Language experience shapes representation of pitch relevant neural activity in the human brainstem

Ananthanarayan (Ravi) Krishnan

Auditory Electrophysiology Laboratory

SPEECH, LANGUAGE, AND HEARING SCIENCES

PURDUE UNIVERSITY

FFR Workshop, May22-23 UCL, London

Research supported by NIH Grant, 1R01DC008549

Why study Pitch?

- **Pitch plays an important role in the perception of speech, language, and music.**
- **Therefore there is considerable interest in understanding:**
  - **(i)** *How pitch relevant information is representation at both subcortical & cortical levels;*
  - **(ii)** *How long term language experience influences this experience-dependent; and*
  - **(iii)** *The nature of interplay between cortical and subcortical components in the pitch processing hierarchy*

Language experience shapes pitch processing

Pitch processing-hierarchical-includes both cortical and sub-cortical stages of processing

Pitch processing of lexical tones at the cortical level is influenced by language experience.

Present results from the brainstem that supports the view *that language experience also influences representation of pitch relevant neural activity in the brainstem*

Experimental Strategy: Cross-linguistic approach

Examine: 1. *native & non-native contours*
2. context (speech vs. non-speech) of contours
3*. sensitivity to temporal regularity*
4. relationship to behavioral measures
5. relationship between brainstem, cortical and behavioral measures relevant to pitch

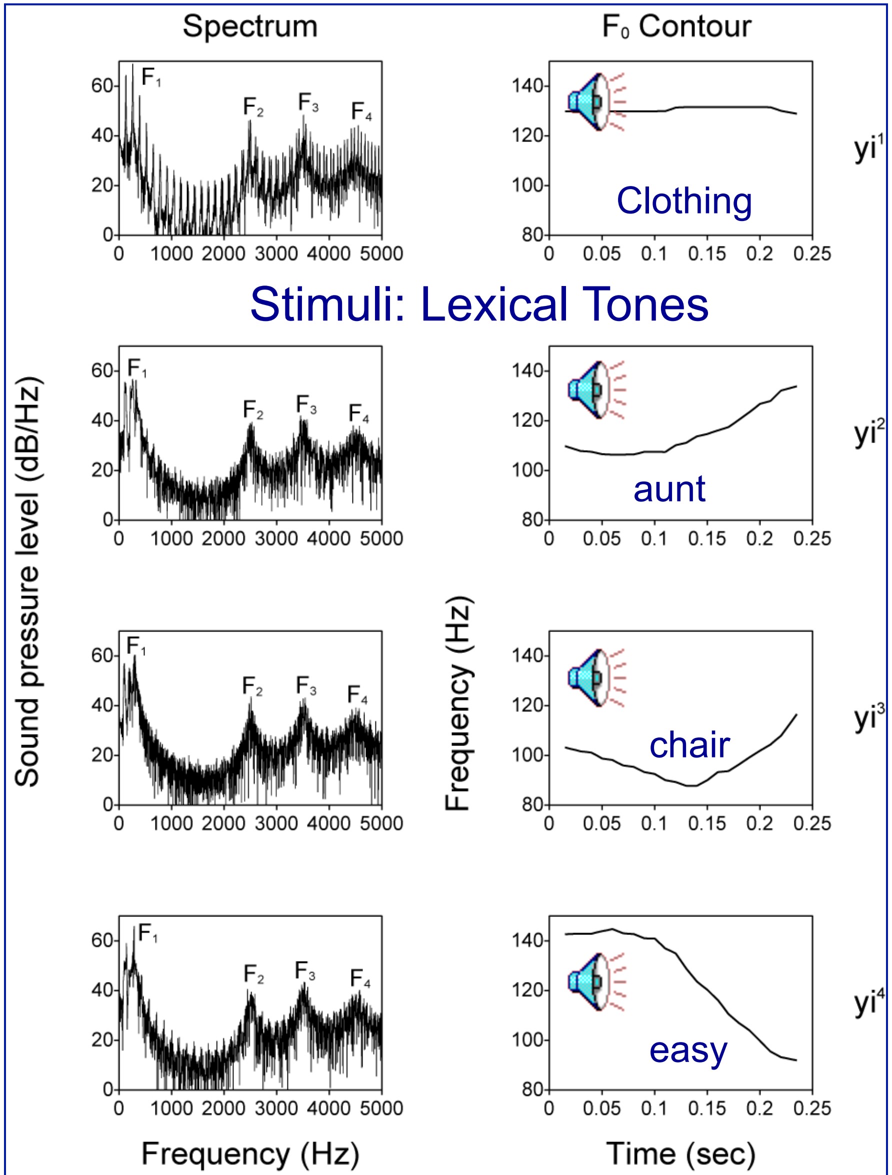
Subjects: *Chinese (Mandarin) & English subjects:*
right handed, no music experience
Mean age when Chinese started to learn English: 11 yrs

Dependent Variables:
Pitch Tracking Accuracy
Pitch strength (periodicity strength)

Methods: Chinese Subjects

- Normal hearing native speakers of Mandarin Chinese
- **Closely matched in age** (24.50 ± 3.53 years), **years of formal education** (16.90 ± 2.88 years), and were **strongly right handed** (laterality index 93.10 ± 11.22%).
- All participants were **born and raised in mainland China.**
- **None had received formal instruction in English before the age of nine (12 ± 1.24 years).**
- **Little or no music experience**

1. Is brainstem neural activity relevant to pitch influenced by language experience?



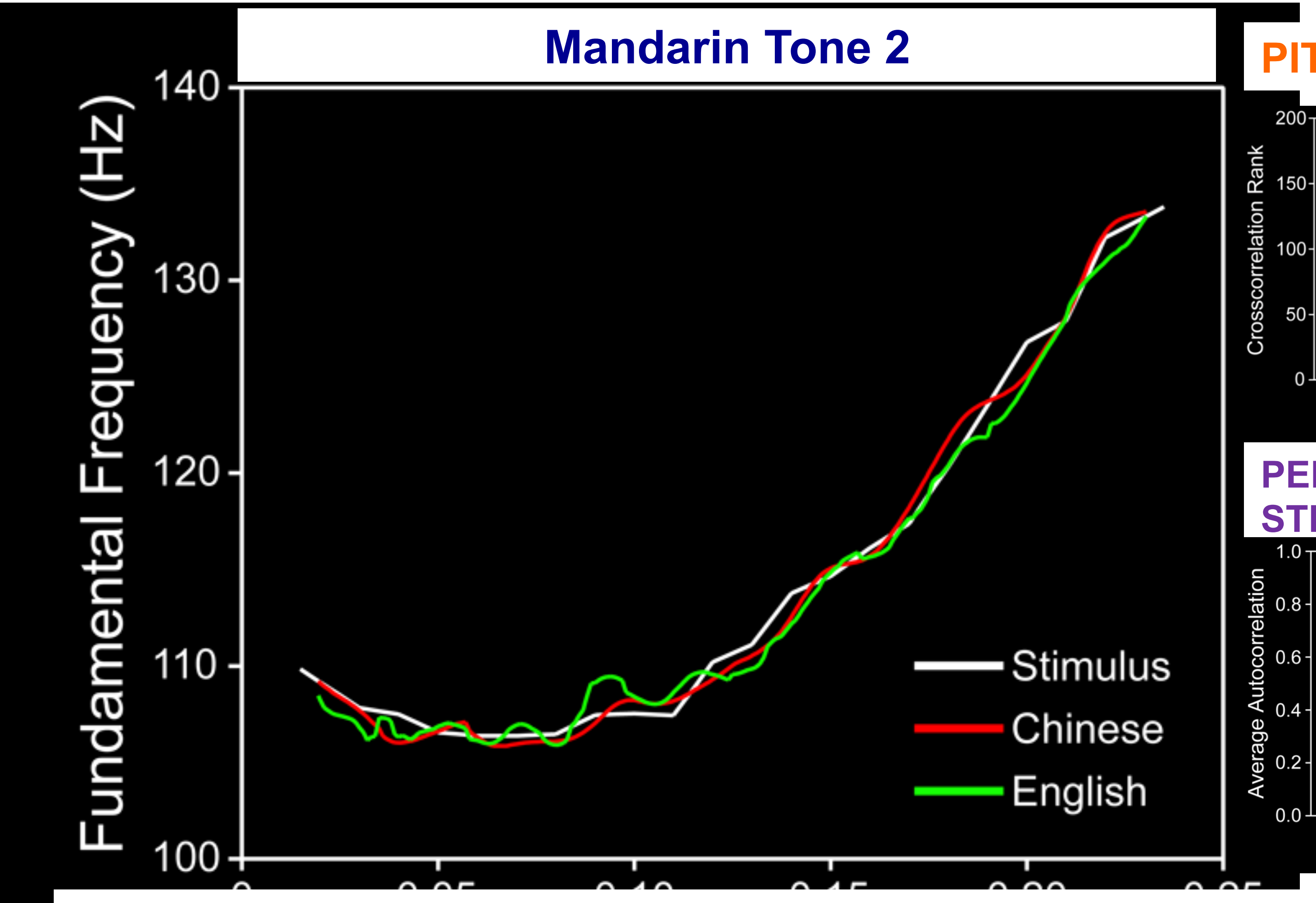
Cross-linguistic approach: Native Mandarin vs non-native English Listeners

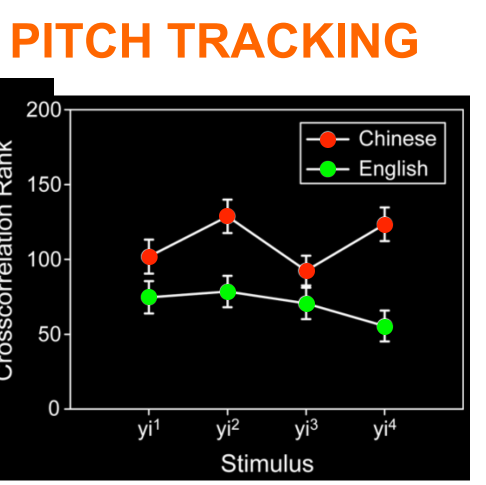
Stimuli: lexical tones

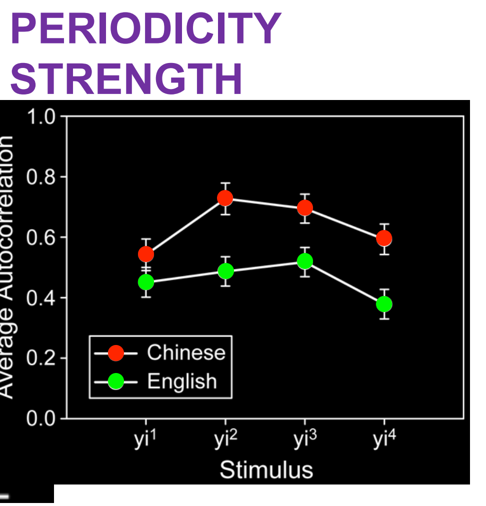
Note: Identical spectra with only pitch contour changing

Krishnan et al. *Hearing Research* (2004); Cog. Br. Res (2005)

Encoding of pitch is sensitive to language experience







PT: crosscorrelation between Fo contours extracted from stimuli and FFRs

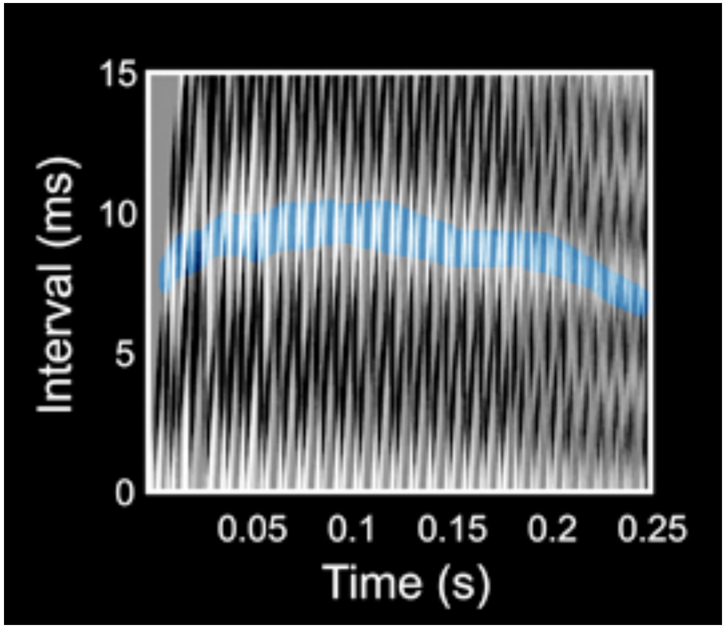
PS: magnitude of normalized autocorrelation peak per time frame

Krishnan, Xu, Gandour, & Cariani *Cognitive Brain Research* 2005

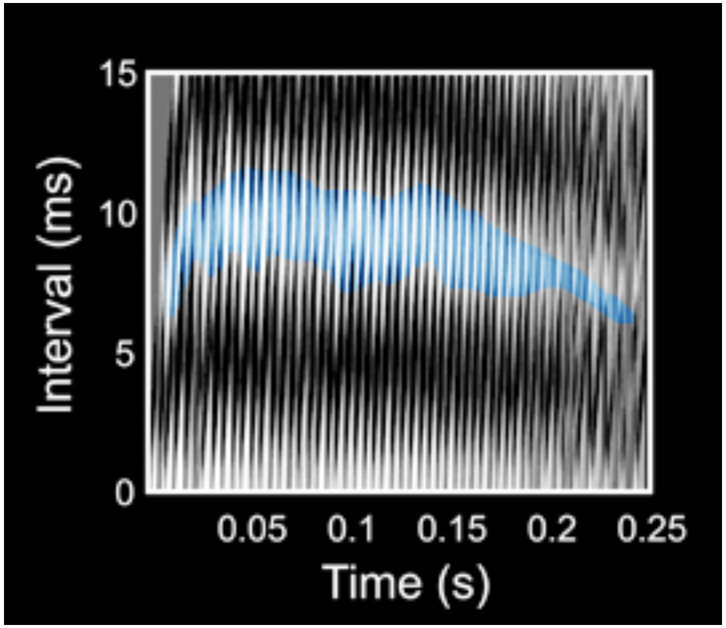
More coherent phase-locking to F0 interval in the Chinese

Blue stripe shows the dominant interval for rising tone;
10 ms = 100 Hz; period is the inverse of frequency

