Pitch:
From basic mechanisms to context effects

Daniel Pressnitzer

Laboratoire des Systèmes Perceptifs, CNRS &
Département d'études cognitives, Ecole normale supérieure

daniel.pressnitzer@ens.fr

Introduction

What is pitch?

- ANSI definition

  That auditory attribute of sound according to which sounds can be ordered on a scale from low to high

- Perceptual “dimension”: many to one
- Separate from other auditory dimensions
- Related to acoustic periodicity

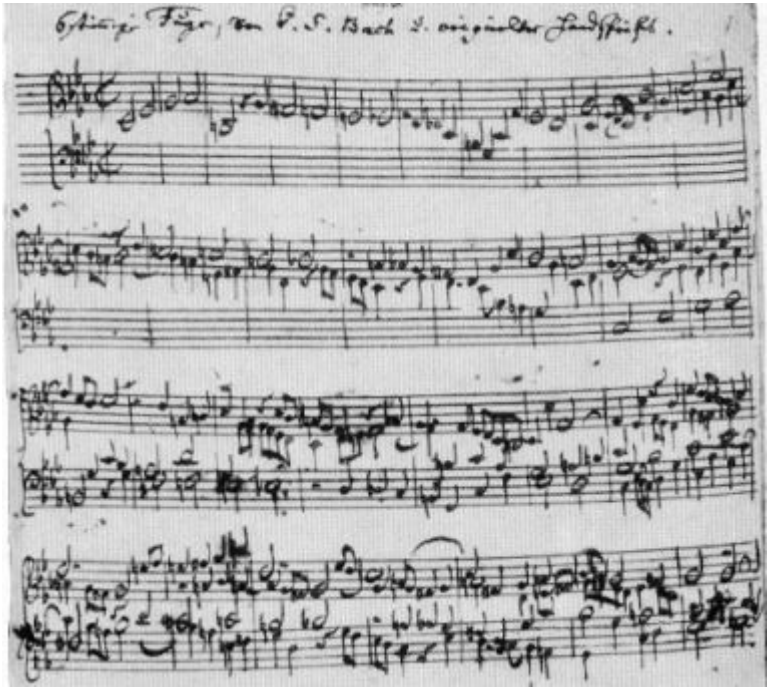
Introduction

What is pitch for?

- Speech intonation
- Information about the sound source
- Music
- Auditory scene analysis

Introduction

Bach, Musical Offering (1747)



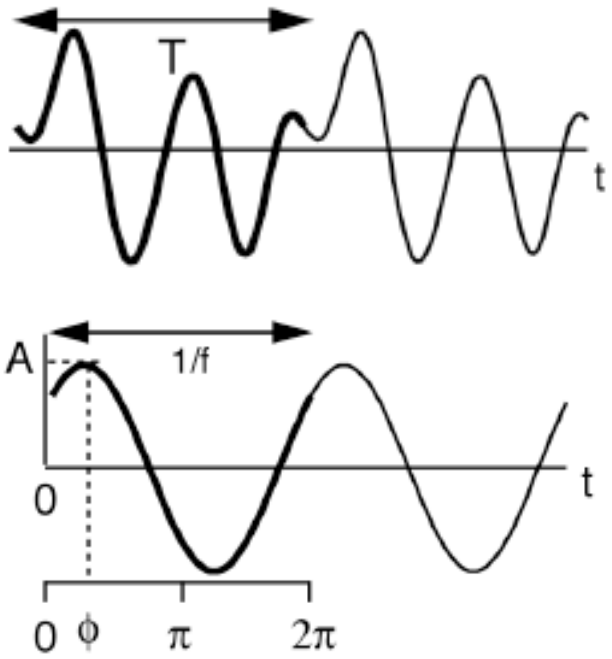
Pitch: from basics to context effects

- Acoustics of periodic sounds
- Models of pitch
- Neural and psychophysical data
- Pitch shifts
- Context effects

Pitch: from basics to context effects

- Acoustics of periodic sounds
- Models of pitch
- Neural and psychophysical data
- Pitch shifts
- Context effects

Acoustics of periodic sounds

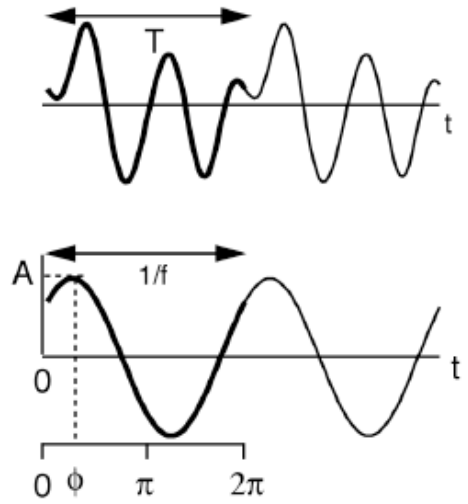


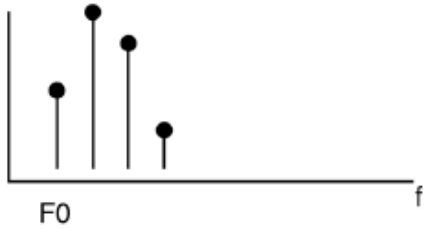
- A periodic sound… repeats itself after some time
- Special case: the sine wave

Acoustics of periodic sounds

- Fourier's theorem:

All sounds can be decomposed into a sum of sine waves

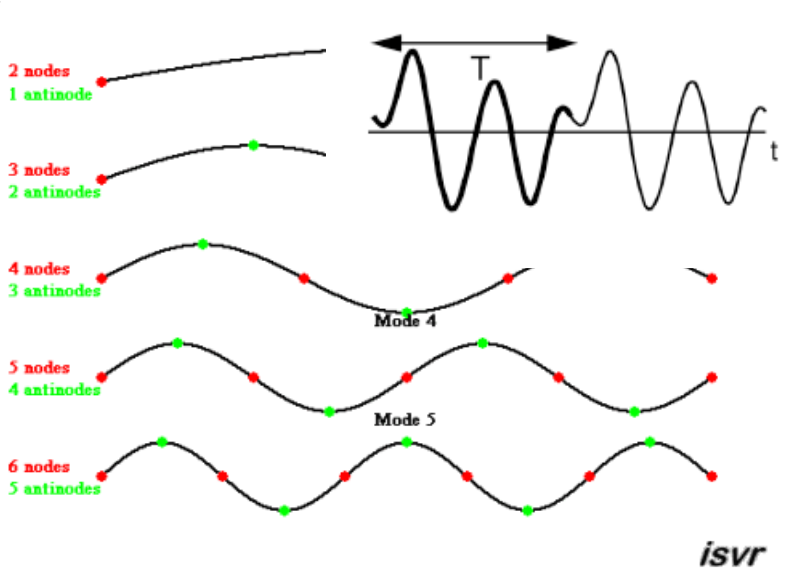


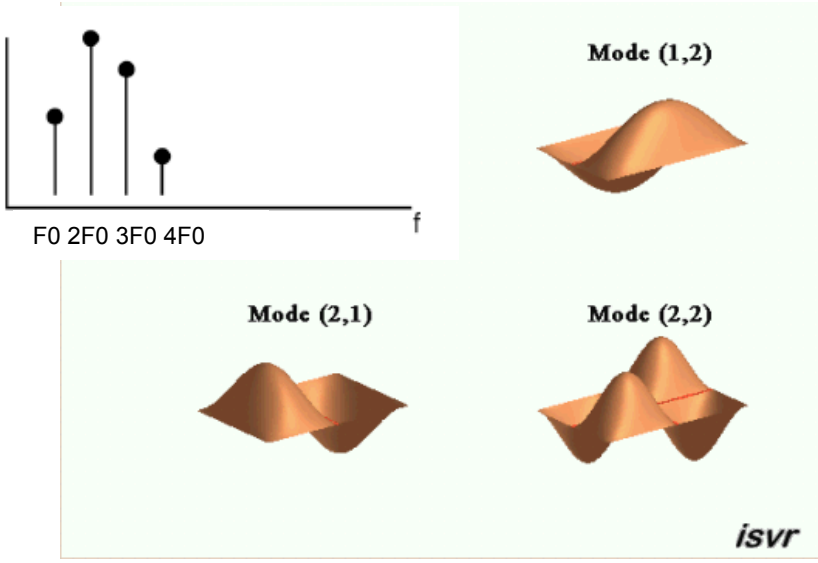


Jean-Baptiste-Joseph Fourier
(1768-1830)

Acoustics of periodic sounds

- Periodic sounds: harmonic relationship between sine waves
- Why? Physics of standing waves

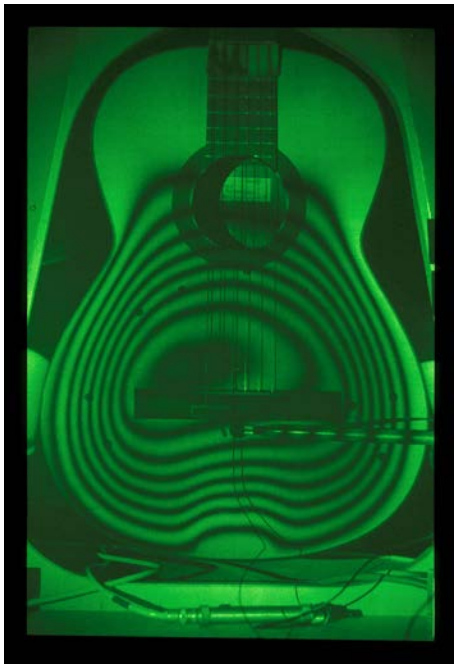


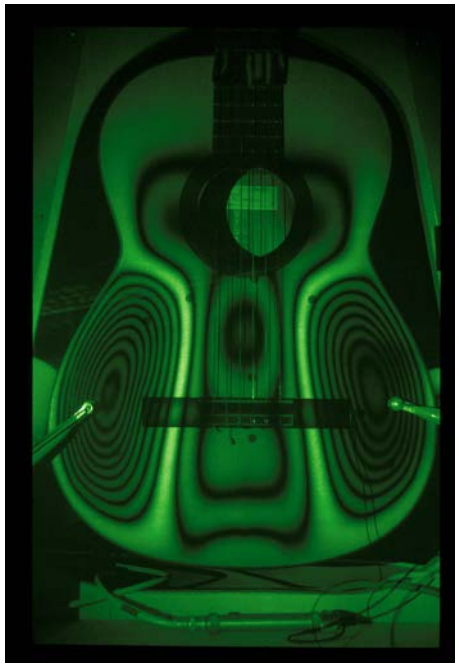


http://resource.isvr.soton.ac.uk/

Acoustics of periodic sounds

- Periodic sounds: harmonic relationship between sine waves
- Why? Physics of standing waves





http://resource.isvr.soton.ac.uk/

Acoustics of periodic sounds

Summary

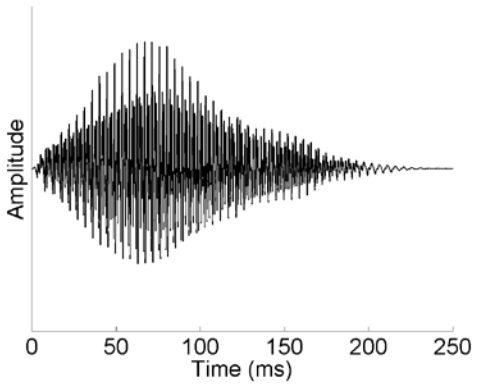
- Periodic sounds common because of physics of sound sources
- In the frequency domain: F0, 2*F0, 3*F0, etc
- Important ecological feature?

