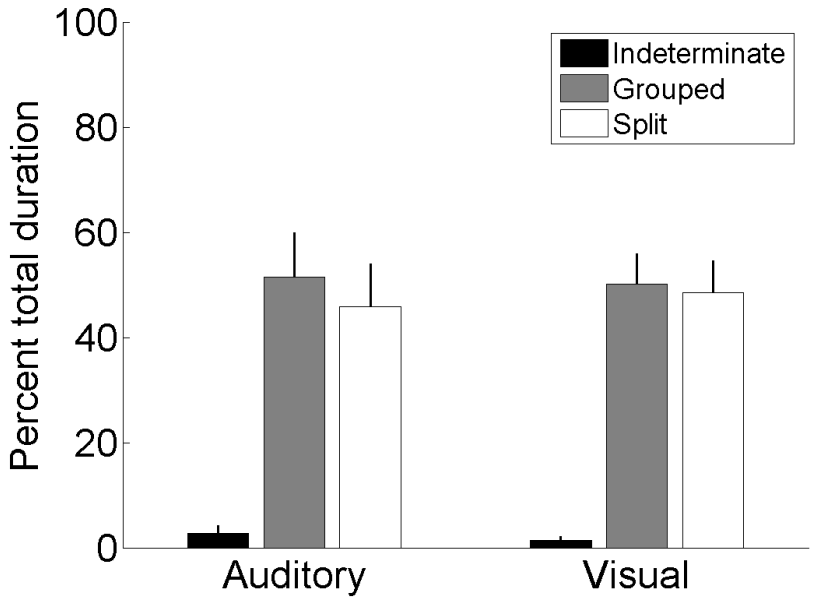
Bistabilité auditive et visuelle

- Comparaison alternances perceptives dans deux modalités
- Le dilemme de l'organisation perceptive: Grouper ou Séparer?
- Caractéristiques de la bistabilité visuelle:
  - * *Exclusivité*
  - * *Aléatoire*
  - * *Inevitabilité*

[Leopold and Logothetis, 1999]