Chinese



English



Krishnan et al. *Cognitive Brain Research* 2005

Summary

FFRs preserved the pitch-relevant information of lexical tones in both native and non-native listeners

Stronger representation of in native listeners in terms of both *tracking accuracy* and *periodicity strength*

These results suggest long term *language experience induced neural plasticity* at the brainstem level may be *enhancing or priming linguistically-relevant features of the speech input*

2. Is this language experience-dependent plasticity sensitive to shape of pitch contours?

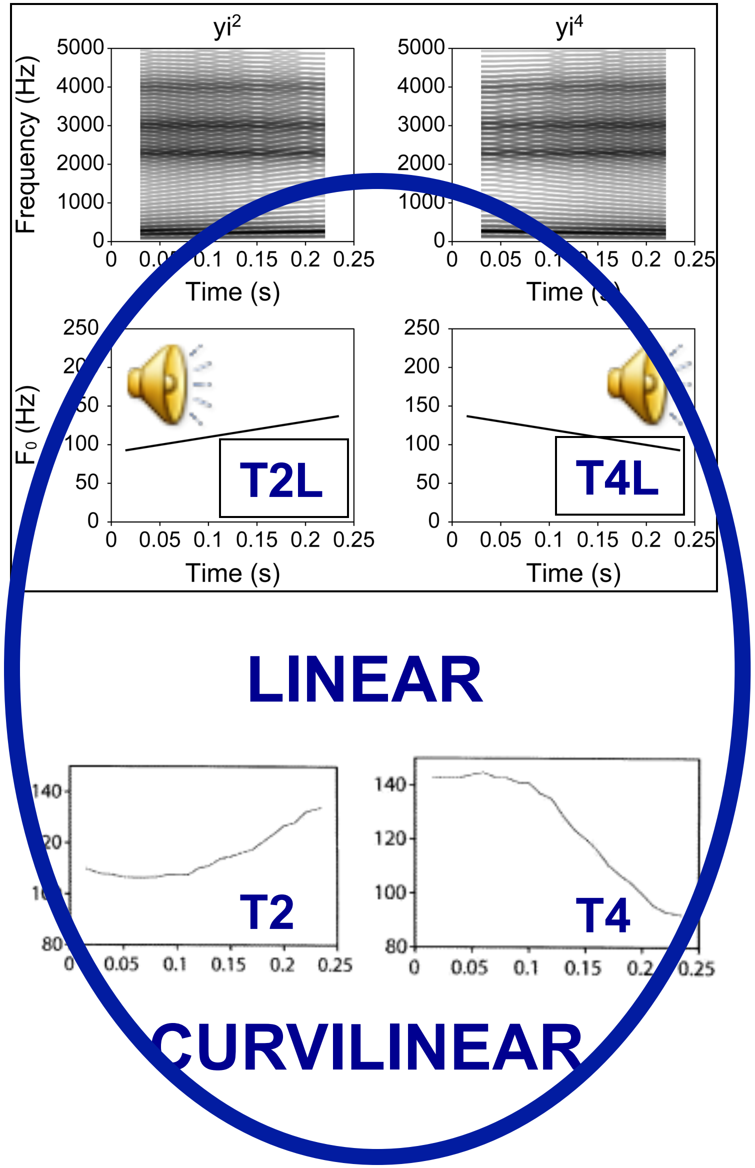
Stimuli used by Krishnan et al. (2005) – *curvilinear* f0 contours that were modeled after Mandarin tones in natural speech.

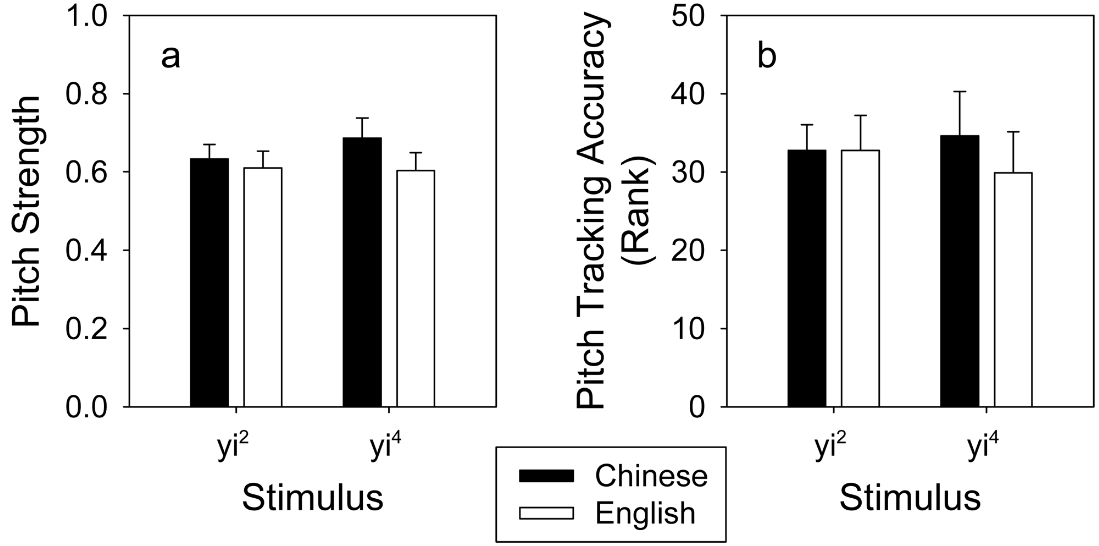
If brainstem reorganization is induced by language experience, will deviations from prototypical f0 contour still produce an experience-dependent effect?

Will linear & curvilinear variants of a higher degree polynomial still yield such results?

Xu, Krishnan, & Gandour *NeuroReport* 2006; Krishnan et al., (2009)

Sensitivity to shape of pitch contours: linear and non-linear contours in speech context

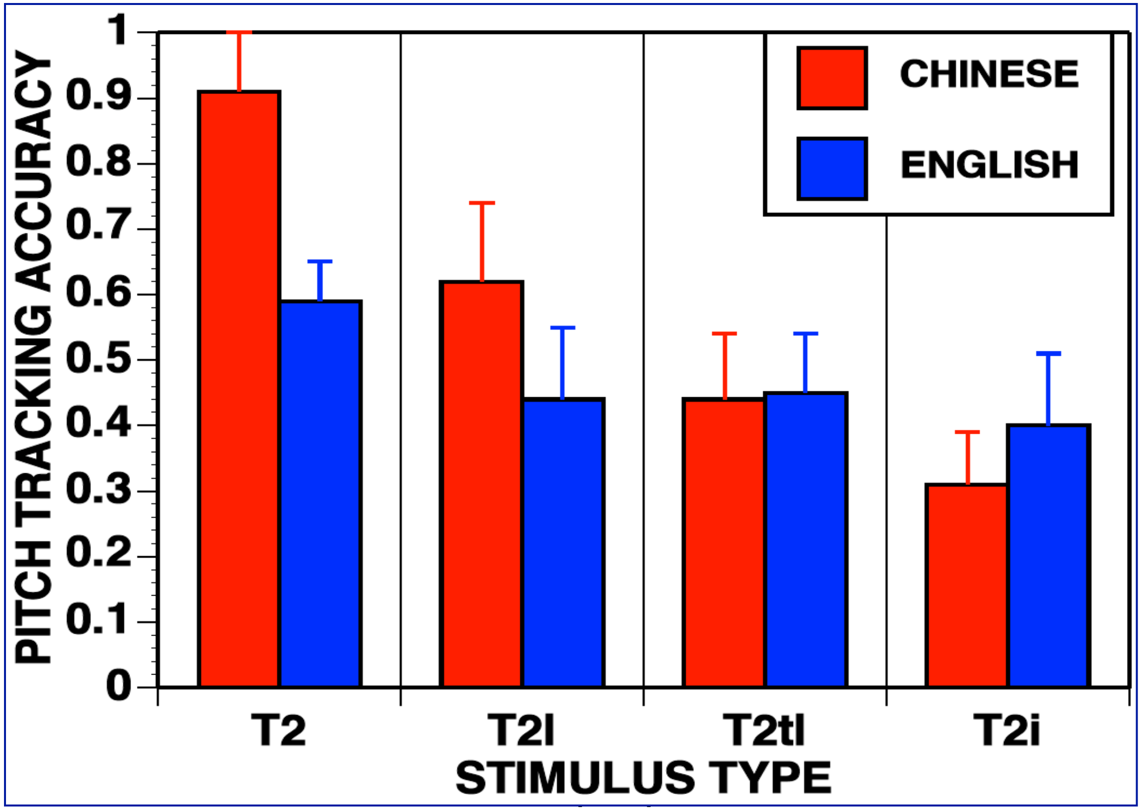


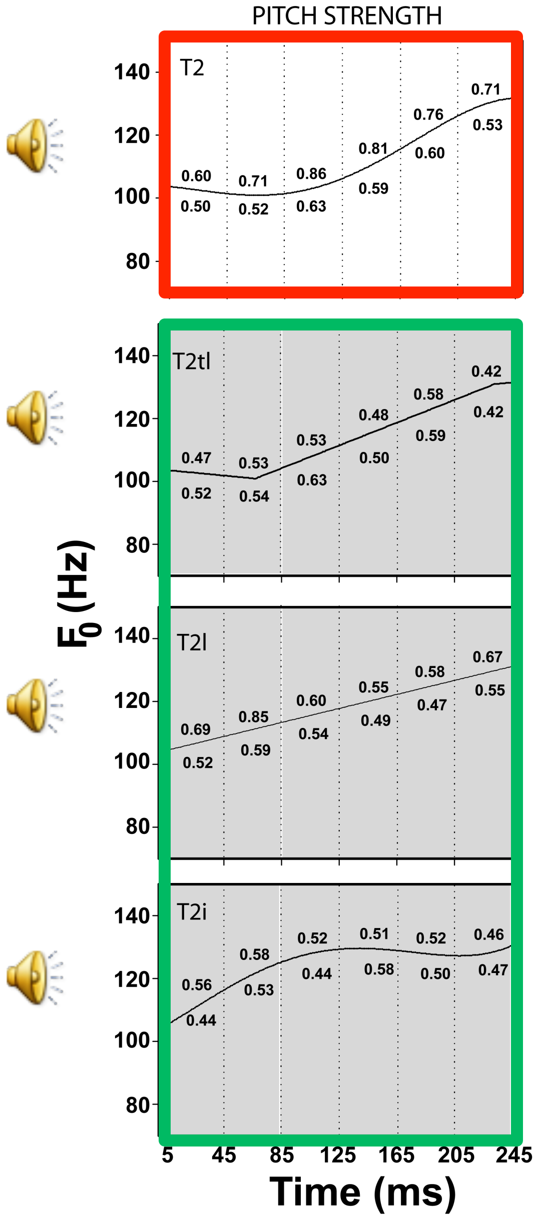


- No crosslanguage differences in periodicity strength or tracking accuracy for linear contours
- Representation of pitch-relevant information appears to dependent on specific fine-grained *features* of pitch contours that occur in natural speech

Xu, Krishnan, & Gandour *NeuroReport* 2006

Sensitivity to shape of pitch contours: linear and non-linear contours in a nonspeech context





- PT & PS: Chinese > English for **T2** only
- English = Chinese for curvilinear (**T2i**) and linear (**T2 l, T2tl**) variants of **T2**

Krishnan, Gandour, Bidelman, & Swaminathan *NeuroReport* (2009)

Summary

Conclude that long-term experience-dependent influence on brainstem representation of pitch relevant information is *specific to contours that are part of their experience.*

Brainstem representation of pitch relevant information in the Chinese appear to be acutely sensitive to *dynamic changes in trajectory throughout the duration of a pitch contour*

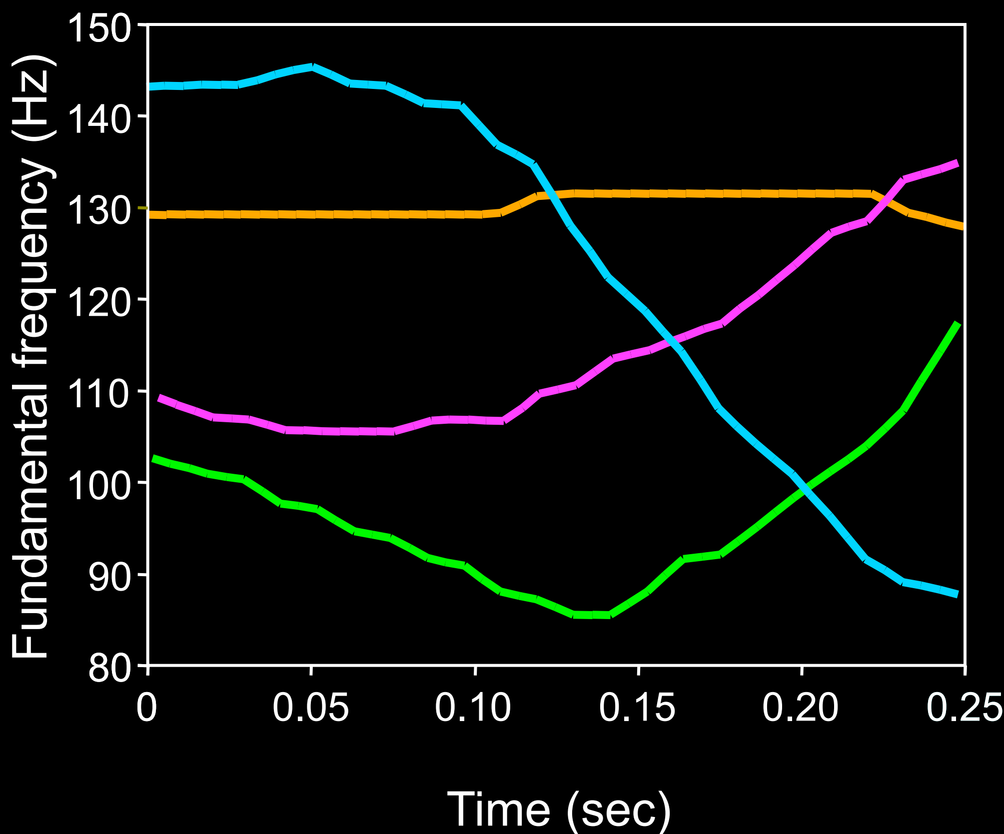
3. Is this language experience-dependent plasticity specific to speech context ?