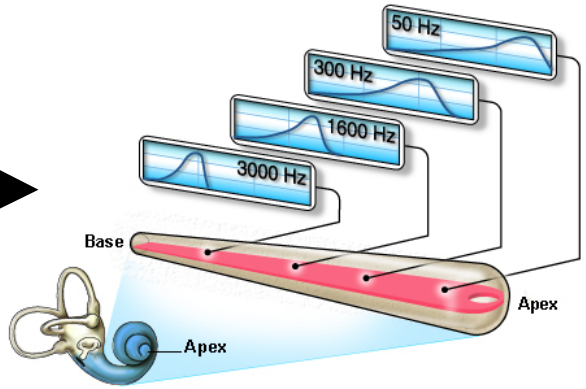
Pitch: from basics to context effects

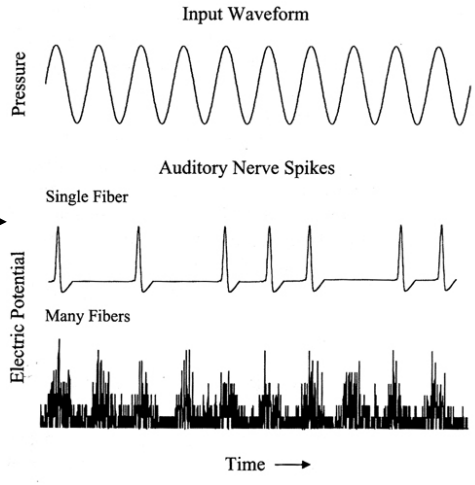
- Acoustics of periodic sounds
- Models of pitch
- Neural and psychophysical data
- Pitch shifts
- Context effects

Models of pitch

The task at hand







Stimulus

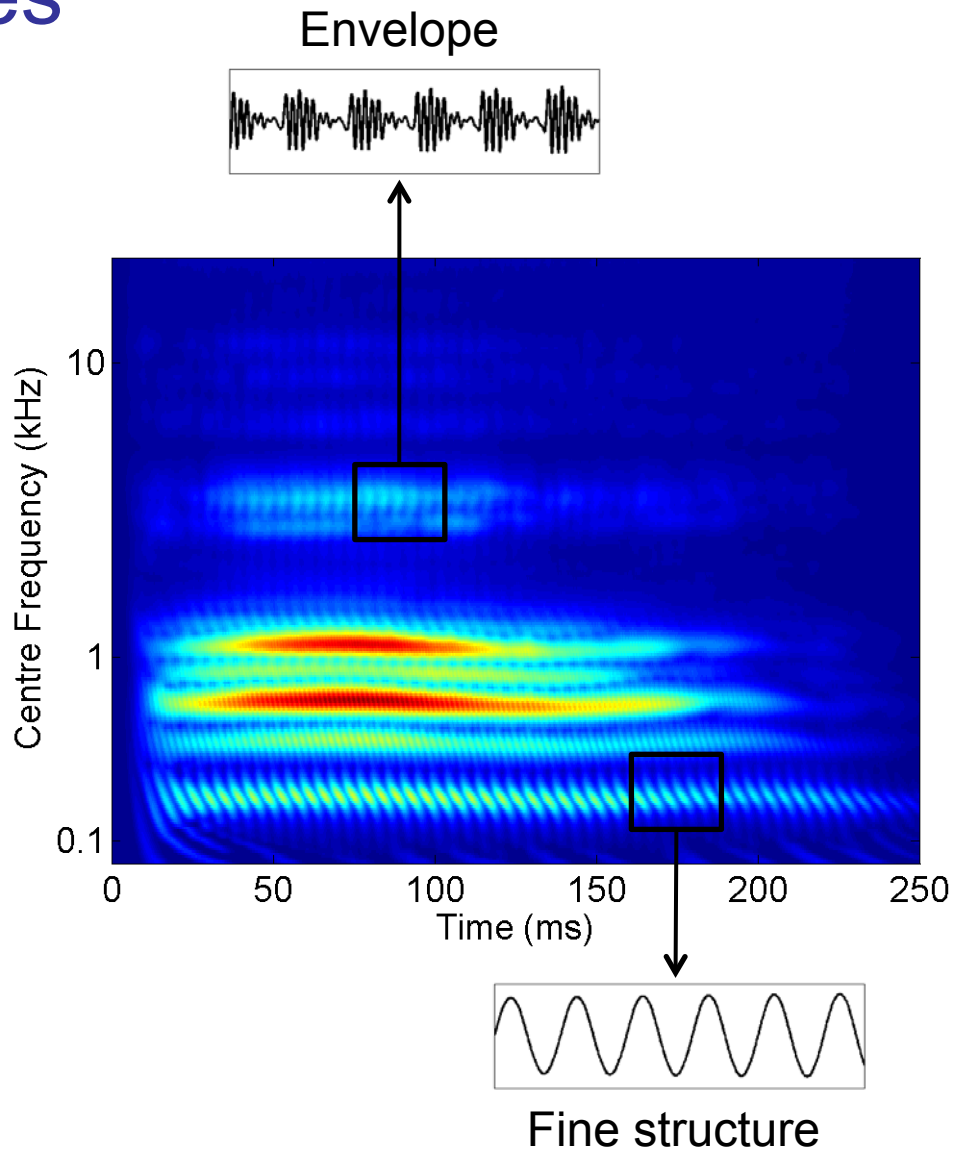
Tonotopic coding

Phase locking

Models of pitch

Periodicity cues

Which cue(s) for pitch?



Models of pitch

The place model

- Place of excitation -> pitch
- Seems obvious for pure tone
- Complex tones: F0
- Missing fundamental?

H. Helmholtz

Models of pitch

The time model

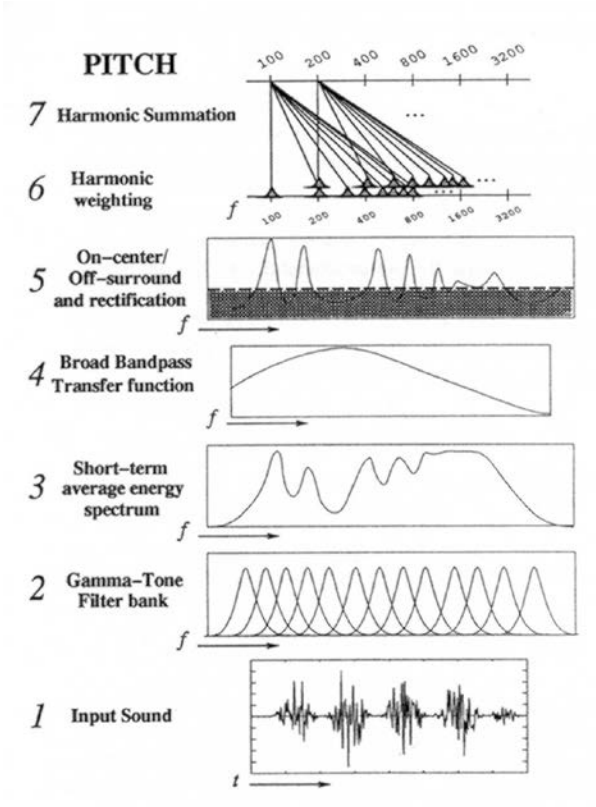
- Period between time intervals -> pitch
- The fundamental is not “missing” anymore
- But low-rank harmonics dominate pitch