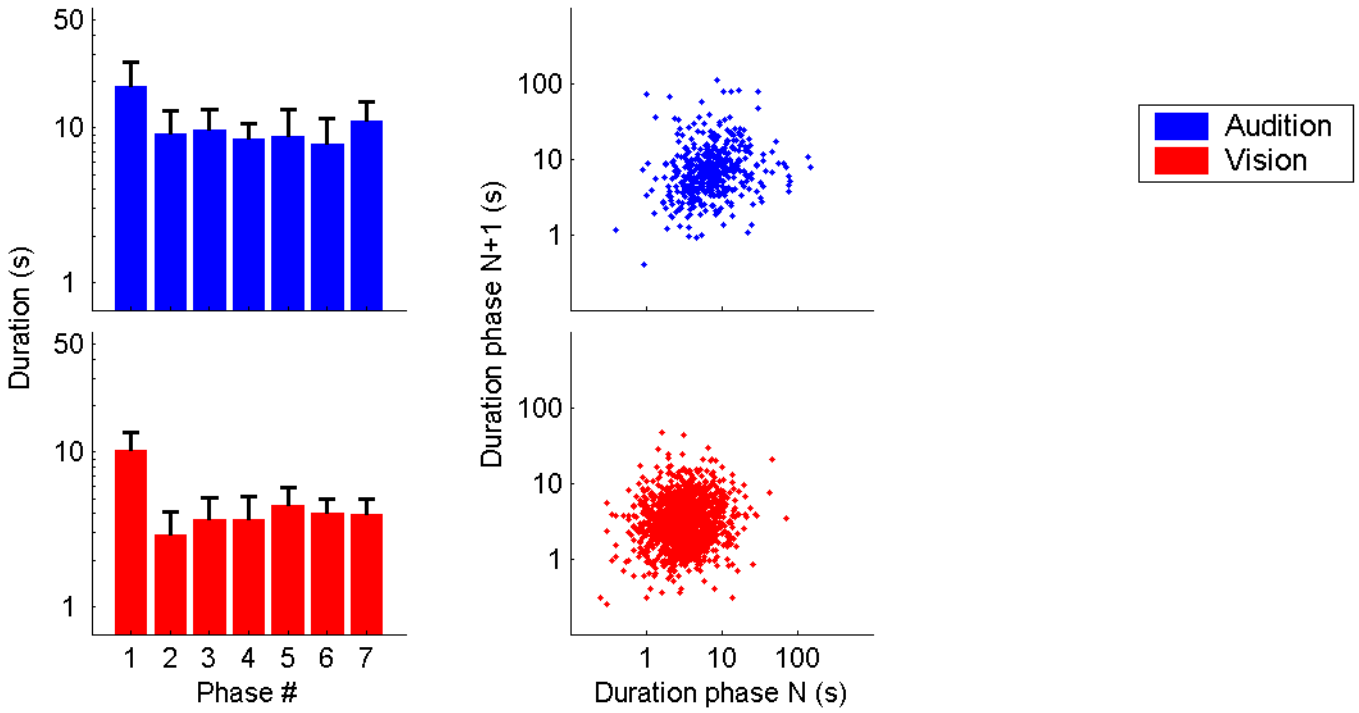


Exclusivité



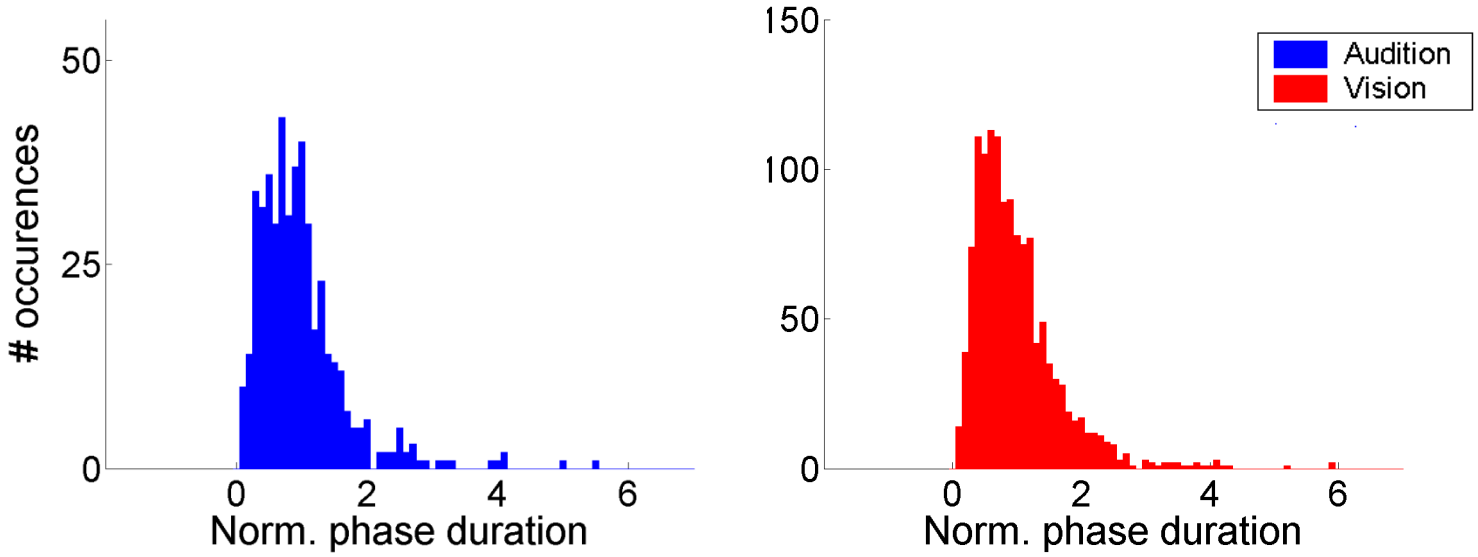
- Percepts auditifs (et visuels) sont mutuellement exclusifs

Aléatoire



- Durée de phase stable après le 1er percept (groupé)
- Indépendance statistique entre phases successives

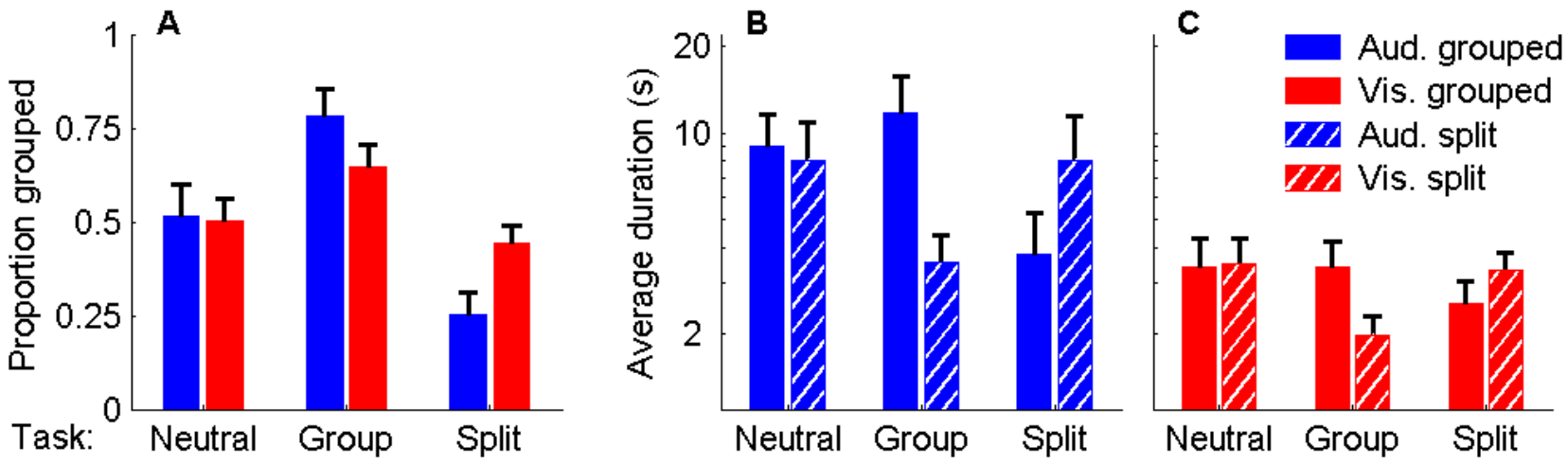
Aléatoire



- Distribution log-normale pour la durée des percepts
- Identiques pour les deux modalités