To answer this question the pitch contours have to presented in a non-speech context

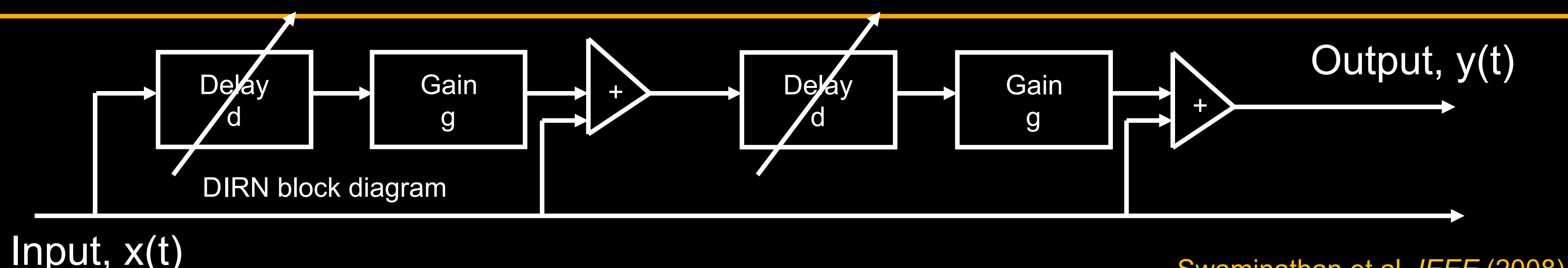
Typically used non speech stimuli (rotated, sine wave, speech in noise etc) has some speech characteristics to it.

We used d*ynamic* curvilinear iterated rippled noise (IRN) stimuli to remove any potential lexical-semantic confound

Pitch contours in a non-speech context: IRN stimuli

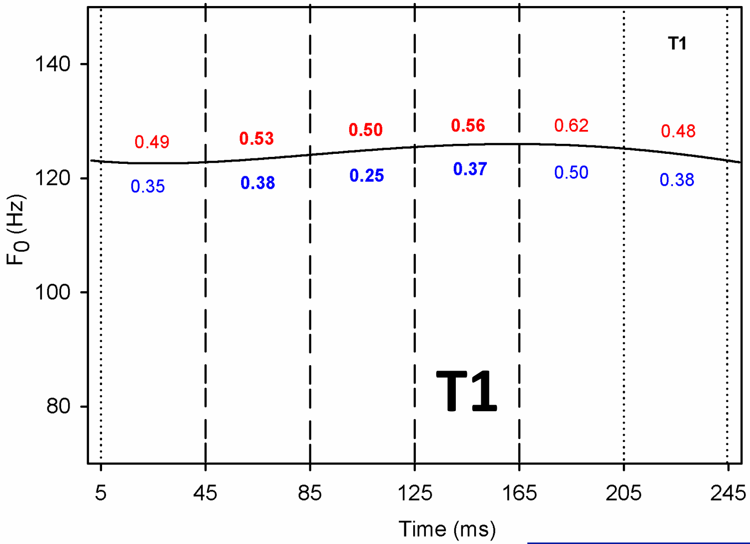


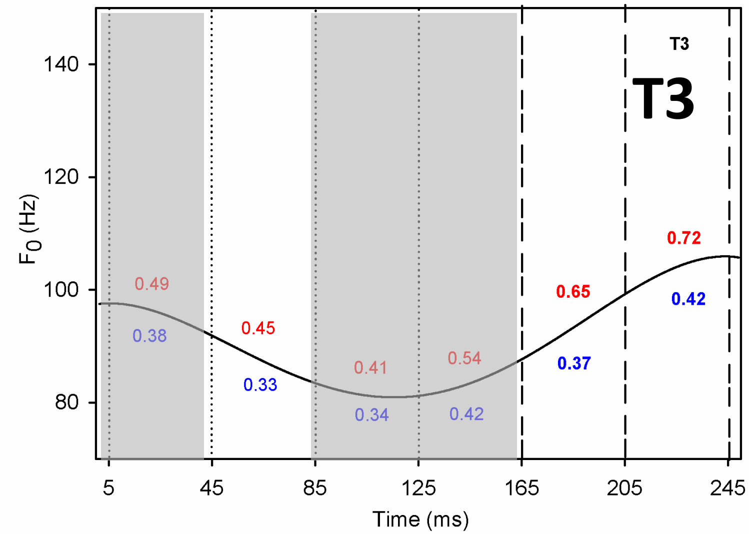
	SPEECH	NON-SPEECH (IRN; N=32)
T1		
T2		
T3		
T4		



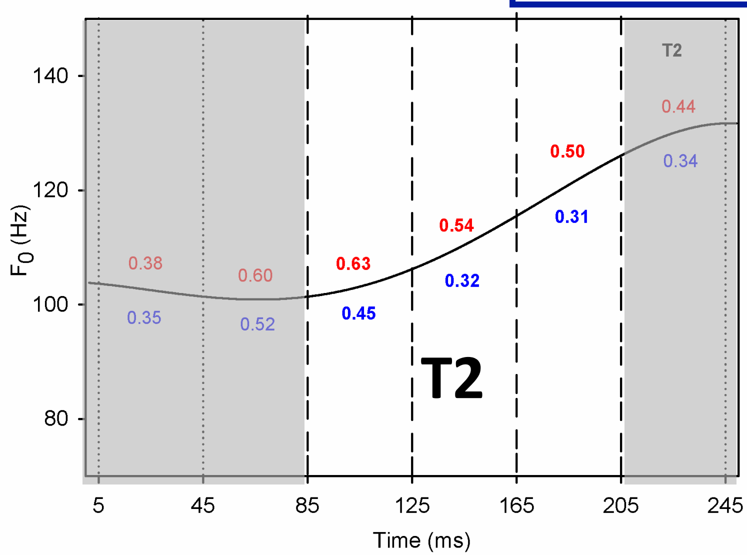
Swaminathan et al, *IEEE* (2008)

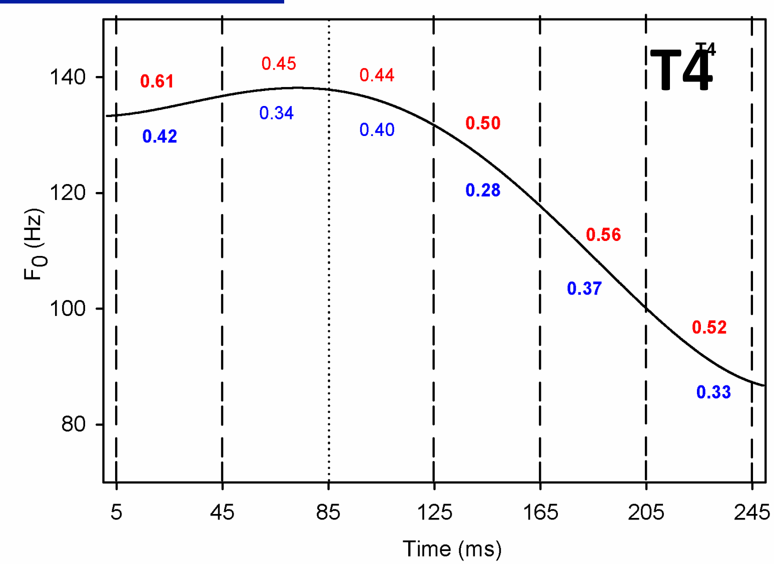
FFR: Mandarin tone; nonspeech; curvilinear; native/nonnative





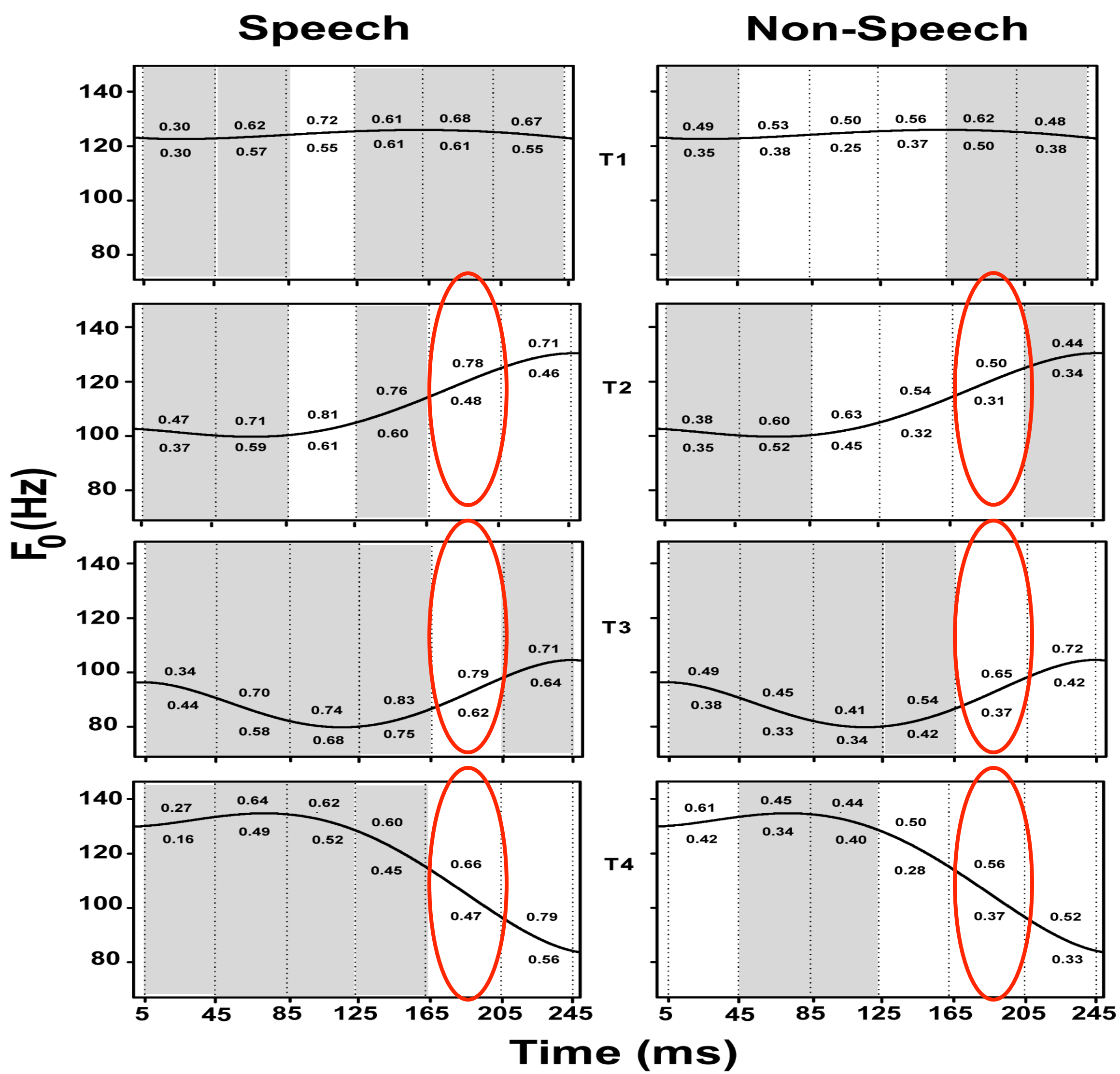
PITCH STRENGTH





Krishnan, Swaminathan, & Gandour ***Journal of Cognitive Neuroscience*** **(2008)**

Periodicity Strength (segmental analysis)

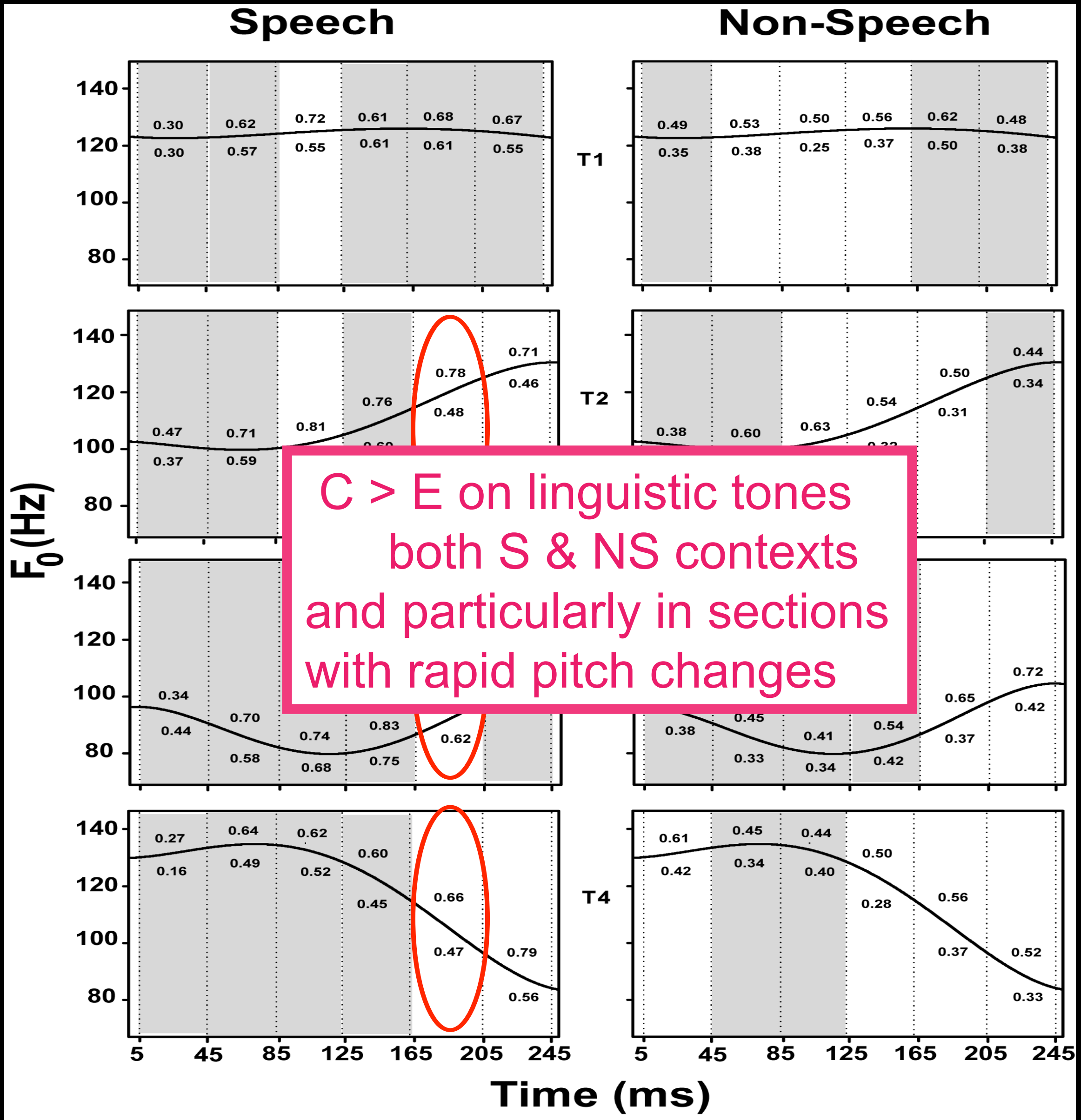


C > E on linguistic tones for both S & NS- *particularly in segments showing rapid changes in pitch*

Swaminathan, Krishnan & Gandour ***Neuroreport*** **(2008)**

Are language effects dependent on context?