W. Rutherford

Models of pitch

The pattern-matching approach

- Fit a harmonic template to the observed excitation pattern

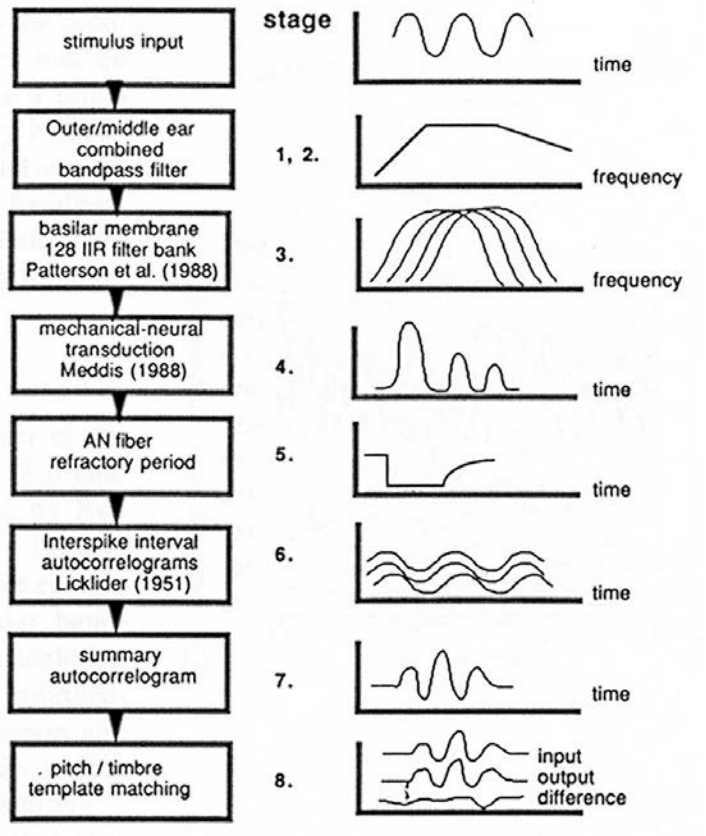


Goldstein, 1973; Terhardt, 1974; Srulovicz & Goldstein, 1983

Models of pitch

The autocorrelation approach

- Compute the most common time-interval across channels



Licklider, 1951; Meddis & O'Mard, 1997

Models of pitch

Summary

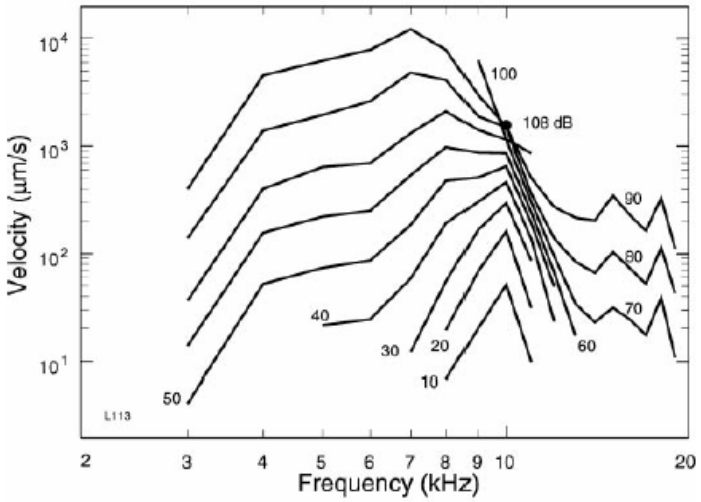
- Many cues to periodicity after peripheral transduction
- Competing models along time/place continuum
- No consensus

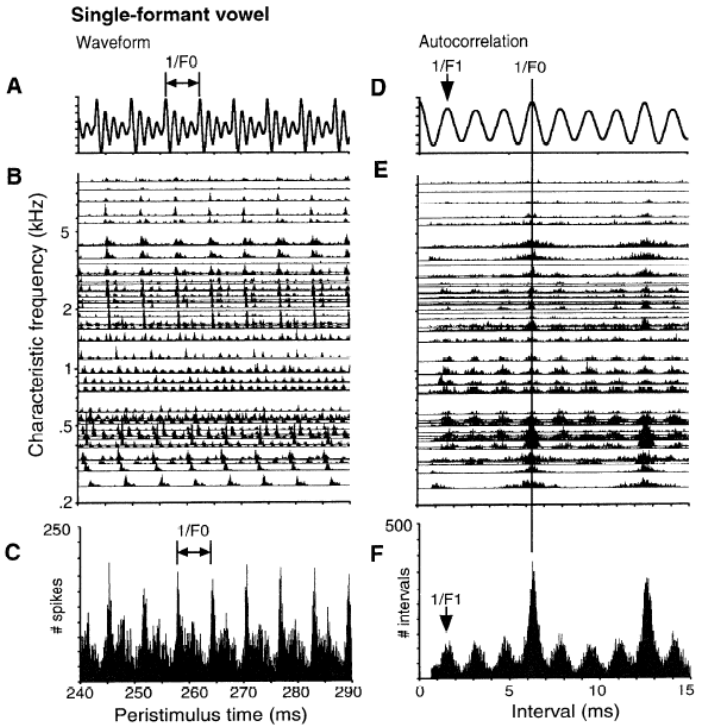
Pitch: from basics to context effects

- Acoustics of periodic sounds
- Models of pitch
- Neural and psychophysical data
- Pitch shifts
- Context effects

Neural data

Auditory periphery

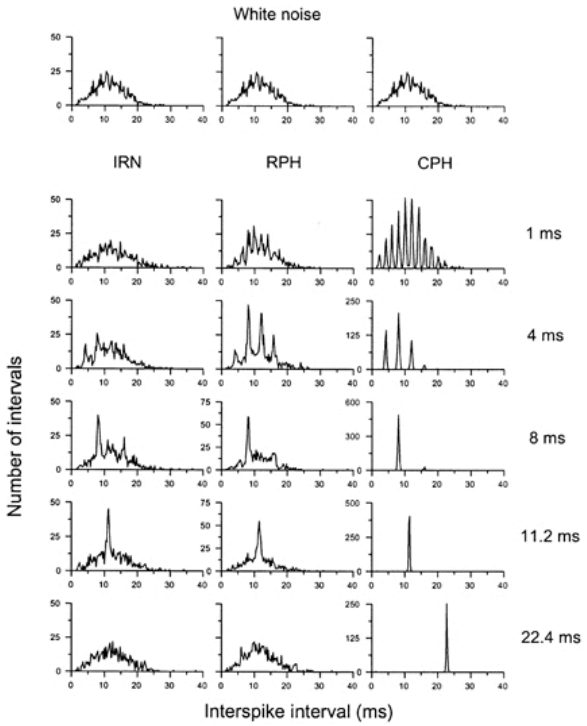




- Place cue is level dependent (e.g. Robbles & Ruggero, 2000)
- Robust timing cues in autocorrelation (Cariani & Delgutte, 1996)

Neural data

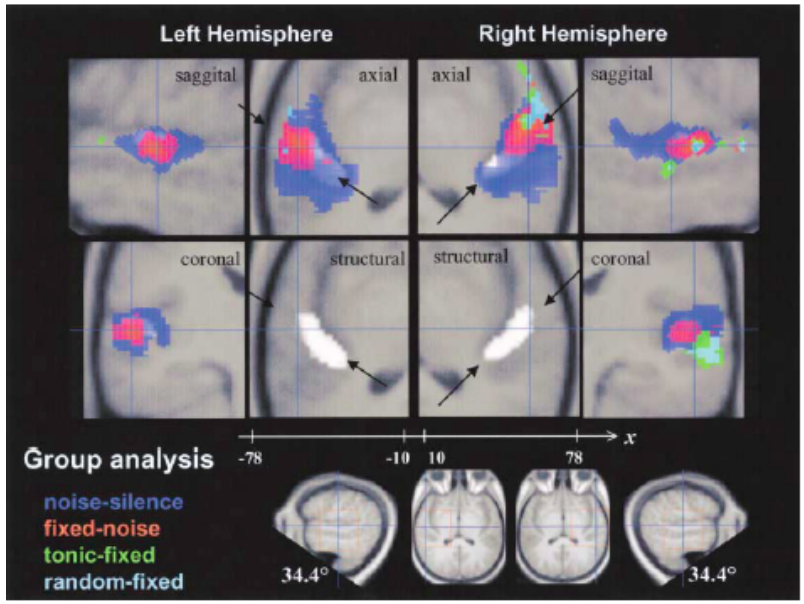
Extracting timing cues

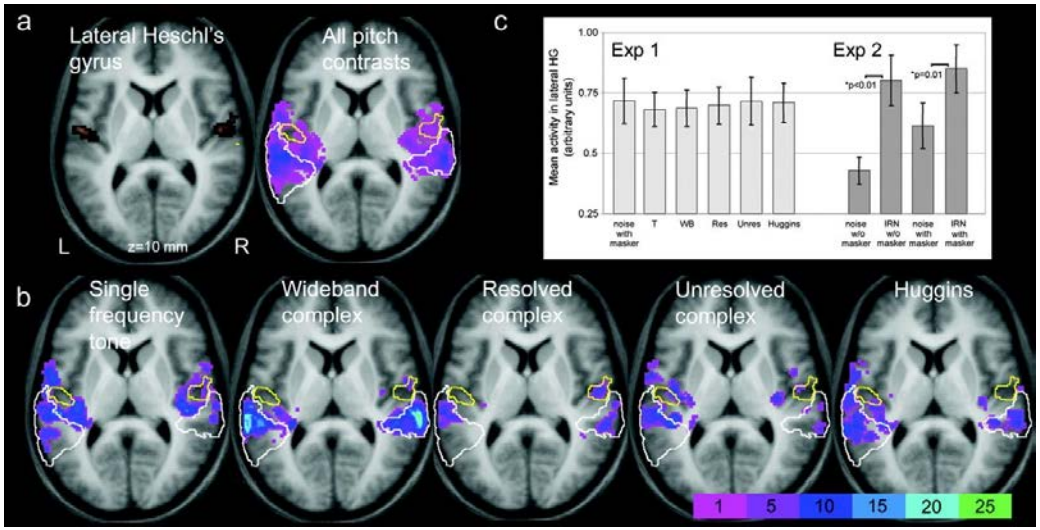


- Conversion to first order code (Winter et al., 2001)
- Further conversion to rate code (Meddis & O'Mard., 2006)

Neural data

A pitch center in the brain?