Inévitabilité

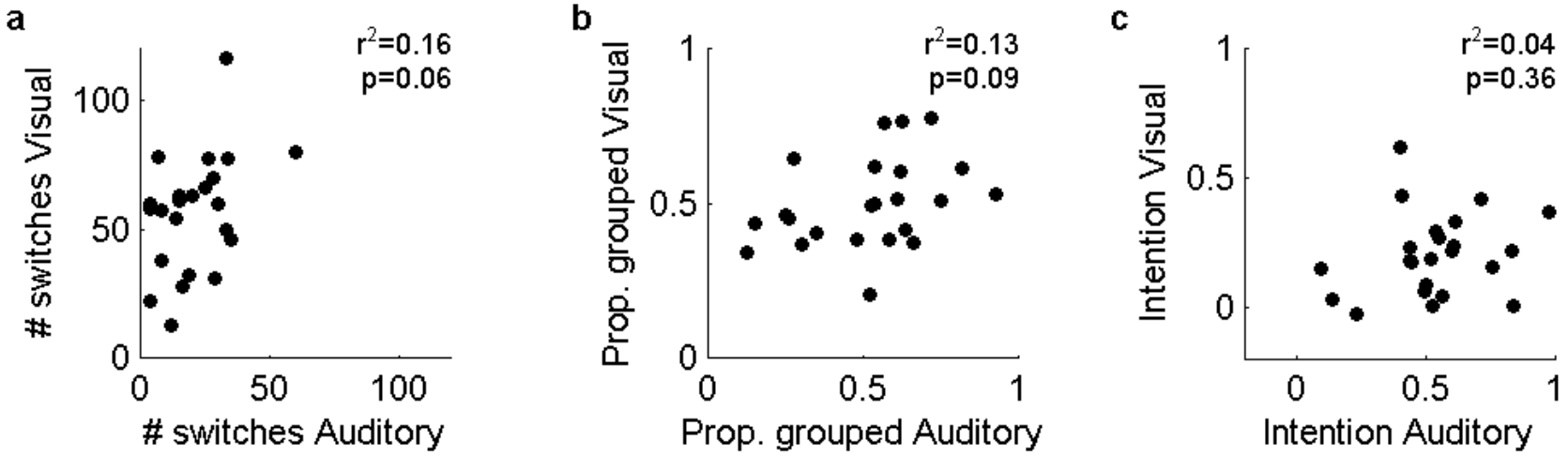
Contrôle volontaire



- Effet de l'intention, mais alternances inévitables
- Pas d'augmentation de la durée des percepts cibles

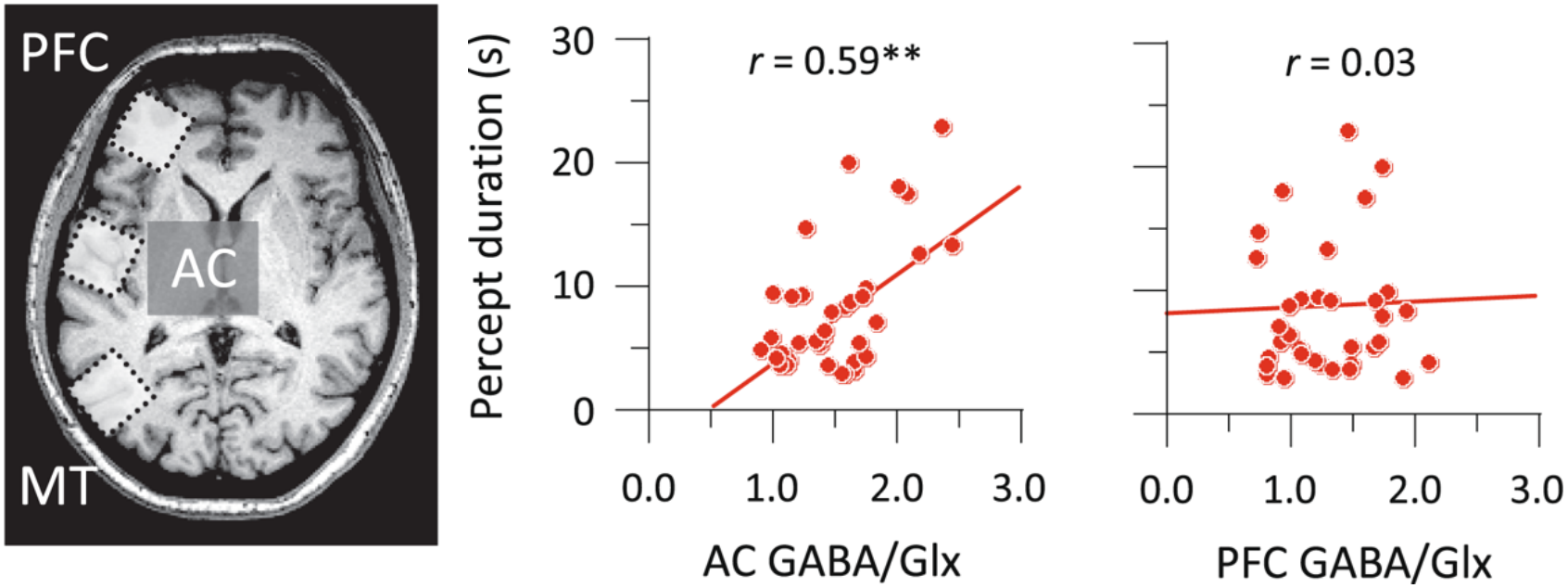
[Levelt, 1968]