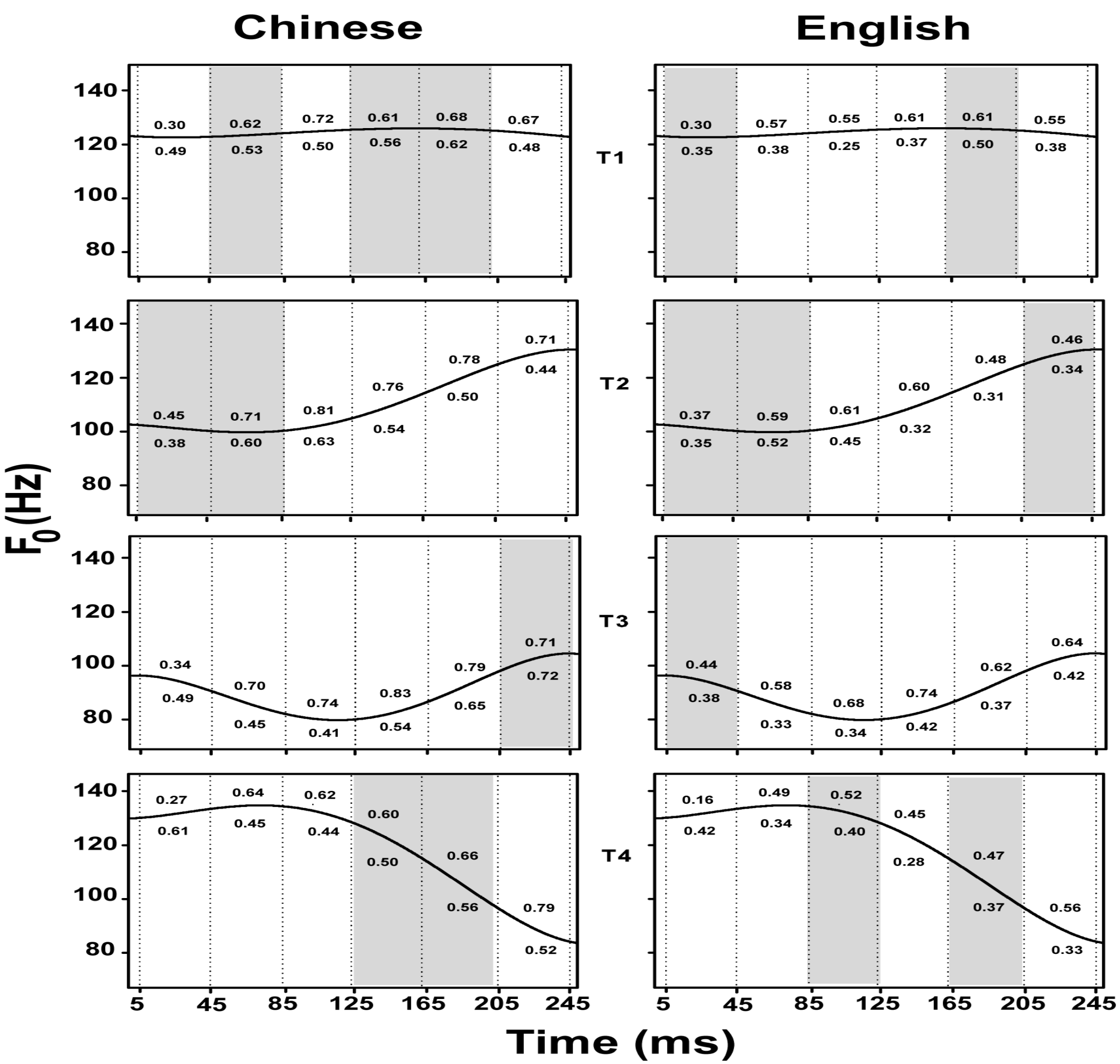
PITCH STRENGTH



C > E on linguistic tones both S & NS contexts and particularly in sections with rapid pitch changes

Swaminathan et al, *NeuroReport* (2008)

Pitch Strength: Speech > Non-Speech



For both groups, *pitch strength for speech greater than for non-speech*

Summary

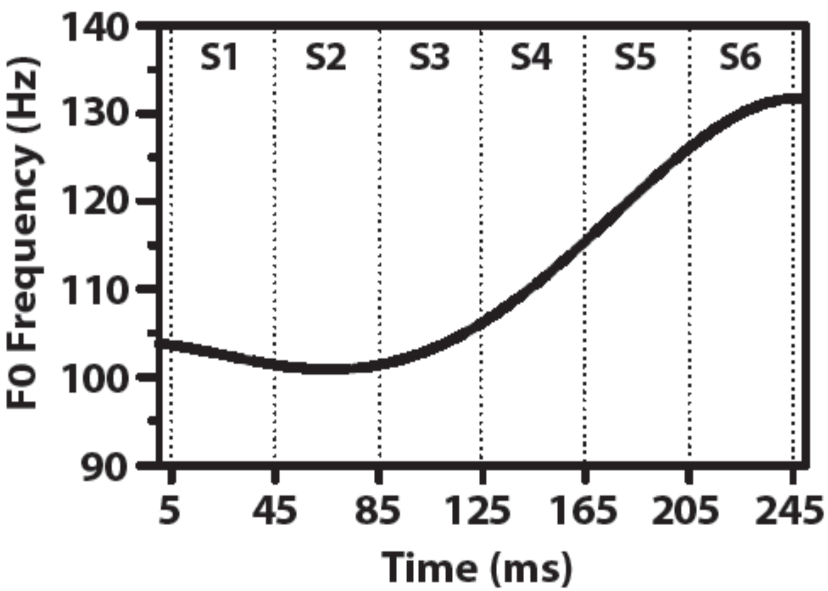
In native listeners, representation of dynamic IRN stimuli were *superior in terms of both tracking accuracy and pitch strength*

Segmental evaluation suggested better sensitivity in the native listeners to *rate of change of pitch*

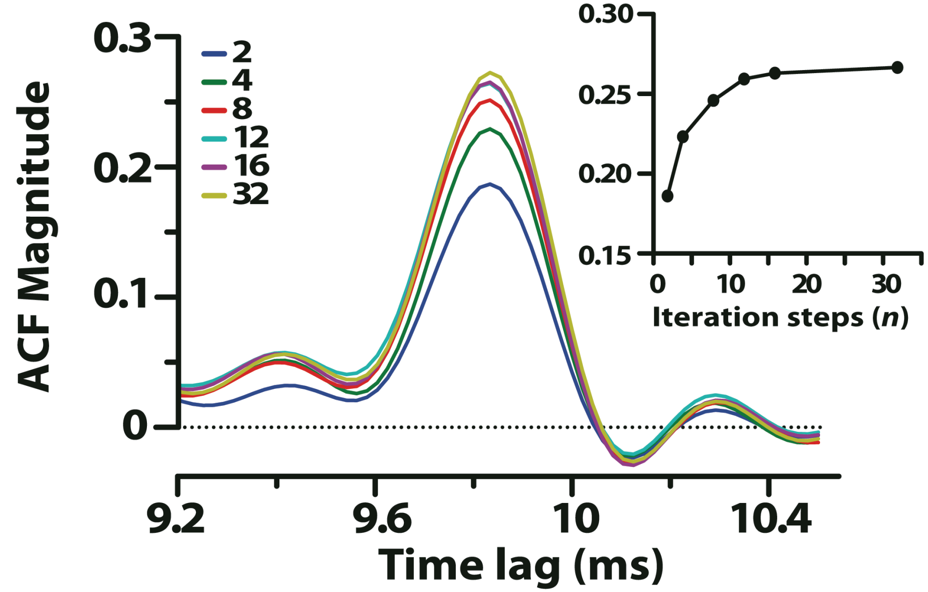
These findings suggest that the experience-dependent enhancement of pitch relevant information *is not specific to speech domain*; and *shows particular sensitivity to the dynamic portions of native pitch contours*.

4. Is this experience-dependent enhancement in pitch representation sensitive to changes in temporal regularity?

PITCH CONTOUR



PITCH STRENGTH

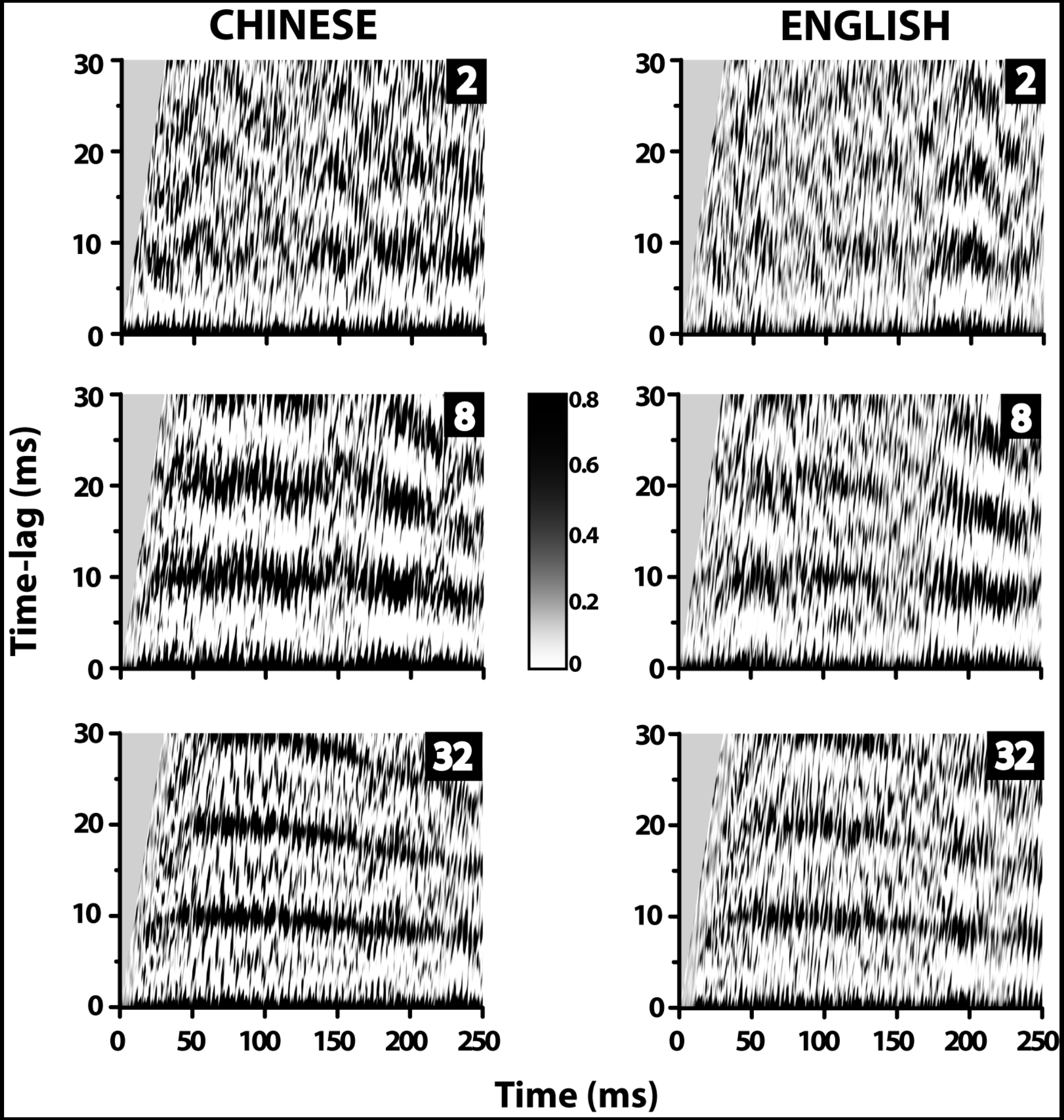


Iteration steps (*n*)

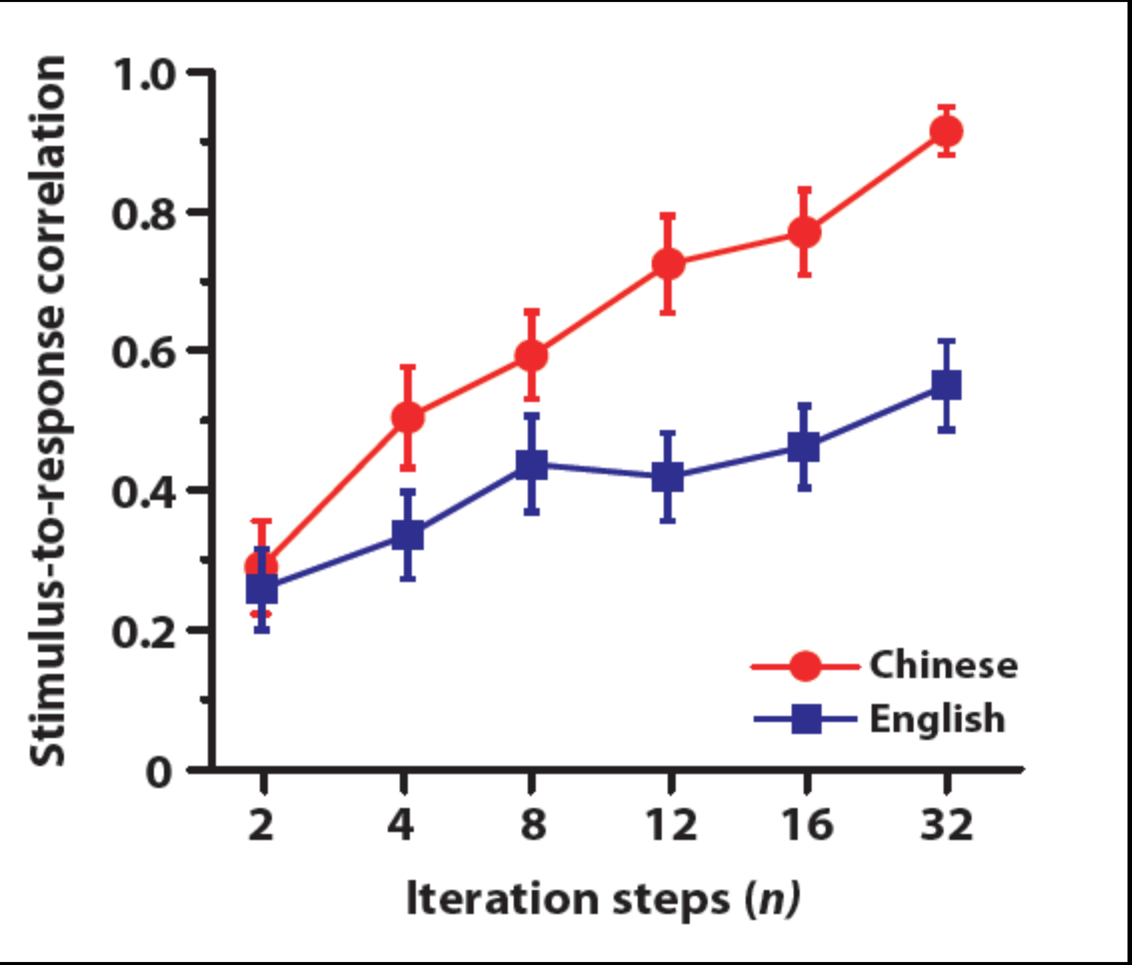
n = 2 *n* = 4 *n* = 8 *n* = 12 *n* = 16 *n* = 32