- Lateral Heschl's gyrus a candidate (Patterson et al., 2002; Krumbholz et al. 2003)
- But seems stimulus-dependent (Hall & Plack, 2009)

Neural data

Summary

- Timing cues in the periphery sufficient for pitch
- No single pitch map for a range of stimuli yet

Schnupp, King, Nelken, 2010. Auditory Neuroscience. MIT Press

Psychophysical data

A large literature

- To characterize pitch perception in normal human listeners
- To pit one model against another

Psychophysical data

Difference limen for pure tones

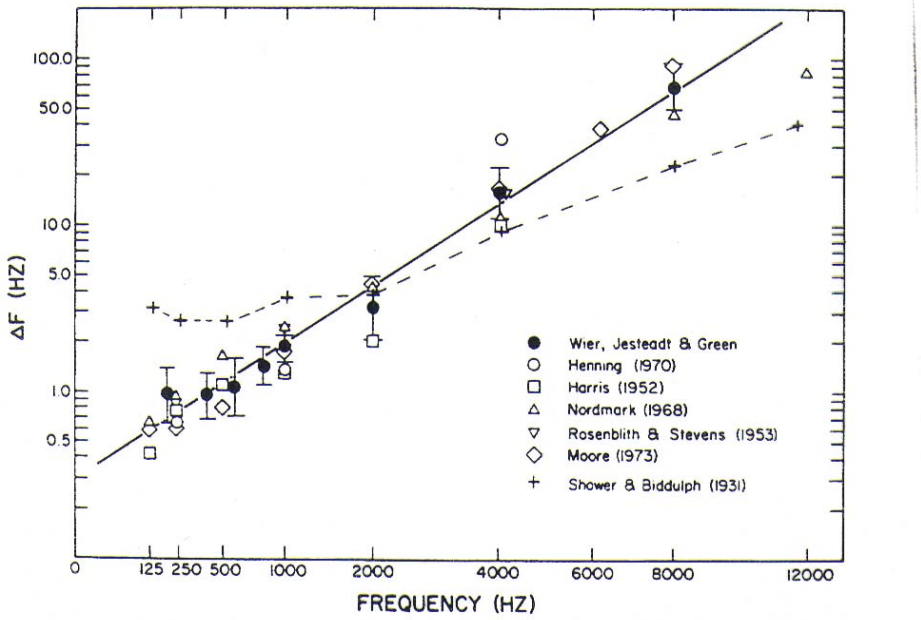
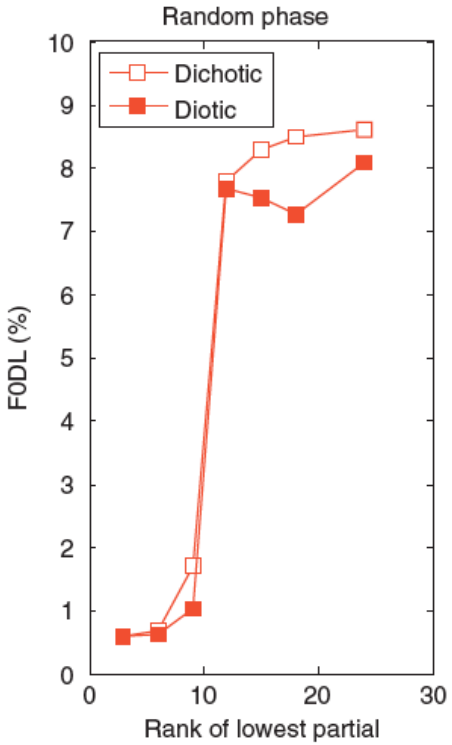


FIG. 5.1 Summary of the results of several studies measuring frequency discrimination thresholds. The thresholds, ΔF, are plotted in Hz as a function of frequency. All of the studies measured DLFs except that of Shower and Biddulph, they measured FMDLs. From Wier *et al.* (1977), by permission of the authors and *J. Acoust. Soc. Am.*

- Exceedingly good for trained subjects: 0.2% (1 semitone, 6%)
- But variable and effect of training (Ahissar, 2006; Micheyl et al., 2006)

Psychophysical data

Difference limen for complex tones



- Effect of harmonic rank
- Cochlear resolution vs time-limited interval extraction

Bernstein & Oxenham, 2003

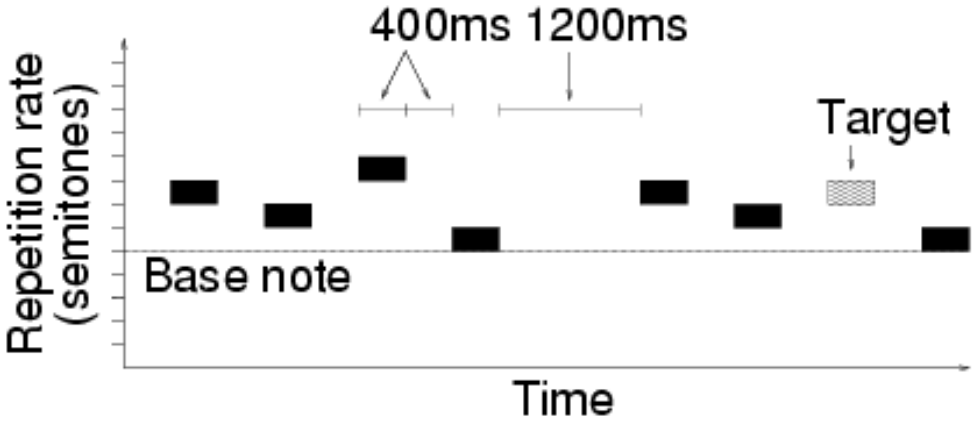
Psychophysical data

Existence region: lower limit

- Most sounds that produce pitch contain a temporal regularity
- Not all temporal regularities produce pitch

Psychophysical data

Lower Limit of Melodic Pitch

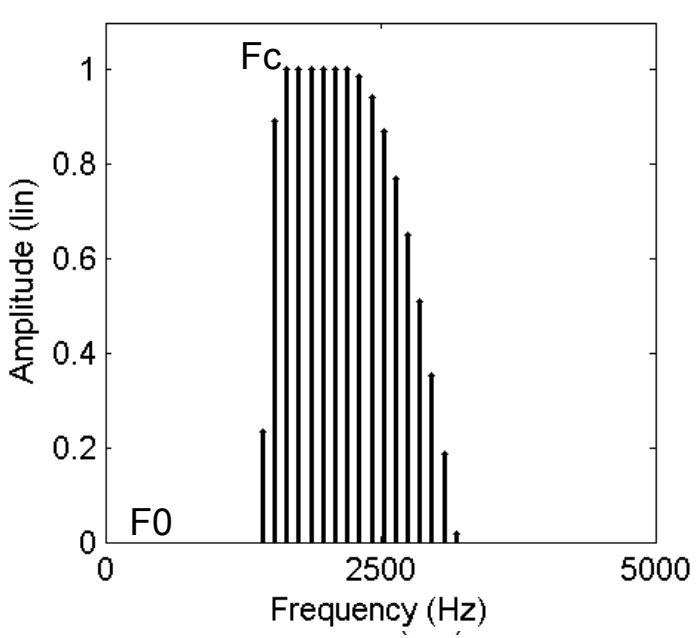


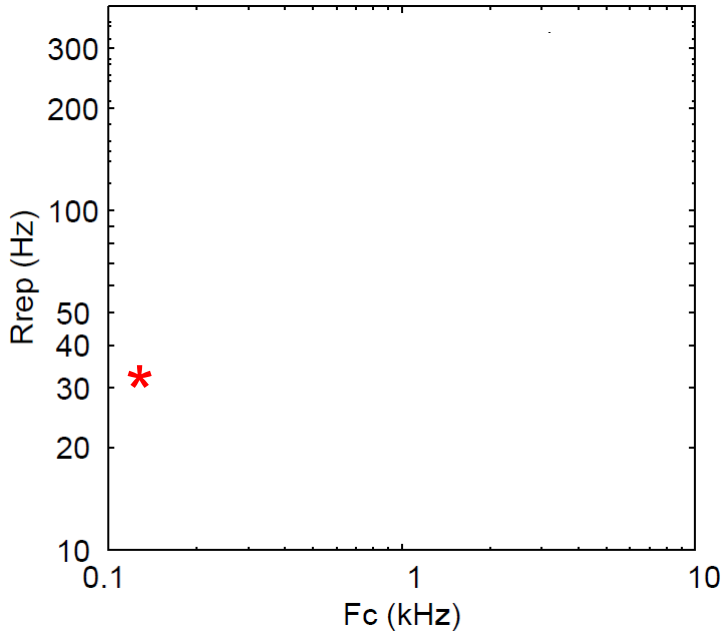
- Objective melody task

Pressnitzer, Patterson & Krumbholz, 2001

Psychophysical data

Lower Limit of Melodic Pitch

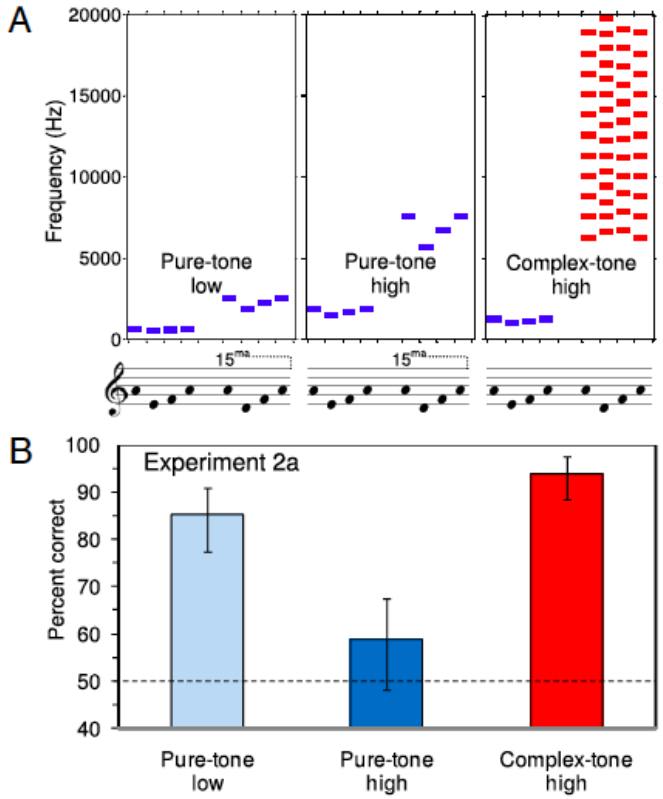




- LLMP of about 30Hz for broadband case
- Influence of spectral region and phase
- Accounted by a modified autocorrelation model