Biais Audition et Vision



- Indépendance des biais idiosyncratiques entre modalités

Auditory scene analysis

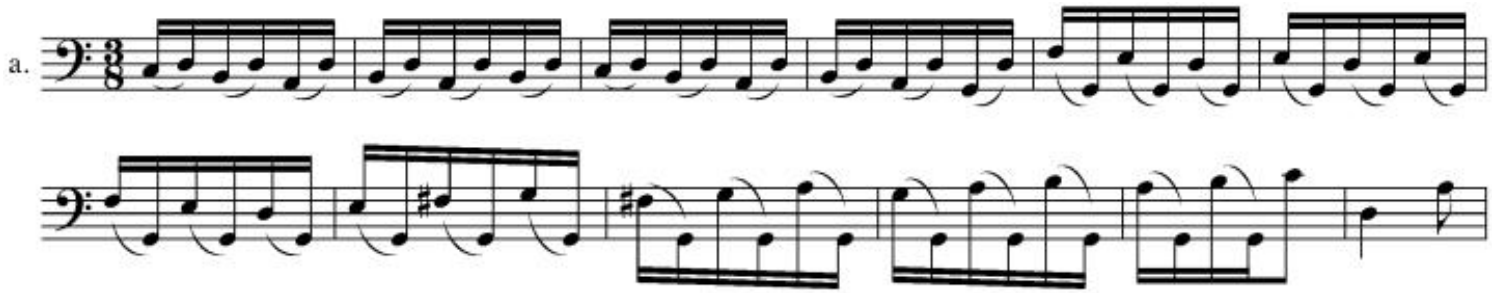


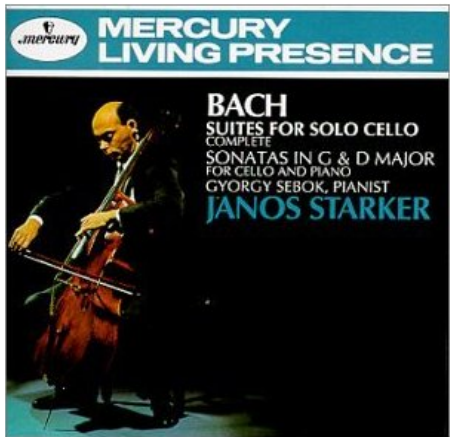
- Same acoustics, different conscious percept
- A powerful tool to explore inter-individual differences

Kondo, Pressnitzer et al., *Scientific Reports*, 2018

Musical interlude

Implied polyphony

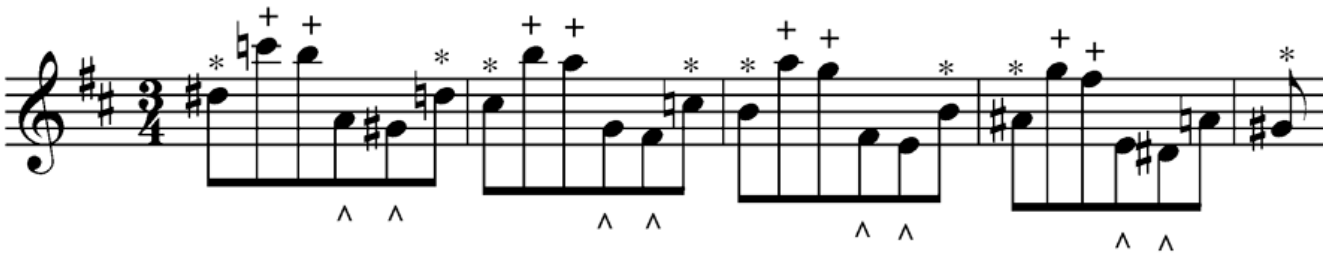




Davis, S. *Music Perception,* 2006

Musical interlude

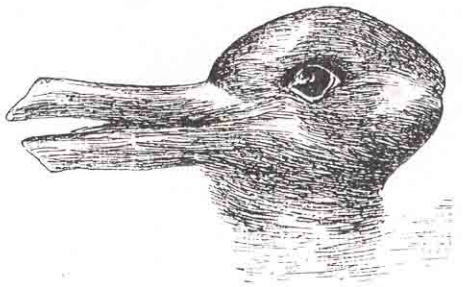
“Illusory voices” in implied polyphony



Davis, S. *Music Theory Online,* 2011

Auditory scene analysis

- Prior knowledge provides necessary information to solve the ill-posed problem of auditory scene analysis
- When sensory information is ambiguous, knowledge decides
- Similar to classic bistable illusions in vision