Krishnan, Bidelman, & Gandour *Hearing Research*
(Brain Res., 2009; Hear Res., 2010;)

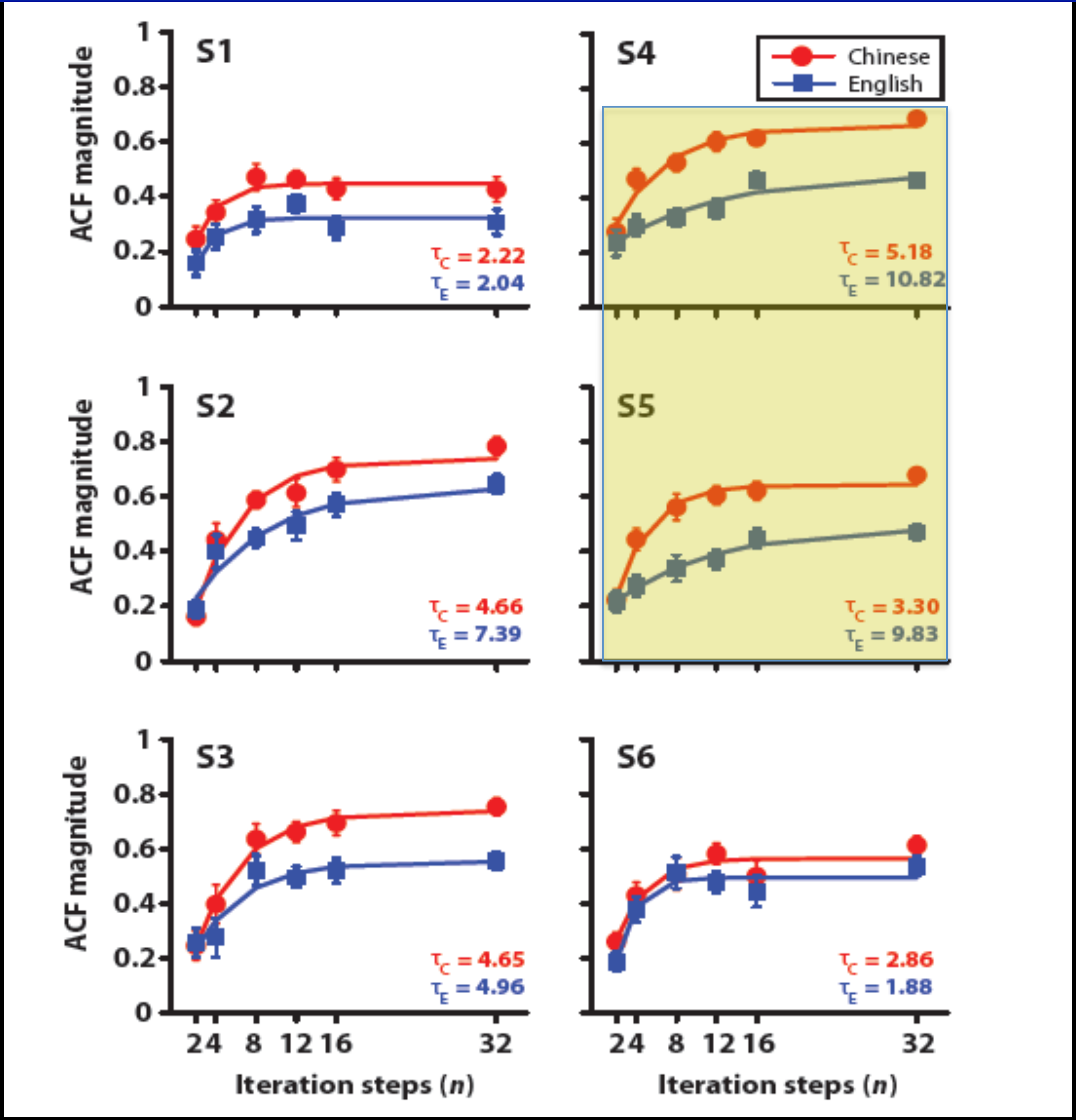
Pitch relevant information appears to emerge at a lower iteration number in Chinese listeners



Pitch tracking accuracy better in Chinese and at a smaller iteration step



Pitch Strength grows more rapidly with iteration steps for Chinese listeners



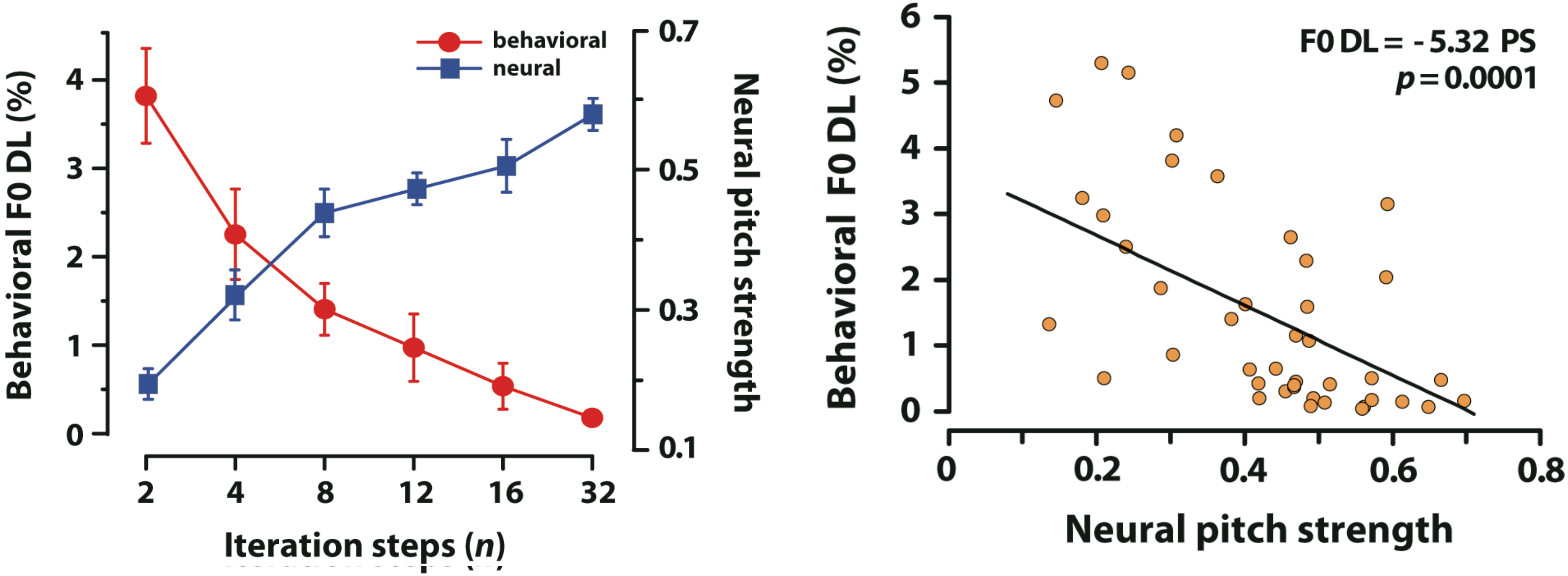
Summary

Pitch-tracking accuracy & periodicity strength shows greater sensitivity to pitch salience in the native tone language group (Chinese)

Periodicity strength emerges 2–3 times faster in the Chinese group with increasing pitch salience

These results suggest that long term language experience enhances the representation of pitch relevant neural activity in the brainstem that may underlie pitch salience.

Relationship between neural and behavioral measures



Information related to *pitch salience* emerges early along the auditory pathway in pre-attentive, sensory-level processing

Krishnan, Bidelman, & Gandour *Hearing Research* (2010)

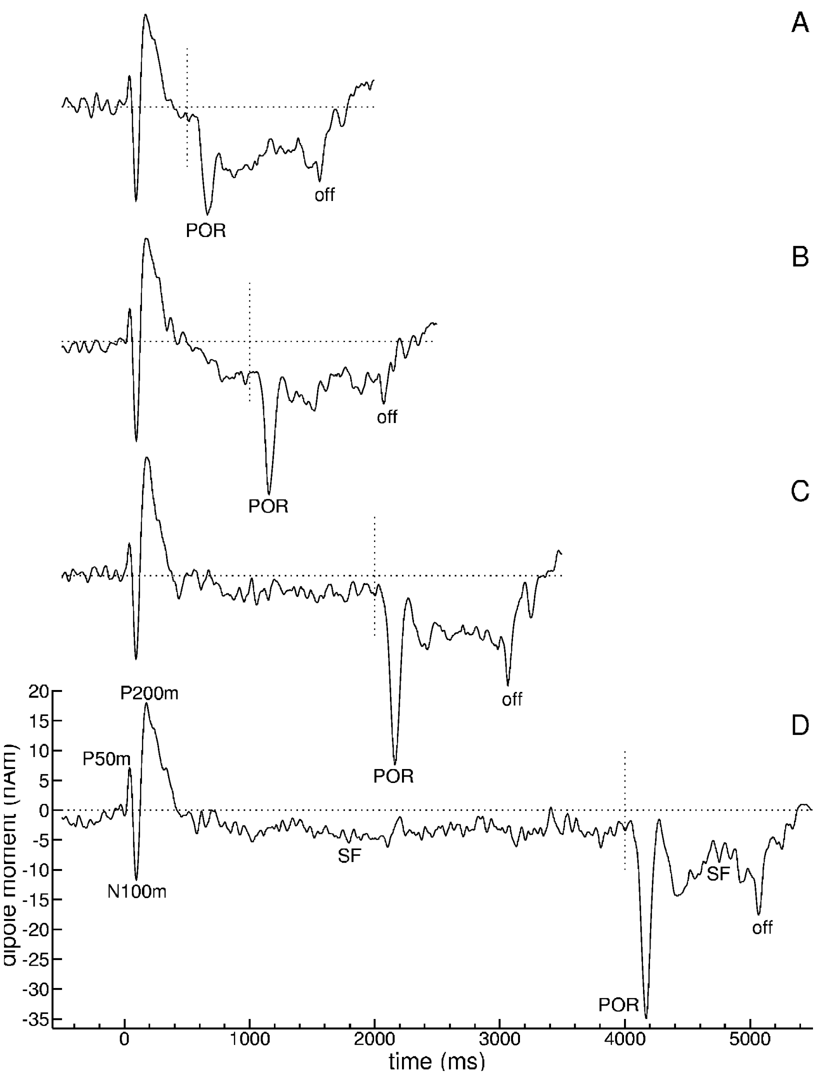
Relationship between brainstem, cortical, and behavioral measures relevant to pitch

The pitch Onset Response (POR)

- Human POR, as measured by MEG, reflects synchronized cortical neural activity specific to pitch

- POR latency and magnitude, for example, has been shown to depend on pitch salience.