Psychophysical data

Existence region: upper limit

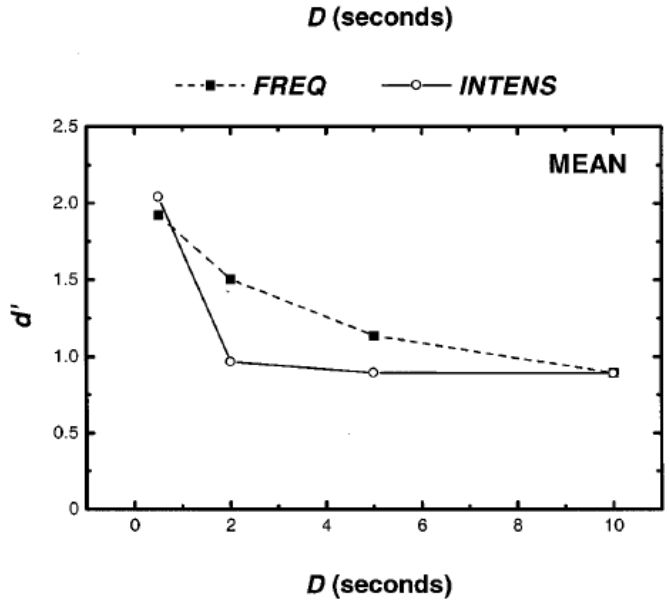


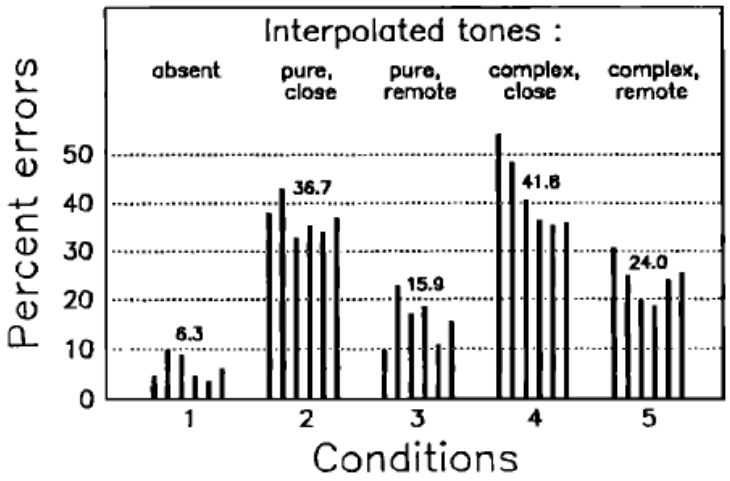
- Melodic pitch beyond the hypothesized limit of phase locking

Oxenham et al., 2011

Psychophysical data

Memory for pitch





- Evidence for a robust pitch memory-store

Semal & Demany, 1991; Clément et al., 1999

Psychophysical data

Summary

- Accurate discrimination (0.2%)
- Large existence region (8 octaves)
- Robust memory

Pitch: from basics to context effects

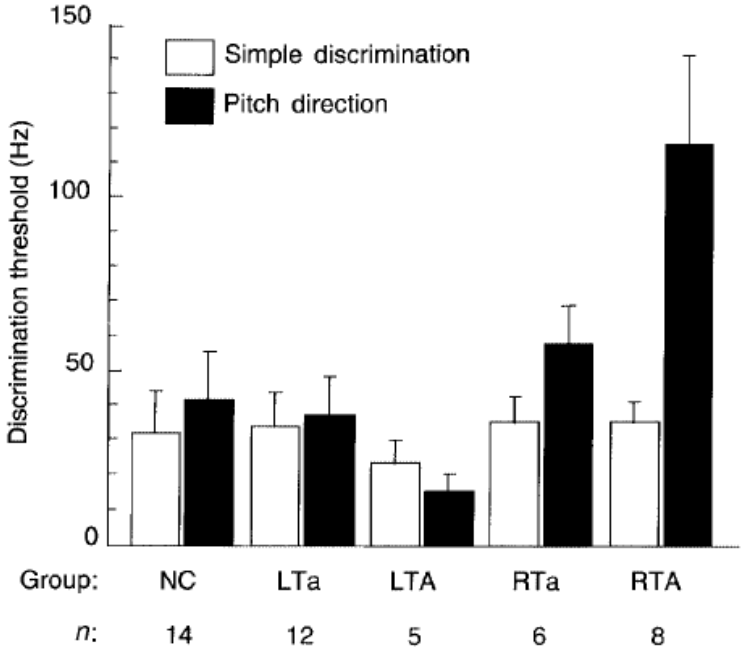
- Acoustics of periodic sounds
- Models of pitch
- Neural and psychophysical data
- Pitch sequences
- Context effects

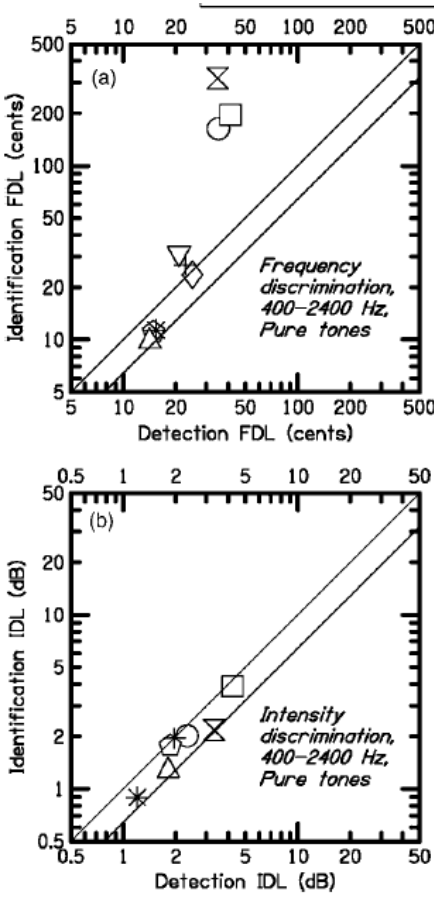
Pitch shifts

- Melody and intonation are pitch sequences
- Two ways to compute pitch shifts: compare absolute values, or encode the pitch shift

Pitch shifts

Discrimination vs identification



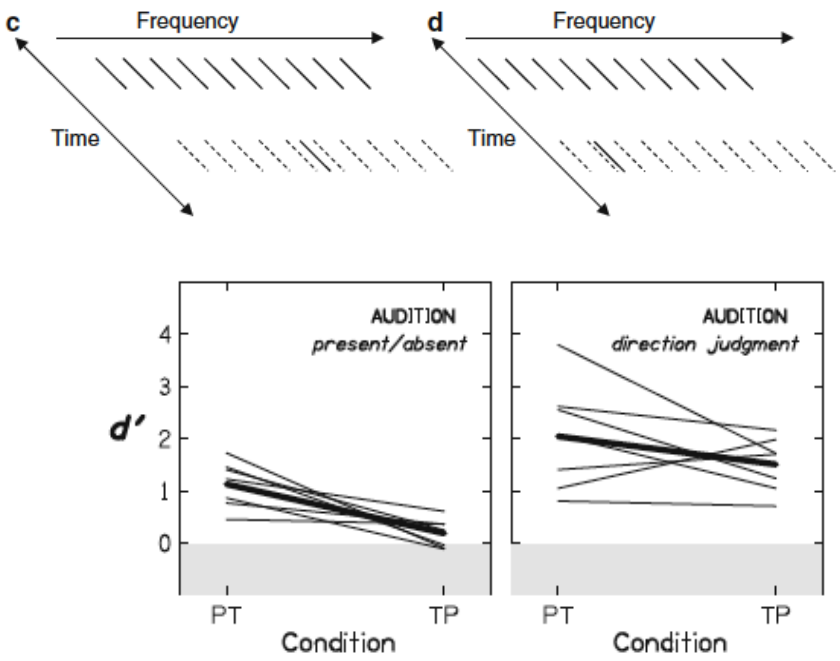


- Pitch discrimination differs from shift-direction identification

Johnsrude et al., 2000; Semal & Demany, 2006

Pitch shifts

Frequency-shift detectors

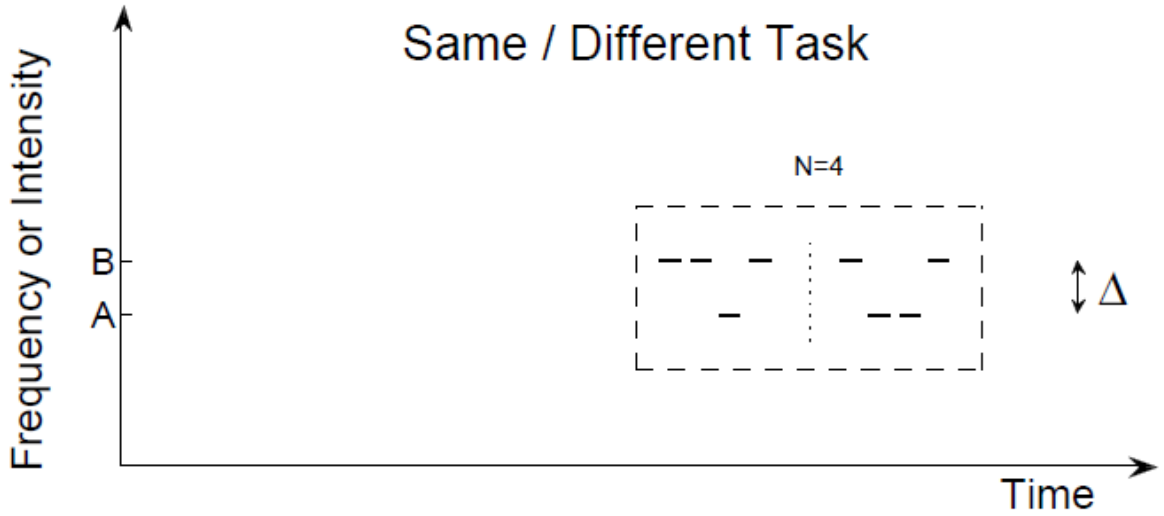


- Pitch-shift easier to judge than present/absent
- Automatic encoding of frequency shifts?