Jastrow, 1899

Wittgenstein, 1953/1958

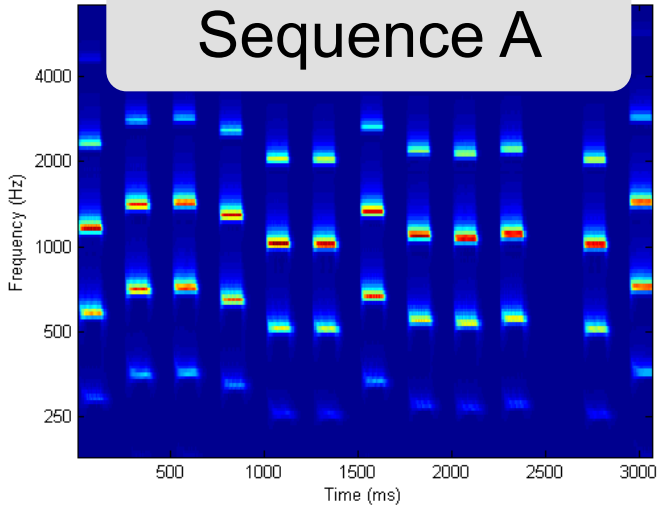
Perception and Memory

- Prelude: “*Laurel*” and “*Yanny*”
- Auditory memory acquisition
- Prior knowledge and auditory scene analysis
- Prior context and basic auditory features

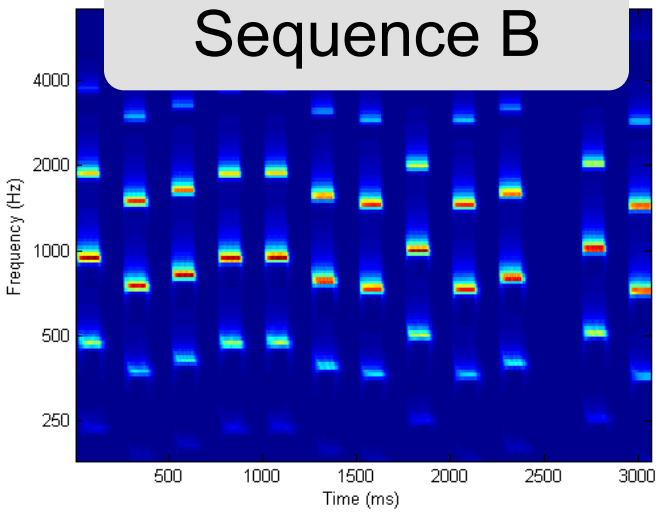
Context effects

You will hear a sequence of tones, a short pause, and then two final tones.
Does the pitch go up or down between the two final tones?