- Anatomical Source: Lateral Heschl's Gyrus-the putative site of pitch processing



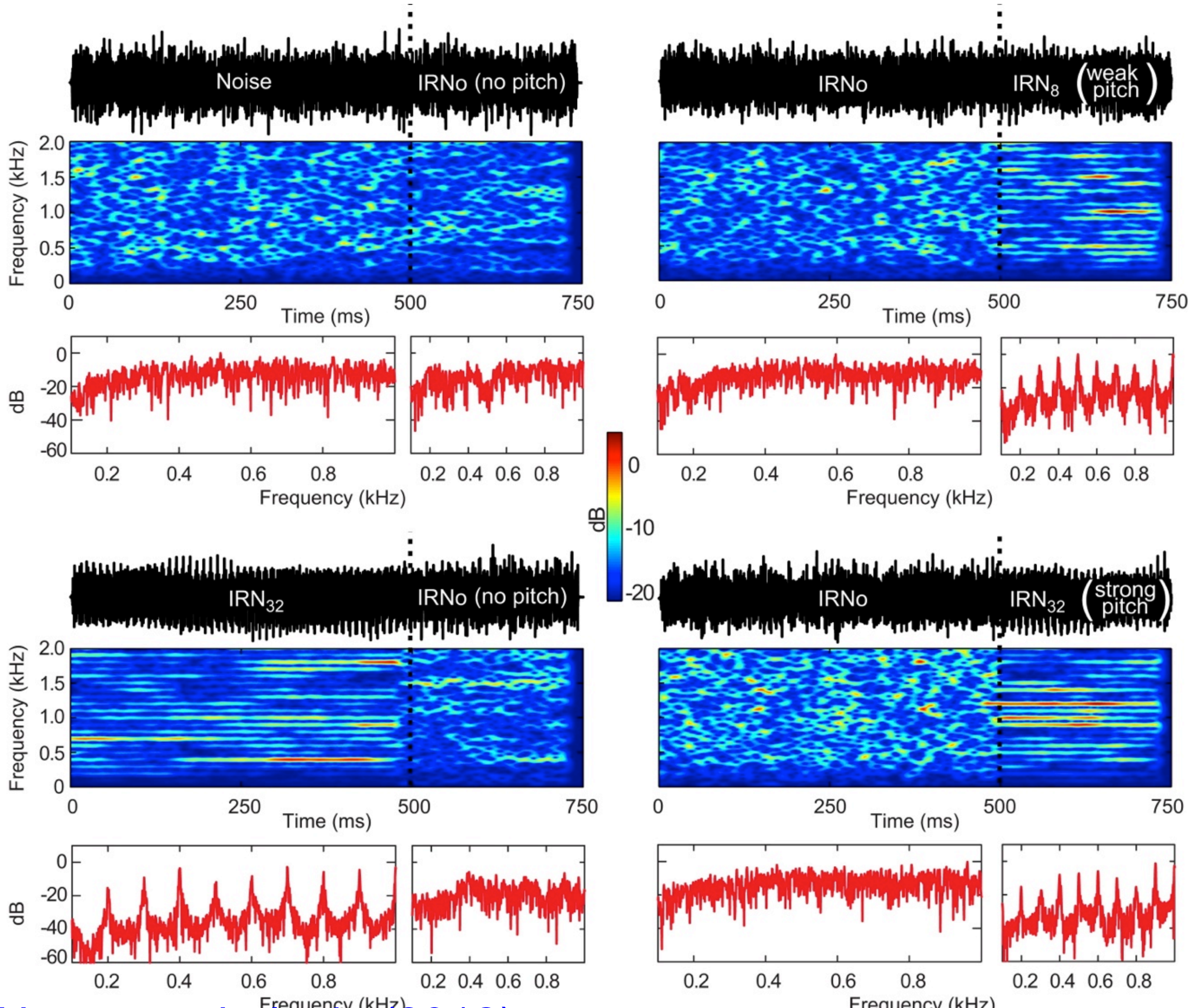
Seither-Preisler et al., 2004

EEG version of POR (CPR): IRN stimuli

Two segments **500 ms** **250 ms**

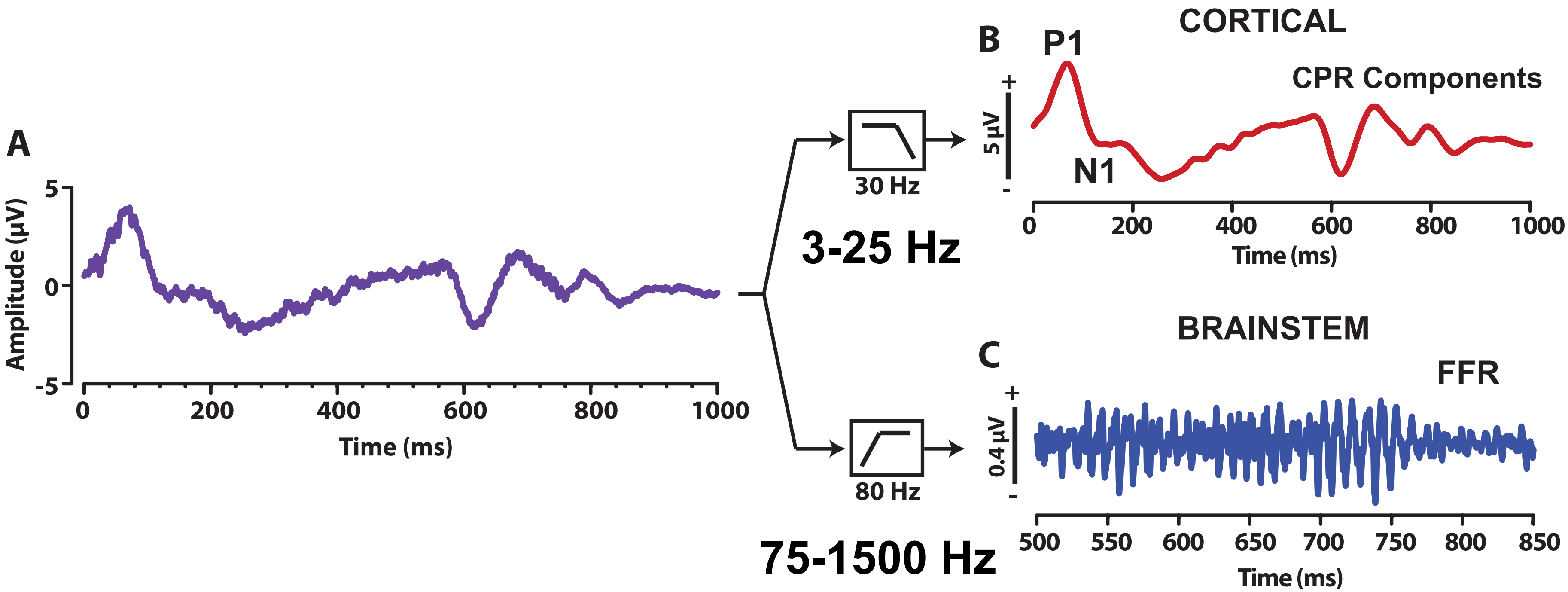
Iteration steps 8 and 32

IRNo: no pitch only slow spectro-temporal fluctuations



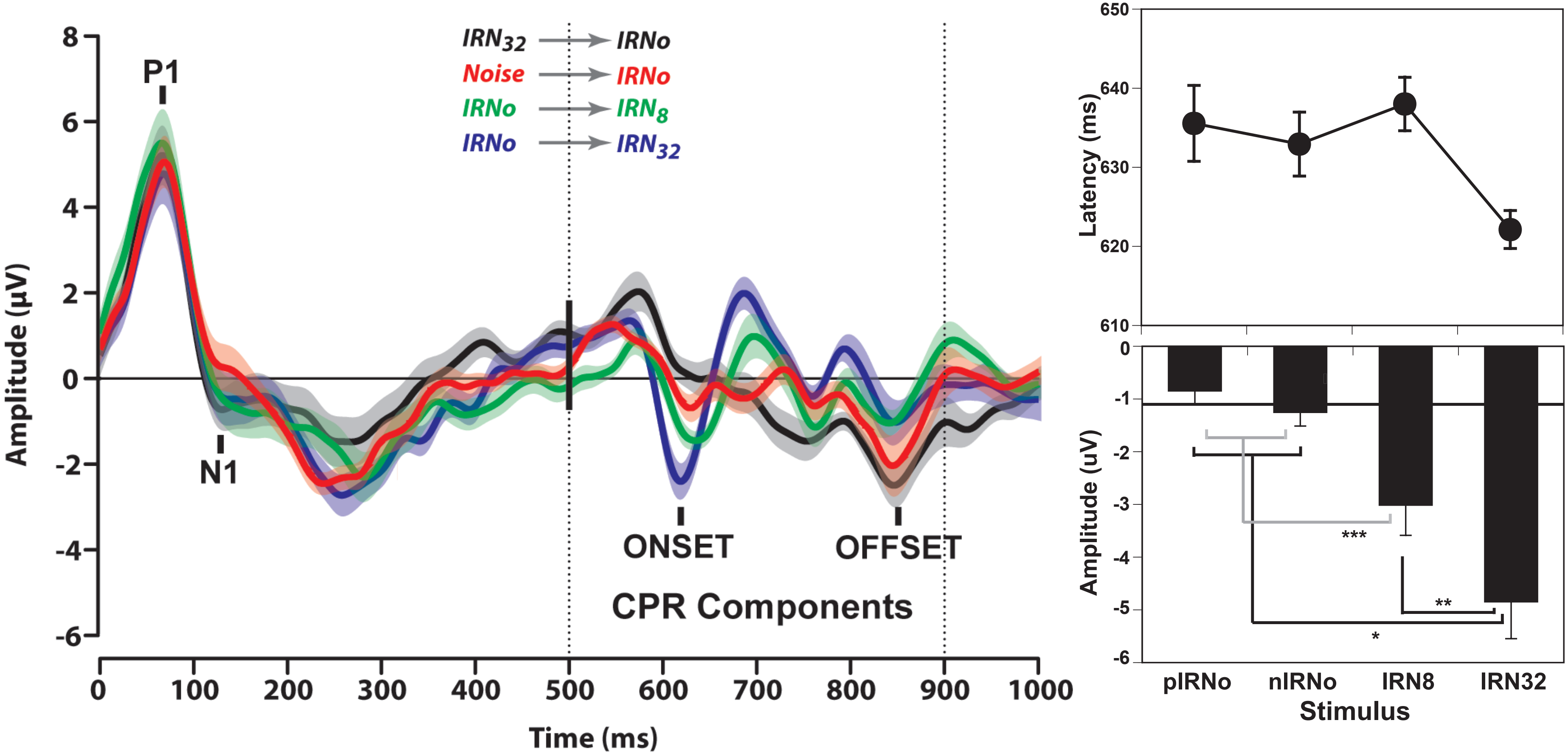
Krishnan et al., Neuropsychologia (2012)

Extraction of brainstem and cortical pitch response



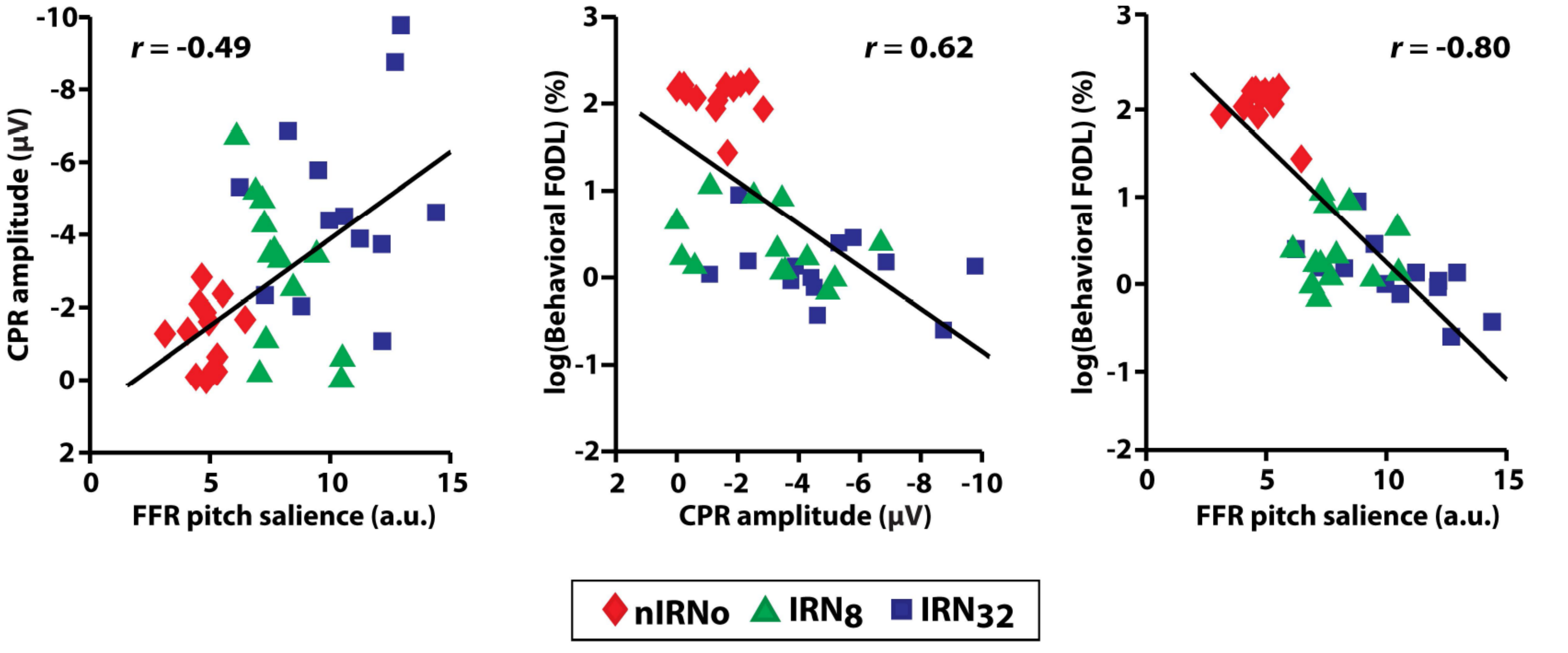
CPR-Average: EEG down-sampled to 2048Hz; Analysis epoch: 1200 ms including 100 ms prestimulus; 1000 sweeps

Pitch Onset Response is sensitive to change in pitch salience



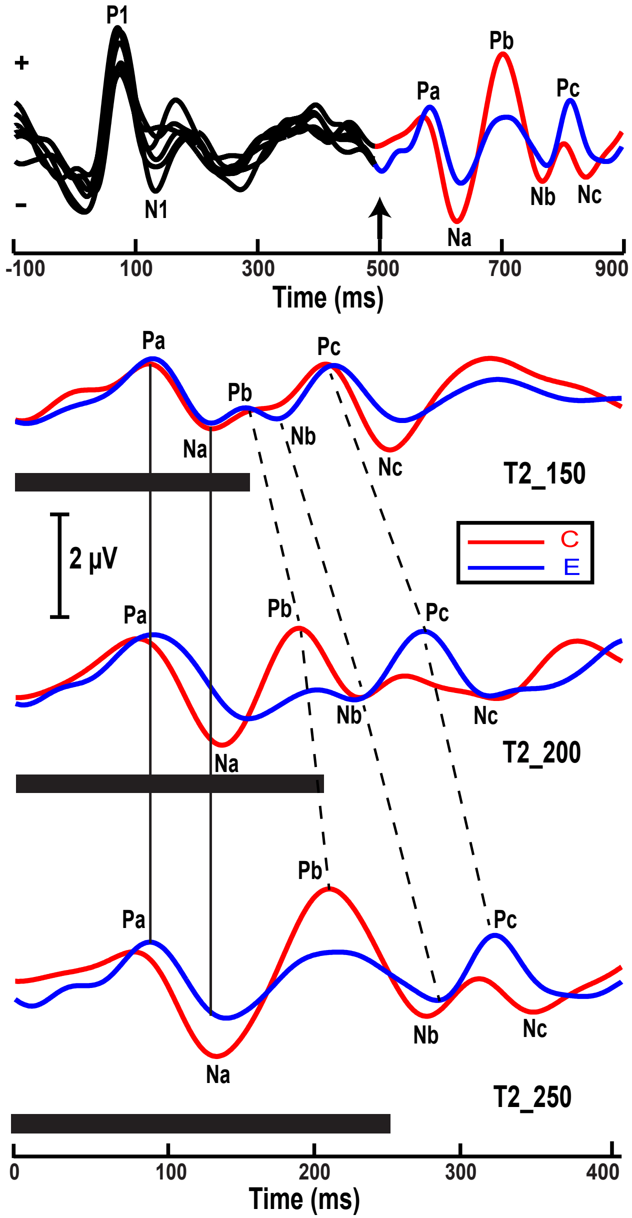
Since there are multiple transient components of the POR
We chose to name our response as the Cortical Pitch Response (CPR)