Demany & Ramos; Demany et al., 2011

Pitch shifts

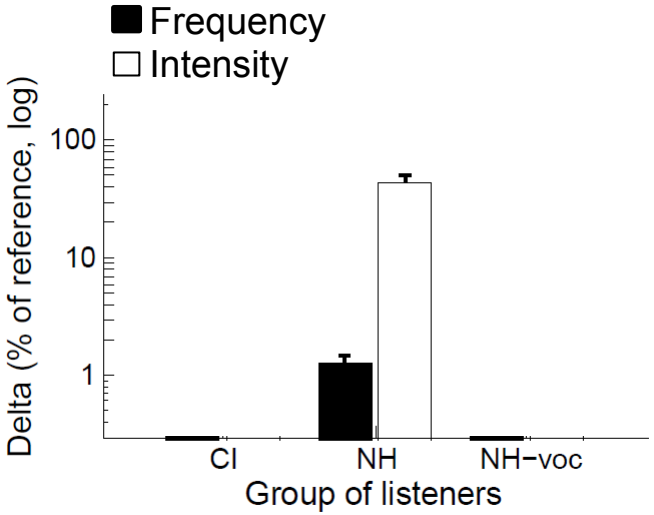
Sequence processing

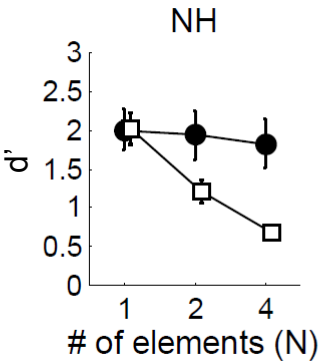


- Δ adjusted to equate discriminability between elements

Cousineau et al., 2009, 2010a, 2010b

Pitch shifts





- Pitch-sequence advantage for normal-hearing listeners
- No pitch-sequence advantage for implant users
- Additional cue for pitch sequences, not available to CI

Pitch shifts

Summary

- Pitch and frequency-shift could be encoded in parallel
- Sequence processing not fully predicted by discrimination

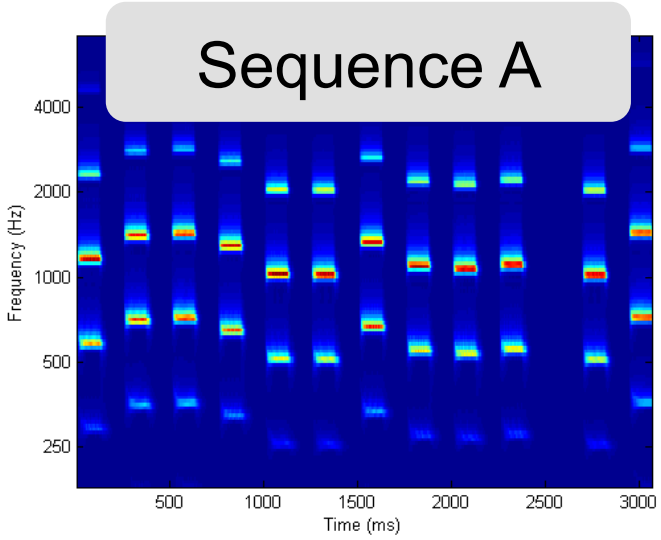
Pitch: from basics to context effects

- Acoustics of periodic sounds
- Models of pitch
- Neural and psychophysical data
- Beyond the standard definition
- Context effects

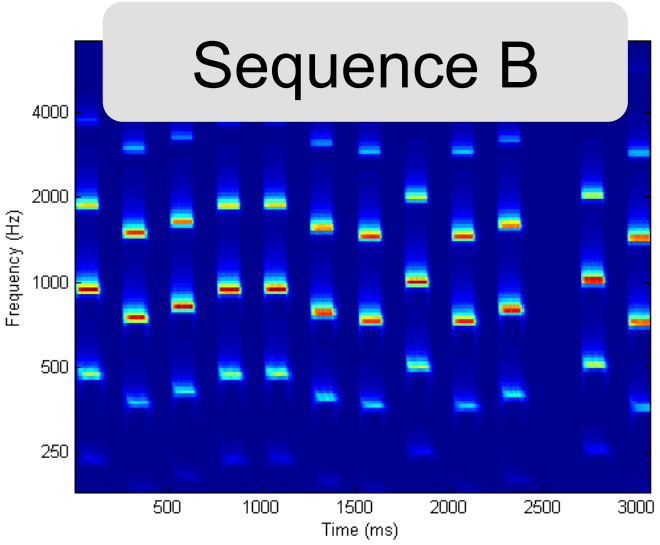
Context

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?

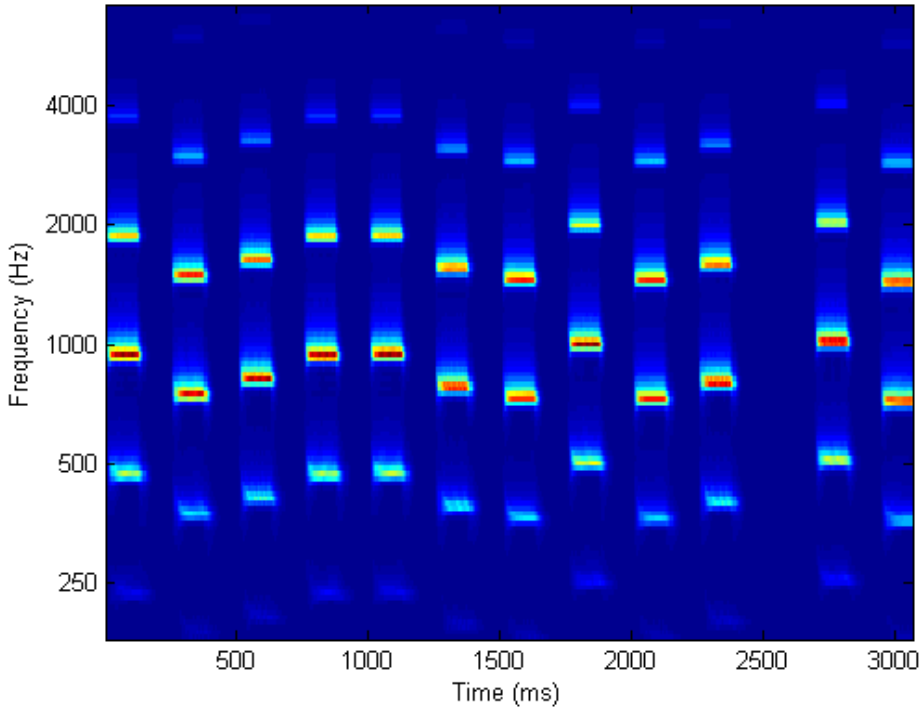
Sequence A



Sequence B



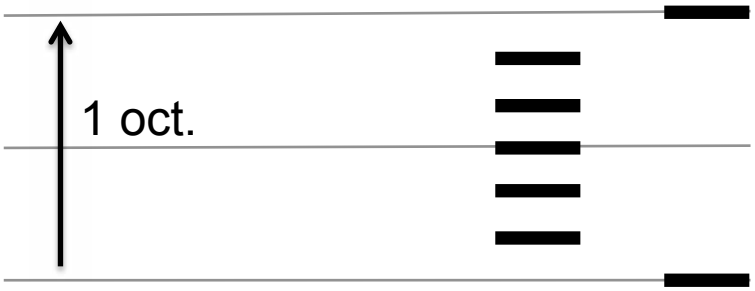
Context

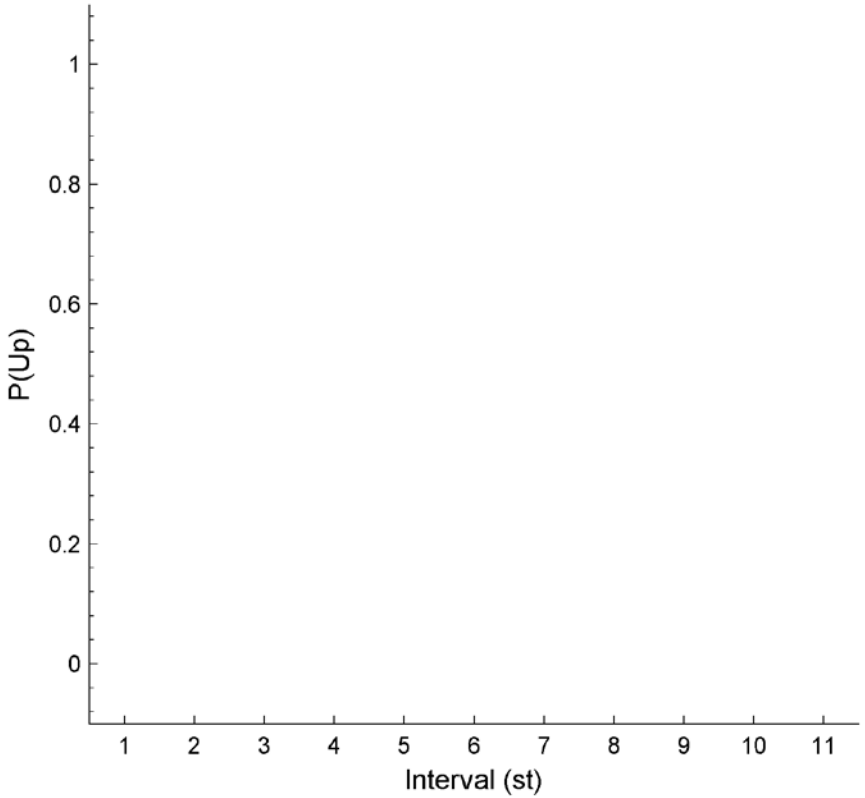


- Sequence of Shepard tones (Shepard, JASA 1964)