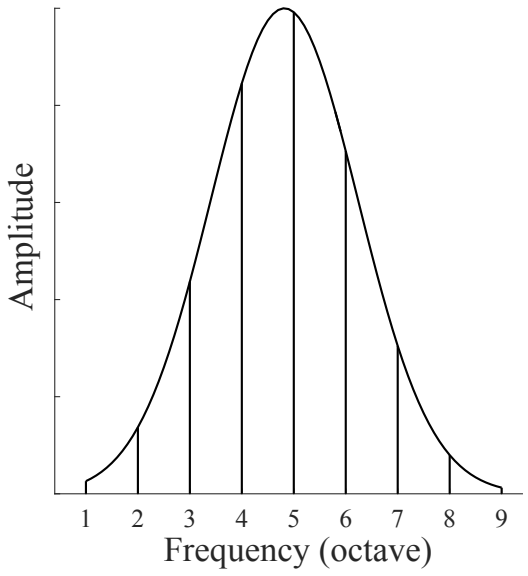
Sequence A

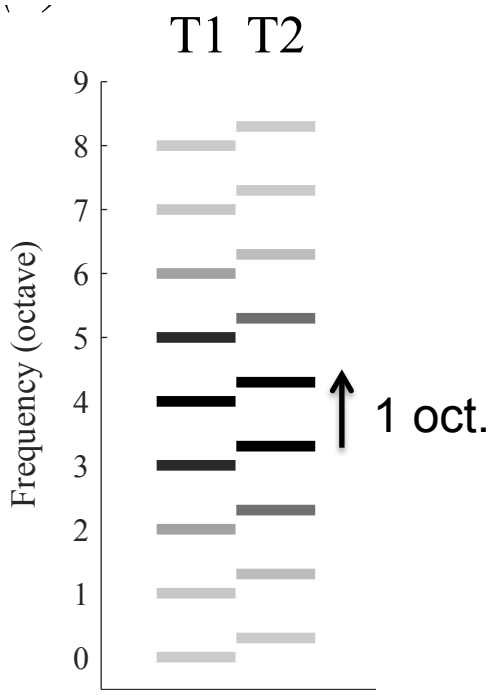


Sequence B



Context effects



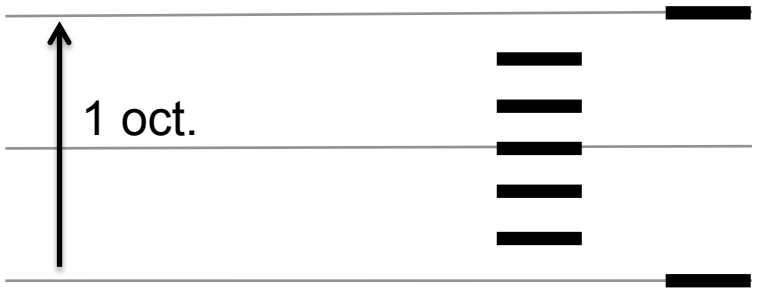


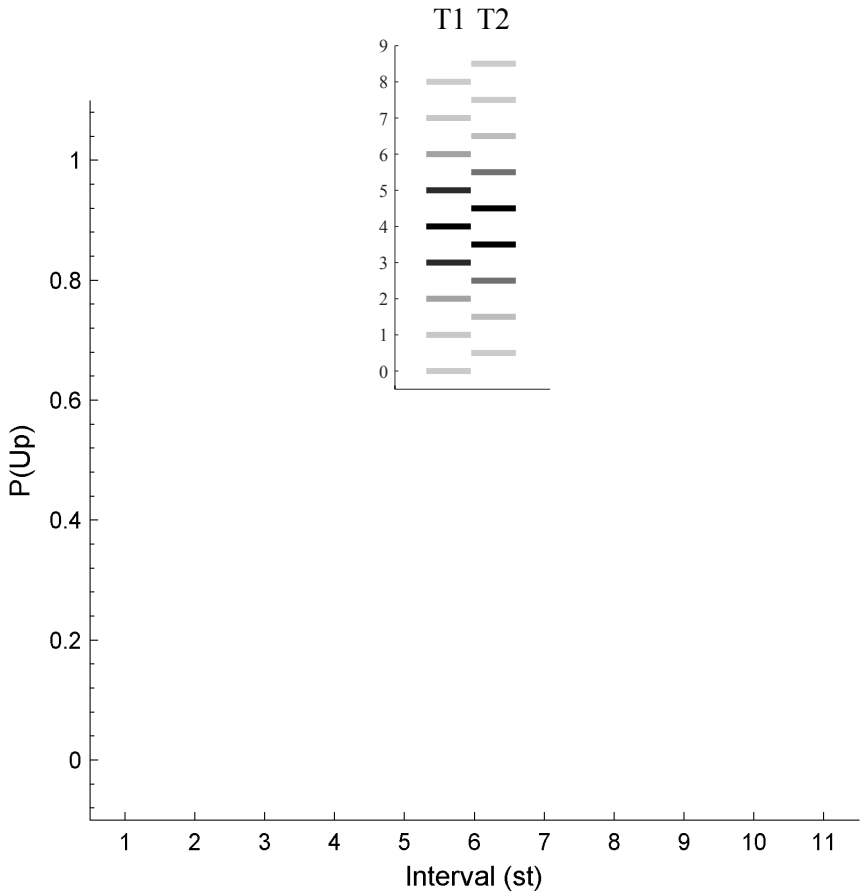
- What you have just heard: Shepard tones

Shepard, R. *J. Acoust. Soc. Am.*, 1964

Context effects

Perceived pitch shift





- Ambiguous pitch shift at 6 semi-tones interval

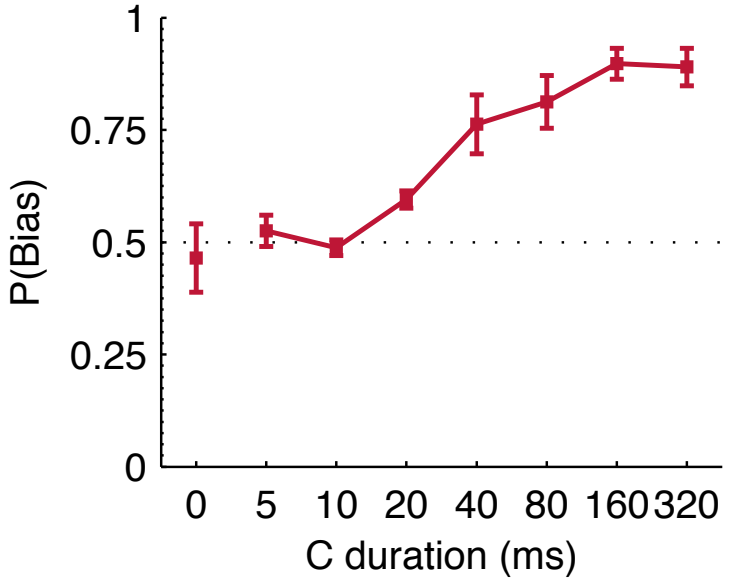
Context effects

Biasing sequence

- Perception can be almost *fully* determined by context

Time-course

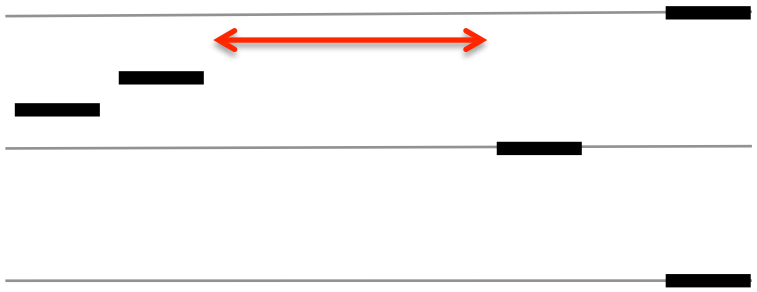
How long does it take?