Comparison between neural and behavioral data



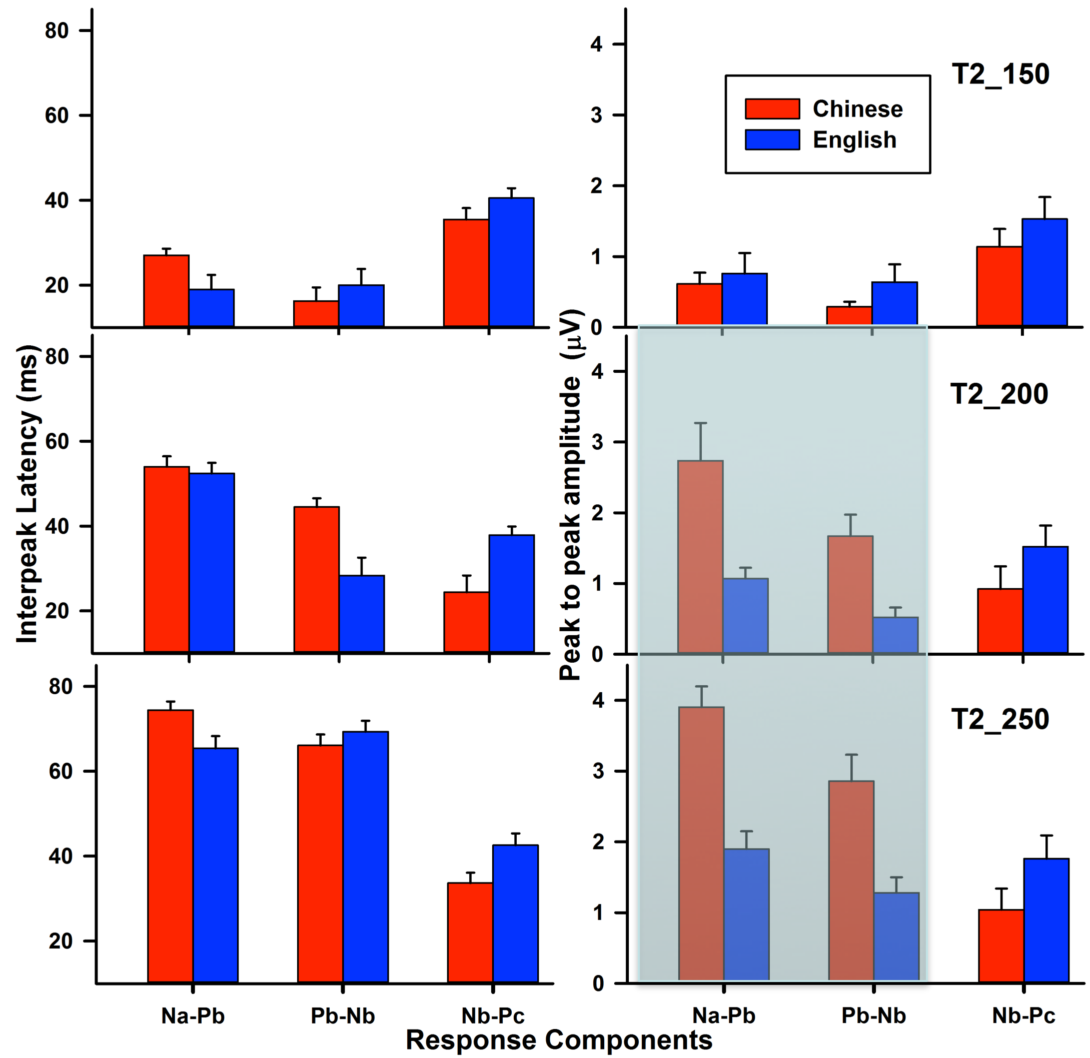
FFR vs CPR; CPR vs F0 DL; and FFR vs F0 DL are correlated suggesting that behavioral pitch responses were well predicted by both neural responses. These results suggest smaller F0 DLs are associated with more robust encoding at brainstem and cortical levels

CPR: Experience-dependent enhancement



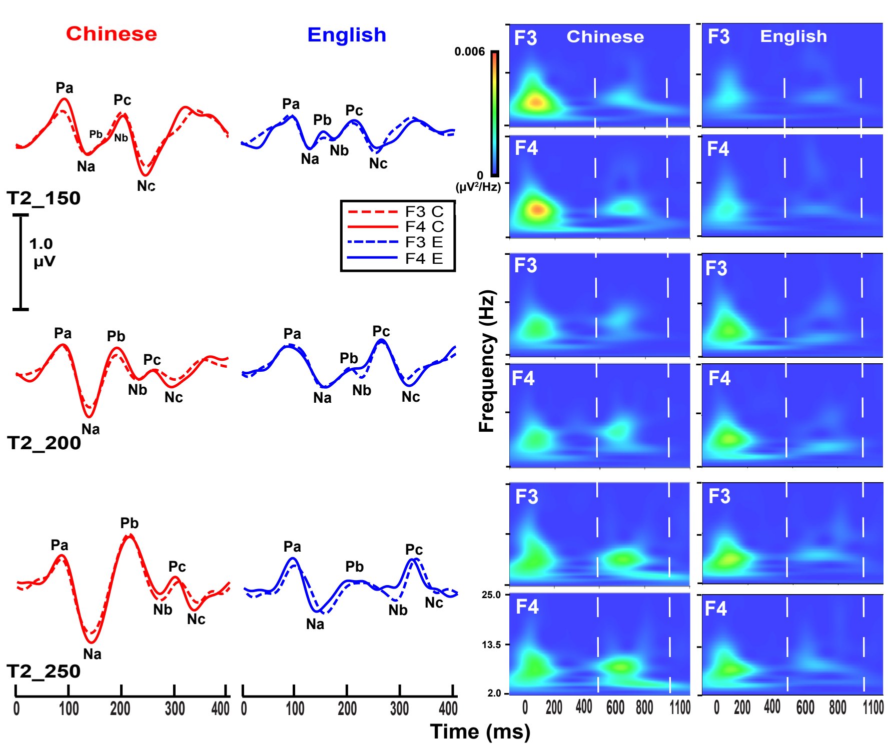
No systematic latency effects

For both Na-Pb & Pb-Nb, C>E

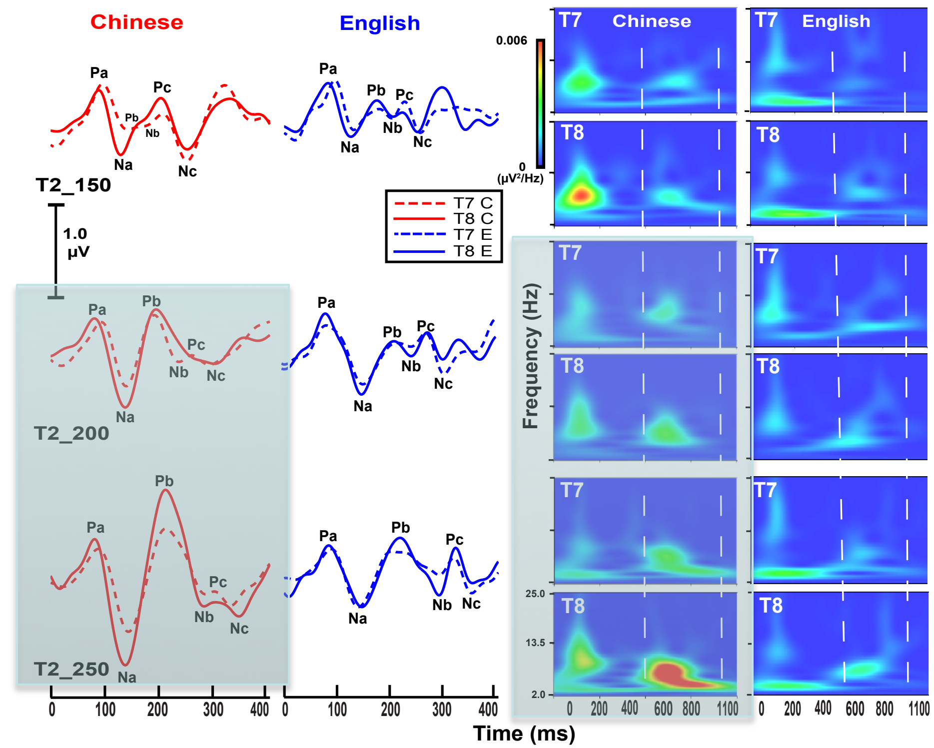


Lateralization only at temporal electrode sites

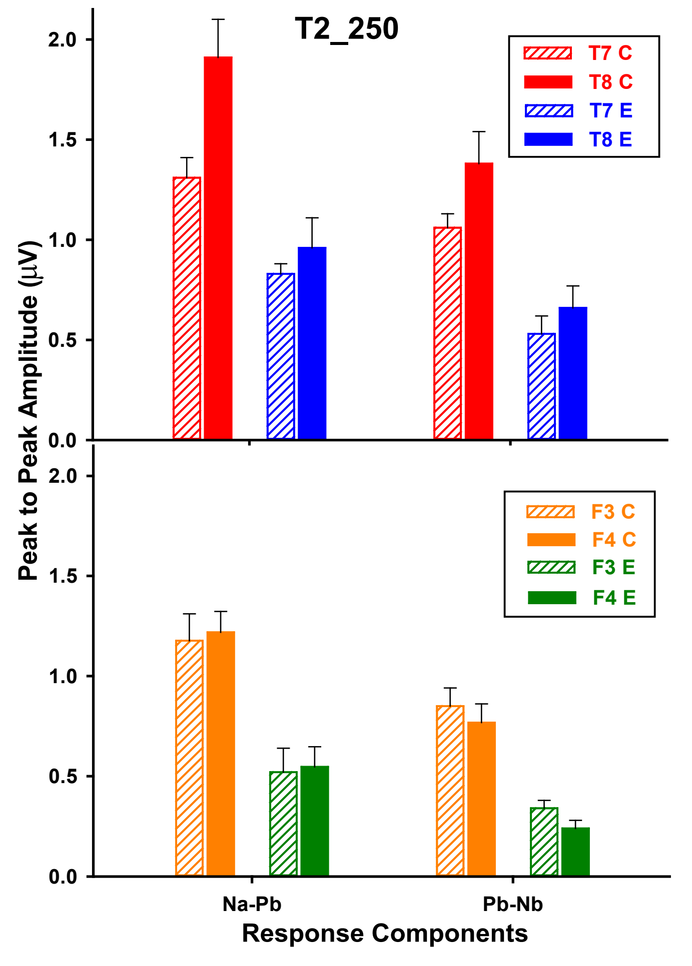
F3/F4: No asymmetry for either group



T7/T8: Stimulus-dependent rightward asymmetry only for the Chinese

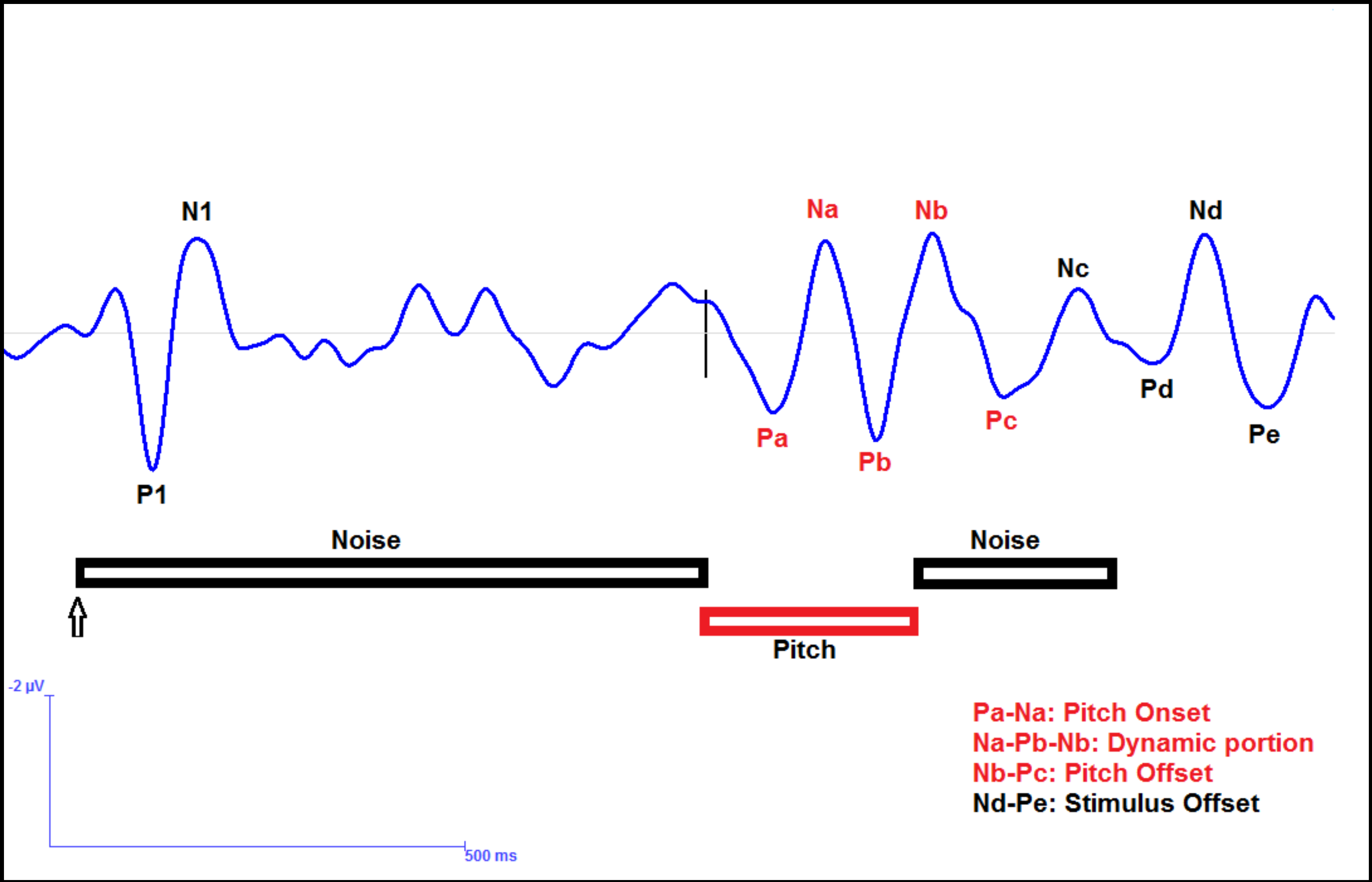


Stimulus-dependent rightward asymmetry for Chinese only for T2-200 and more robust effect for T2-250.