Context

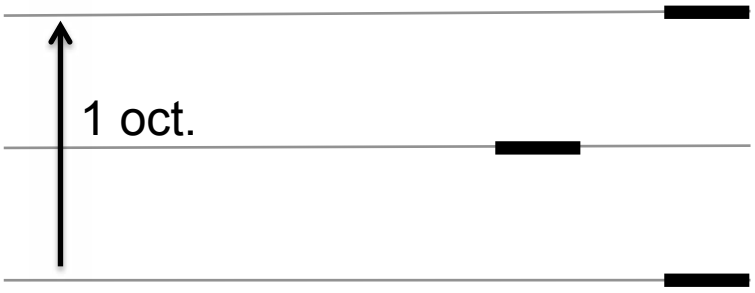
Perceived pitch shift

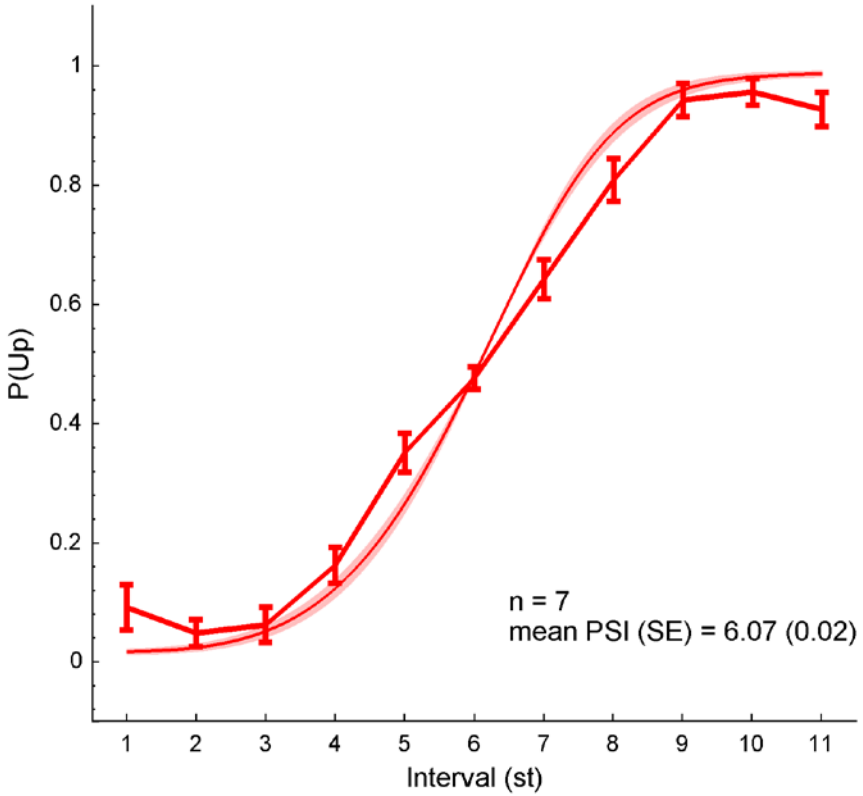




Context

Perceived pitch shift

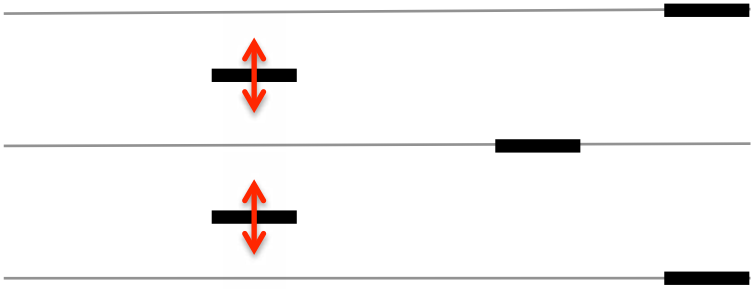


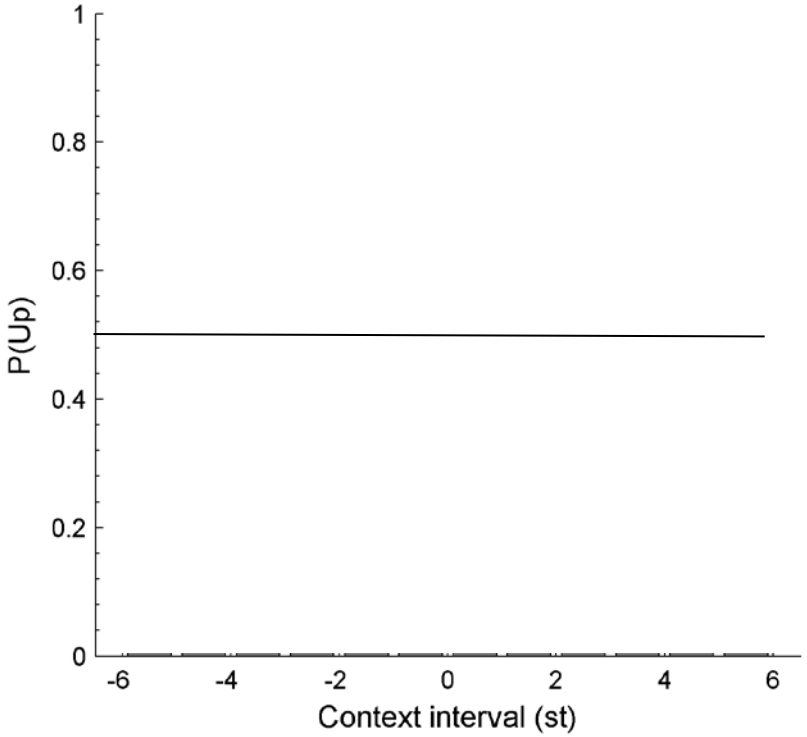


- Ambiguous pitch shift for half-octave step

Context

Context tone

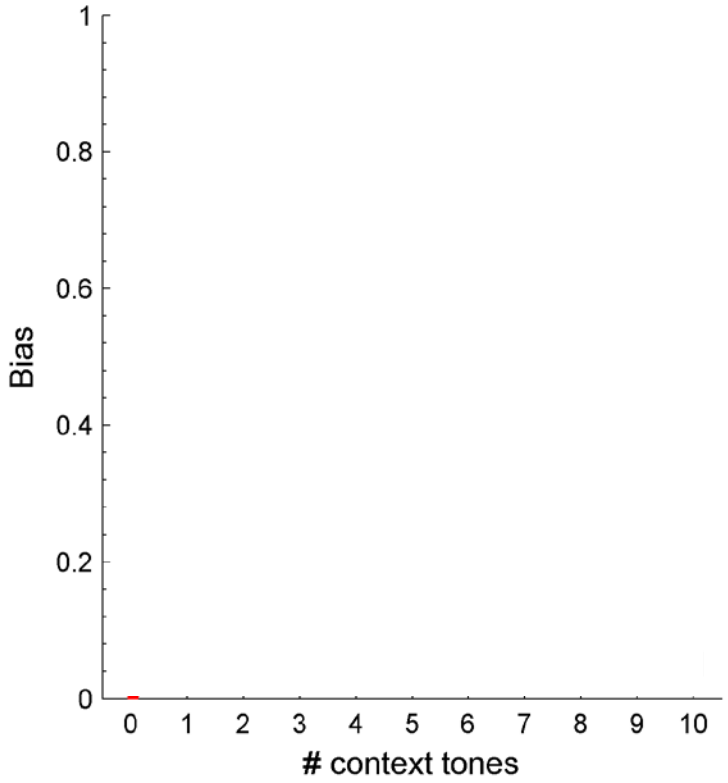




- Context tone biases perception in a “assimilative” manner

Context

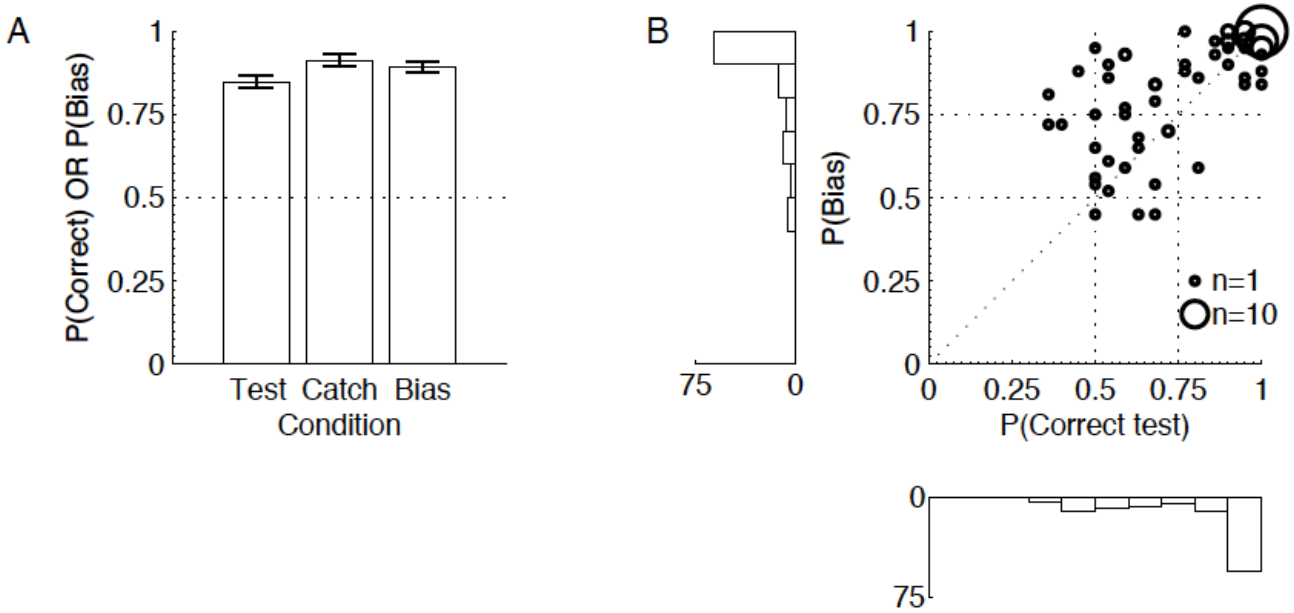
Context tones



- Build-up: perception can be almost *fully* determined by context

Context

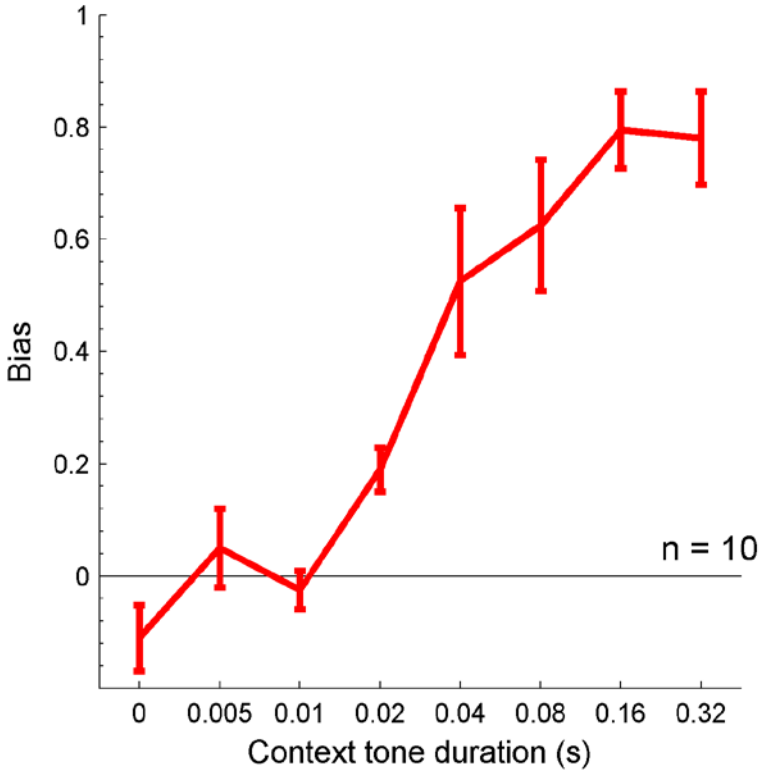
Online experiment



- Context effect for poor performers on pitch comparisons

Time-course

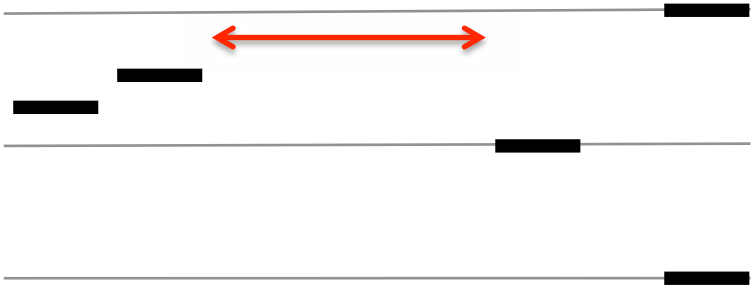
How long does it take?

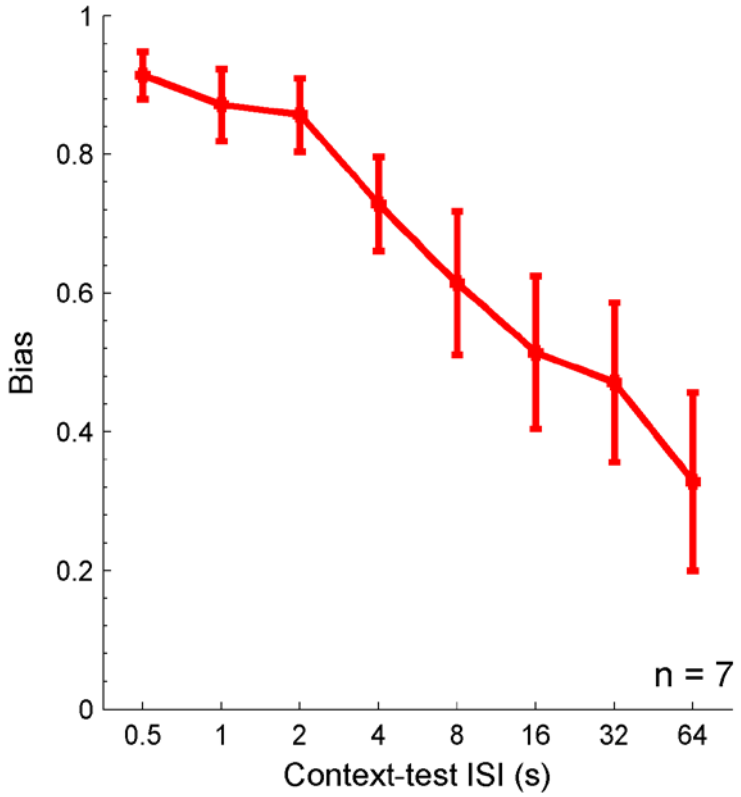


- Bias observed for a 20-ms long context