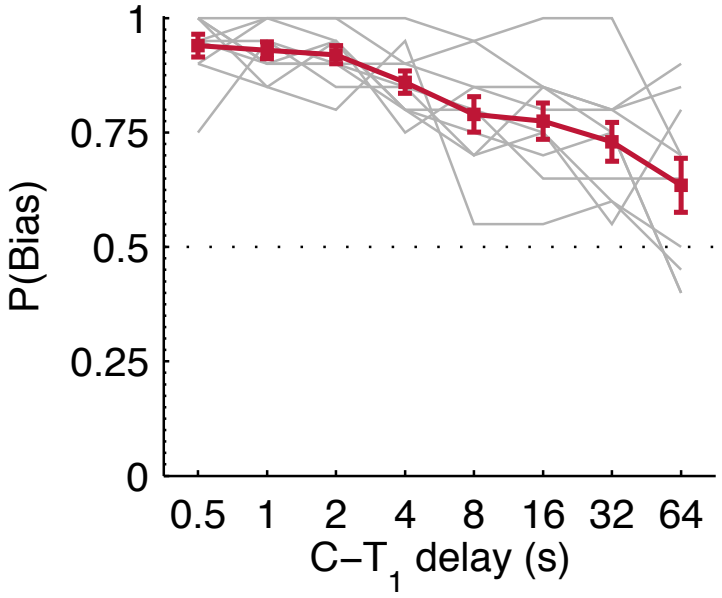


- Bias observed for a 20-ms long context

Time-course

How much does it last?

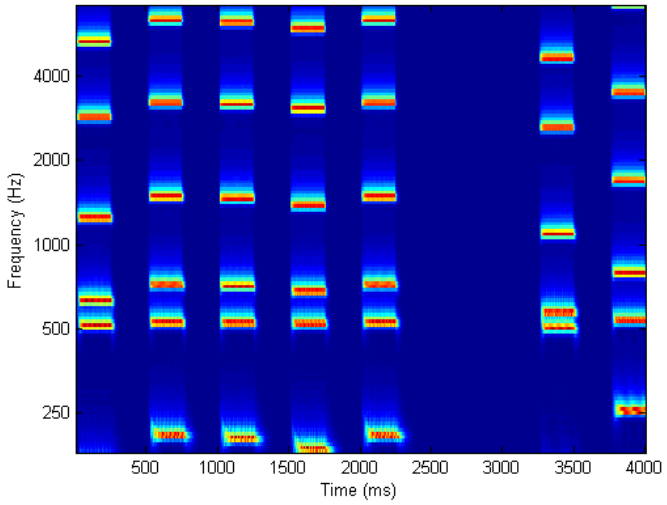


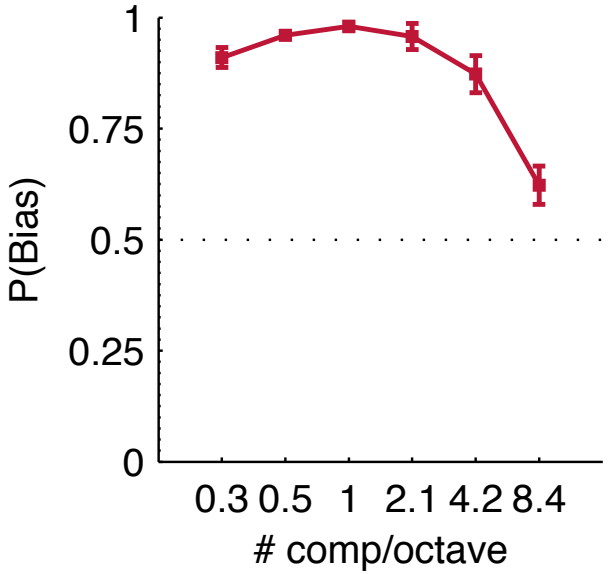


- Bias persists for over 30s

Random spectra

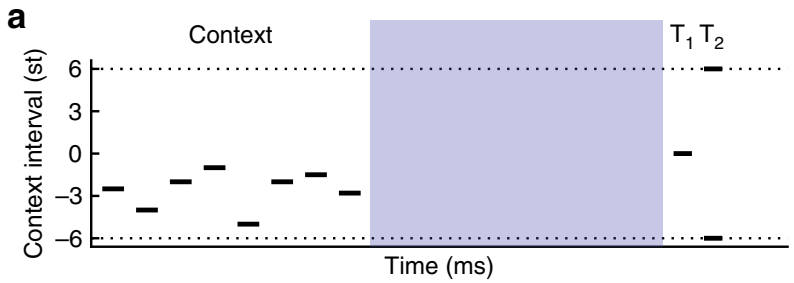
Something to do with Shepard tones?