T2_250
T7 C
T8 C
T7 E
T8 E
F3 C
F4 C
F3 E
F4 E
Peak to Peak Amplitude (µV)
2.0
1.5
1.0
0.5
0.0
Na-Pb
Pb-Nb
Response Components

Isolating pitch related components from stimulus offset component



Correlations between Fz components and pitch acceleration.

Component	Interpeak Latency	Peak-to-peak Amplitude[a]	Peak-to-peak Amplitude[b]
Pa-Na	-.407 (.0255)	-.696 (<.0001)	-.411 (.0240)
Na-Pb	-.778 (<.0001)	-.954 (<.0001)	-.780 (<.0001)
Pb-Nb	-.777 (<.0001)	-.932 (<.0001)	-.776 (<.0001)
Nb-Pc	.053 (.7797)	.056 (.5621)	.056 (.7671)

Note: Values in parentheses represent levels of significance.

[a]Average acceleration from minimum to maximum; [b]Instantaneous acceleration at 80ms after pitch onset

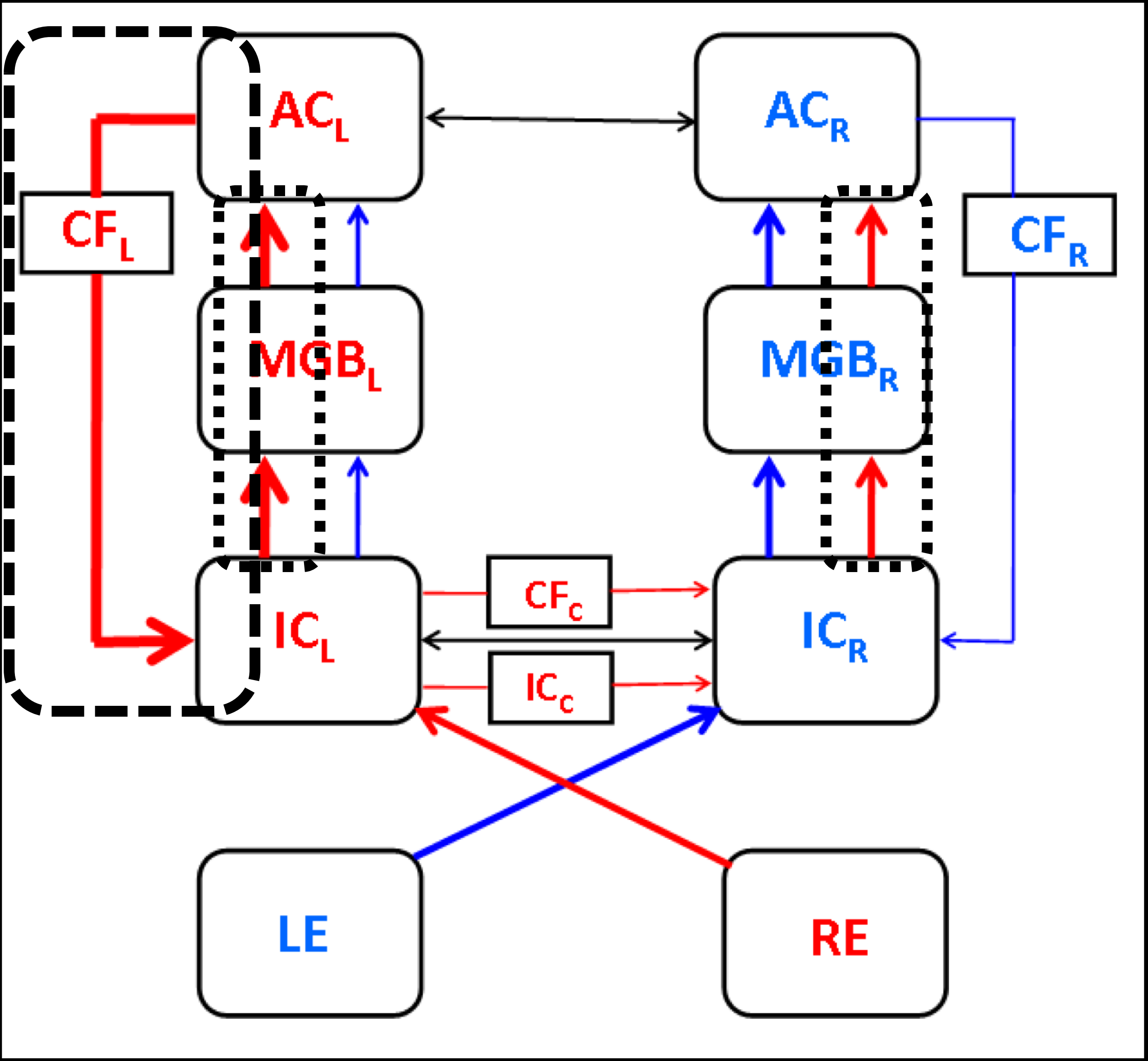
On Hierarchical processing for pitch (Patterson et al., 2002)

- **Stage 1**.Extraction of time-interval information from neural firing pattern in the AN and construction of interval histograms in the IC and Thalamus

- **Stage 2**. Determining the specific value of pitch and its salience from the interval histograms- probably in lateral HG (creates summary histograms and locates the first peak)

- **Stage 3.** Determine continuous (tonal language) and discrete (music) pitch changes and tracking them- beyond PAC in STG or PP. this is were asymmetries emerge!

Mechanisms: Corticofugal pathways in experience-dependent pitch encoding



Experience which engages cerebral cortex shapes subcortical circuitry via corticofugal (CF) modulation

IC, inf. colliculus

AC, auditory cortex

MGB, medial geniculate body

LE, left ear

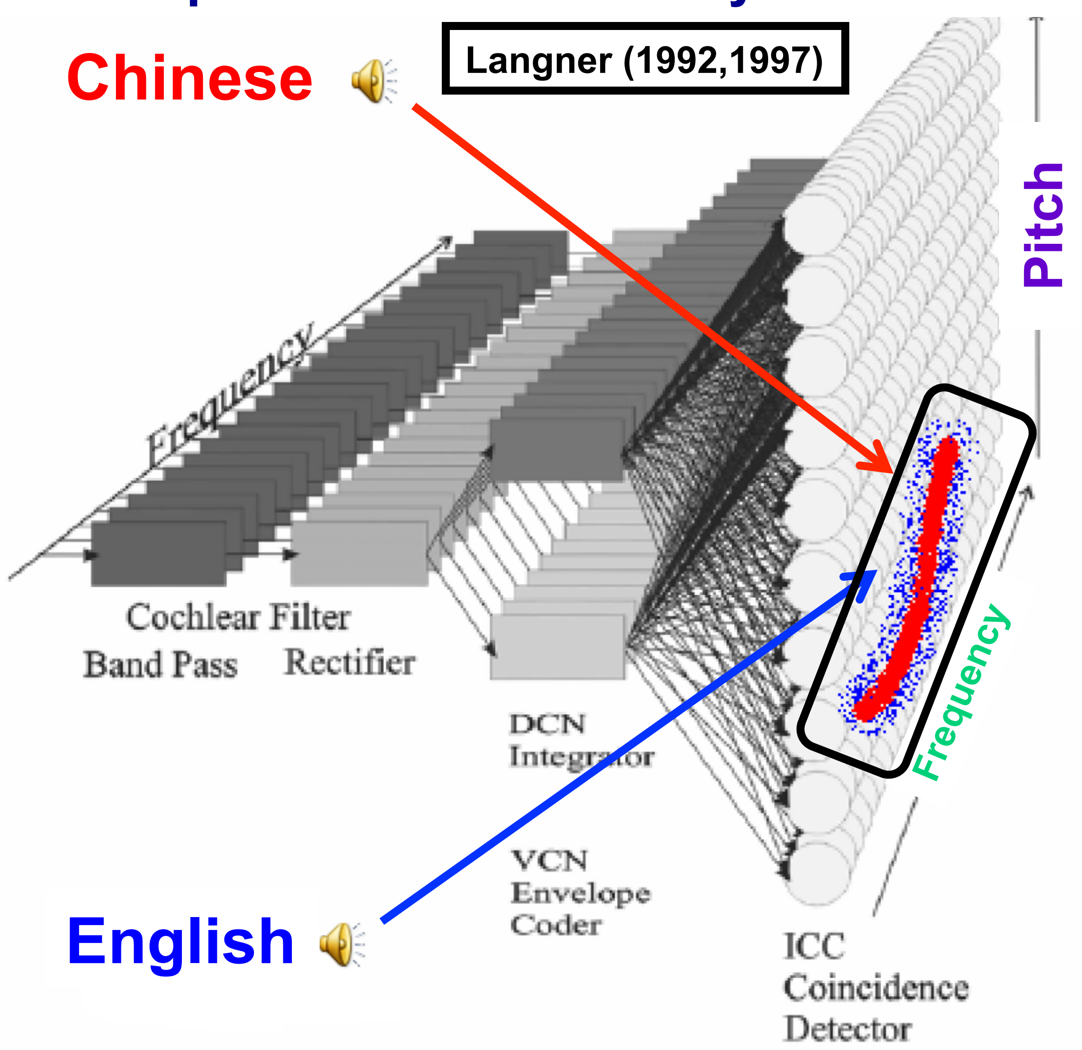
RE, right ear

CF_L, left corticofugal

Krishnan & Gandour *Brain and Language* (2009)

Mechanisms: Local brainstem mechanisms underlying experience-dependent encoding of pitch-relevant information

Temporal correlation analysis model

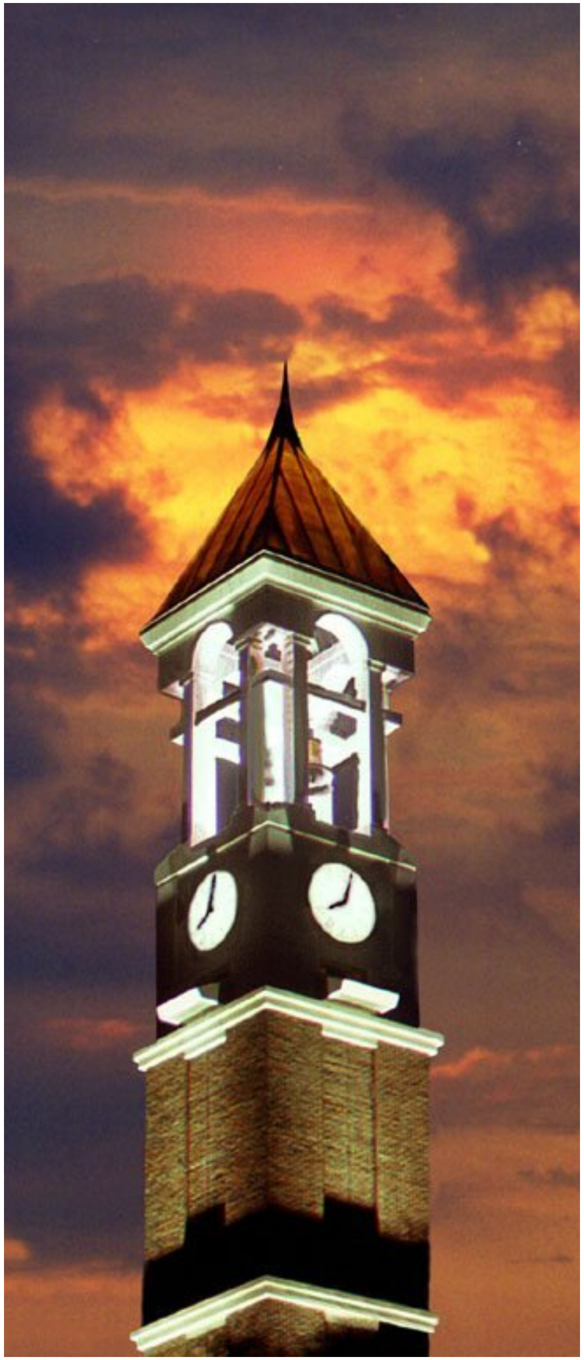


Pitch is organized orthogonal to **frequency** in the IC neurons

Best modulation **frequency** neurons along the **pitch** axis extract pitch relevant periodicities

Long-term experience could sharp tuning, improve coherence of neural-phase-locking, and increase synaptic efficiency

Krishnan & Gandour *Brain and Language* (2009)



Auditory Electrophysiology Lab

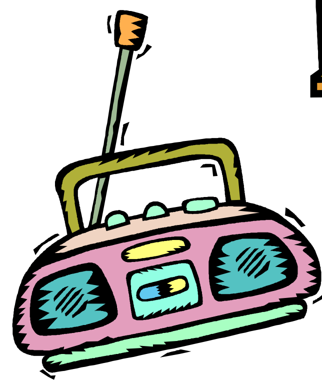
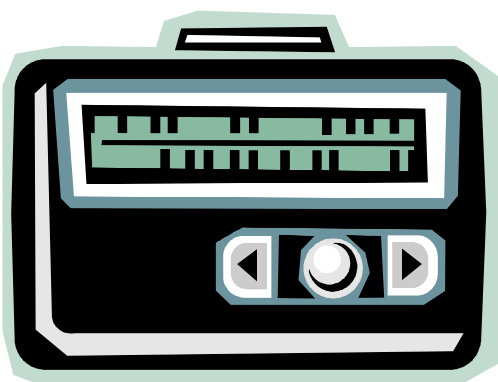
- Ravi Krishnan
- Jack Gandour
- Jayaganesh Swaminathan*
- Gavin Bidelman*
- Chris Smalt*
- Sharada Ananthakrishnan*
- Jill Wendell
- Suresh Chandan
- * Students who have graduated

PURDUE
UNIVERSITY

Our mantra for studying tones





Everybody must get sTONED!