Time-course

How much does it last?

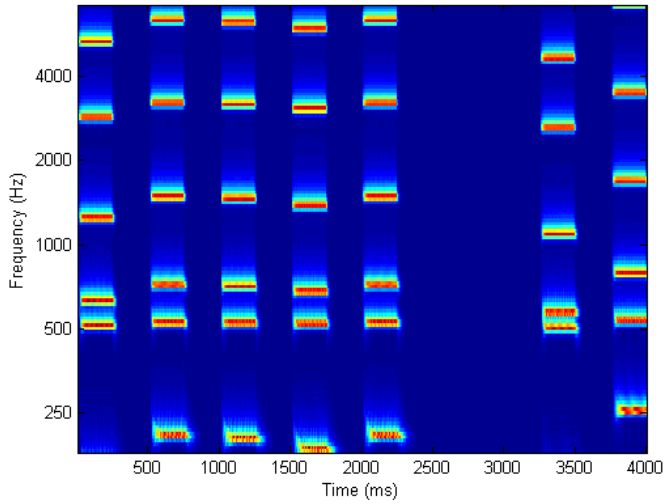


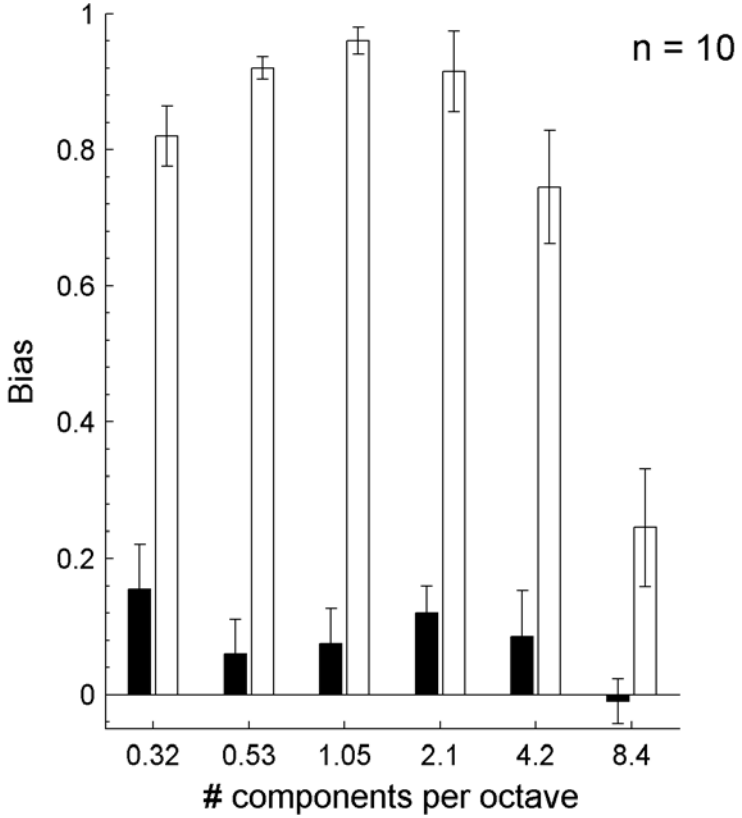


- Bias persists for over 30s

Random spectra

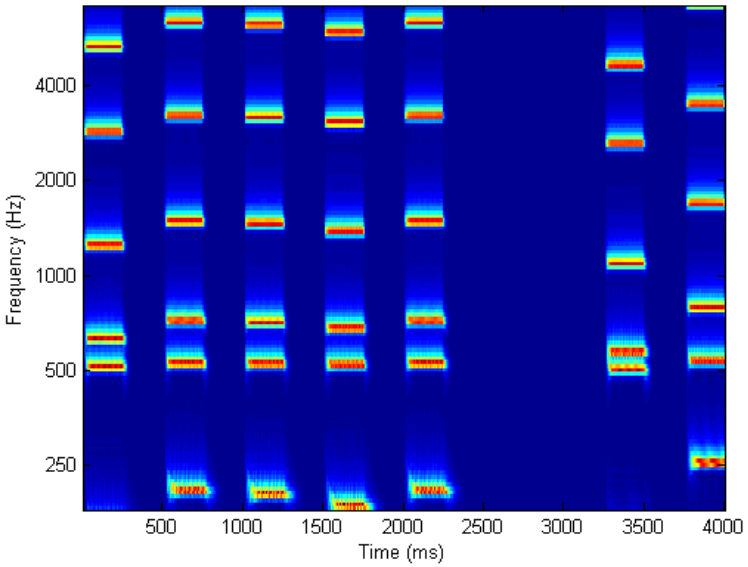
Something to do with Shepard tones?

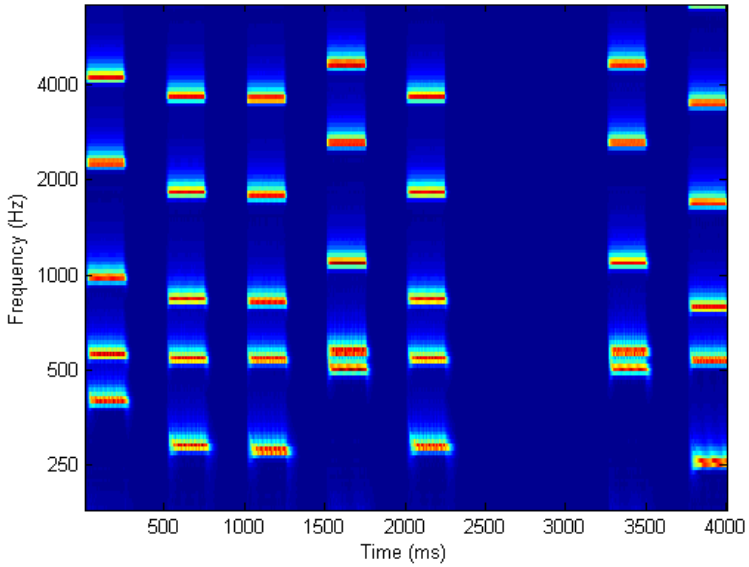




- Generalisation to random spectra, limited by resolvability

Random spectra: demo





Context

Summary

- Direction of large “pitch” shifts is biased by context
- Bias is:
  - fast
  - long-lasting
  - probably based on tonotopy

Chambers & Pressnitzer, 2014
Chambers, Pelofi, Shamma & Pressnitzer, in prep.

Pitch: from basics to context effects

Overall summary

- Periodicity informs about sound sources
- Perceived as pitch, but encoding could be multi-facet
- Interaction with context
- It’s not pitch, it’s what you do with it that counts