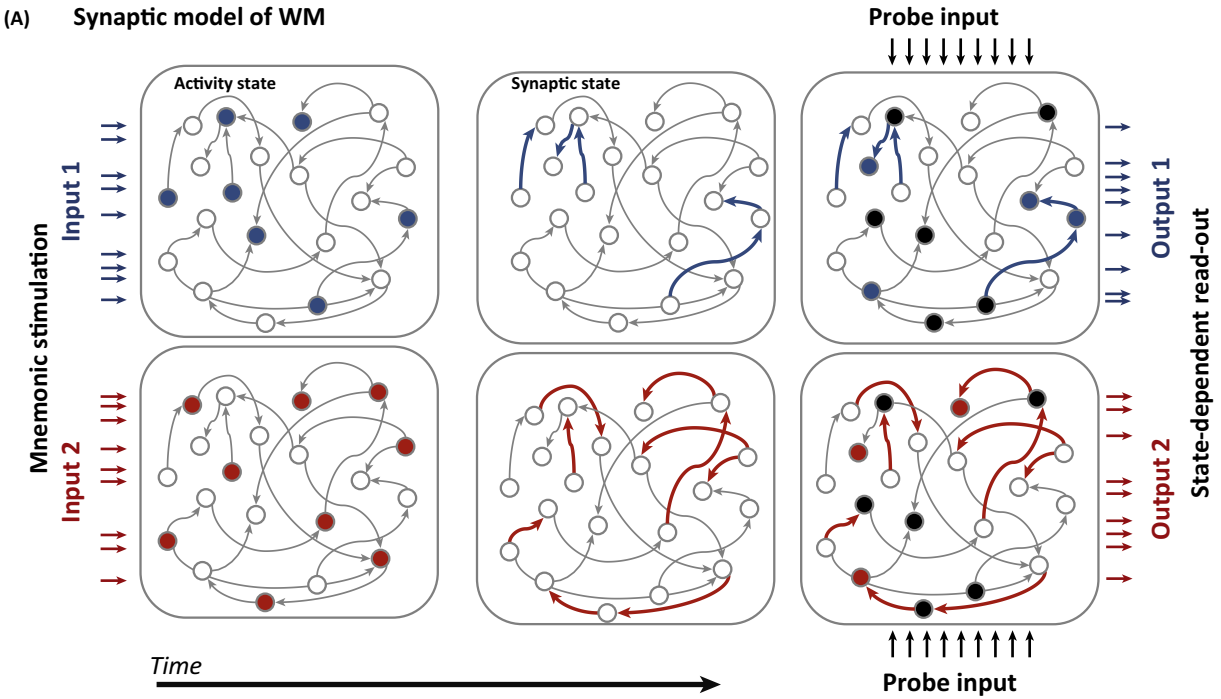
- Generalisation to random spectra, limited by resolvability

Neural correlates (MEG)



- MEG response suppression correlates with behavior

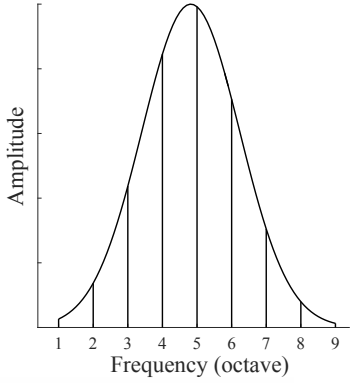
Speculation

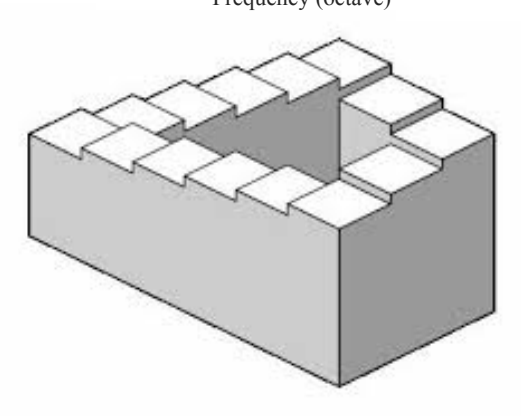


- "Hidden states" to encode memory
- Same neurons could process information *and* encode memory

Stokes, TICS, 2015
Hasson, Chen, & Honey, TICS, 2015

Musical interlude





- Proximity cues and cyclic Shepard tones for “infinite” scale

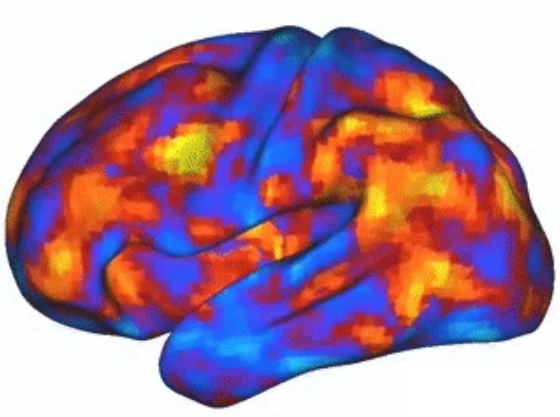
Context effects

- Perception of large frequency shifts can be biased by context
- Bias is fast and long-lasting
- Contextual memory processes, possibly based on adaptation

Chambers, Akram, Adam, Pelofi, Sahani, Shamma, & Pressniter, Nature Communications, 2017
http://audition.ens.fr/dp/illusion/

Summary

Perception



- Auditory perception and memory are deeply intertwined
- Illusions are the rule, not the exception
- Often they match the world, sometimes they are crafted by scientists or musicians