Listening with Cochlear Implants

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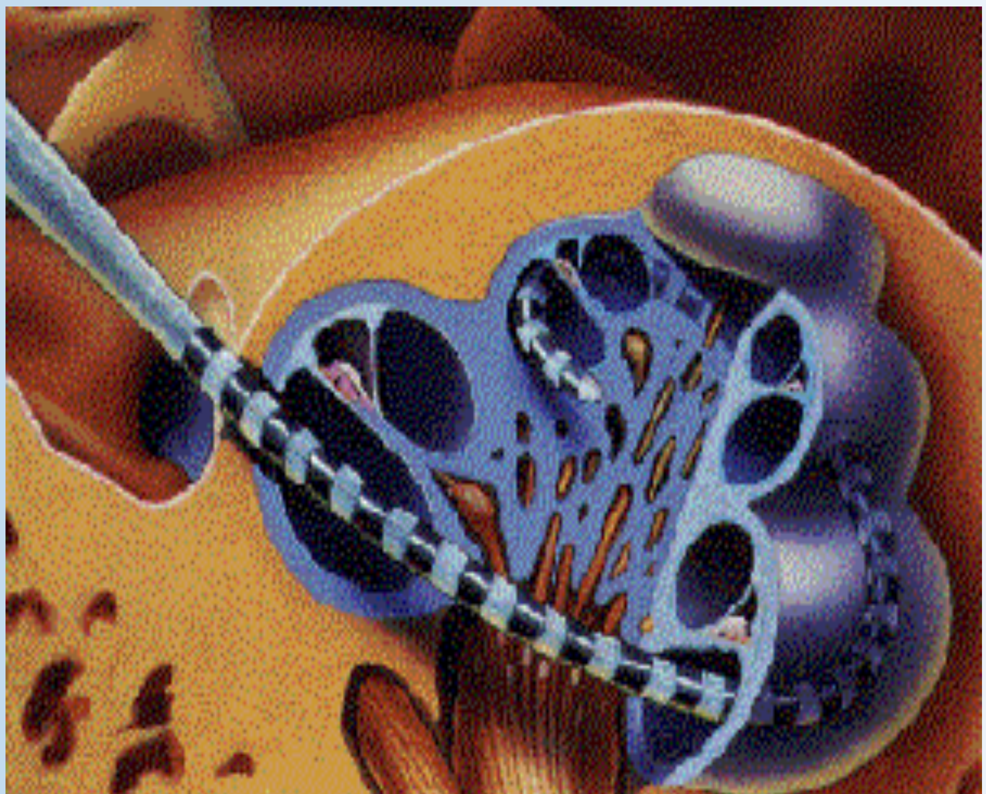
What is a cochlear implant?

A cochlear implant has tiny *electrodes* which send out electrical signals to the auditory nerves in the cochlea. The idea is to try and mimic the function of the hair cells.



OBJECTIVE: To restore hearing by electrically stimulating residual auditory nerve neurons with *sound-appropriate* signals.

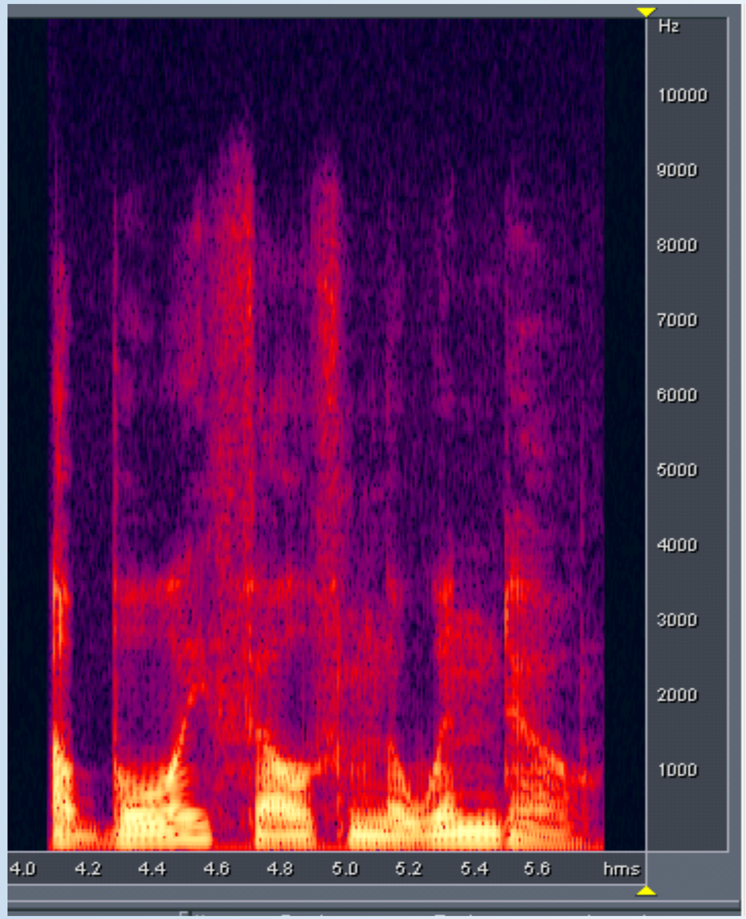
The brain must be able to make sense out of the stimulus.

The auditory system expects signals going from the auditory nerve to the brain to be distributed across the tonotopic axis according to the spectrum of the incoming sound.

Our prosthesis needs to use the place code if it has to talk to the brain.

Sounds are rich with complexity in their frequency structure. The cochlea does a great job of representing this complexity to the brain.

Spectrogram of a sentence



frequency

time

In fact, for a given sound, the time variation of the pattern of excitation on the basiliar membrane looks a lot like the spectrogram of the sound.

A cochlear implant needs to do all that work. It has to show the brain the spectrogram of the sound.

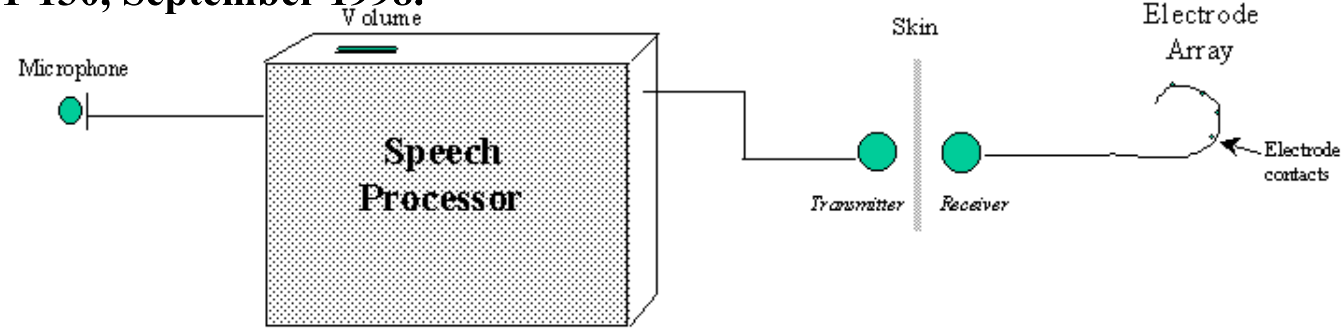
There are three aspects of the pattern that need to be coded:

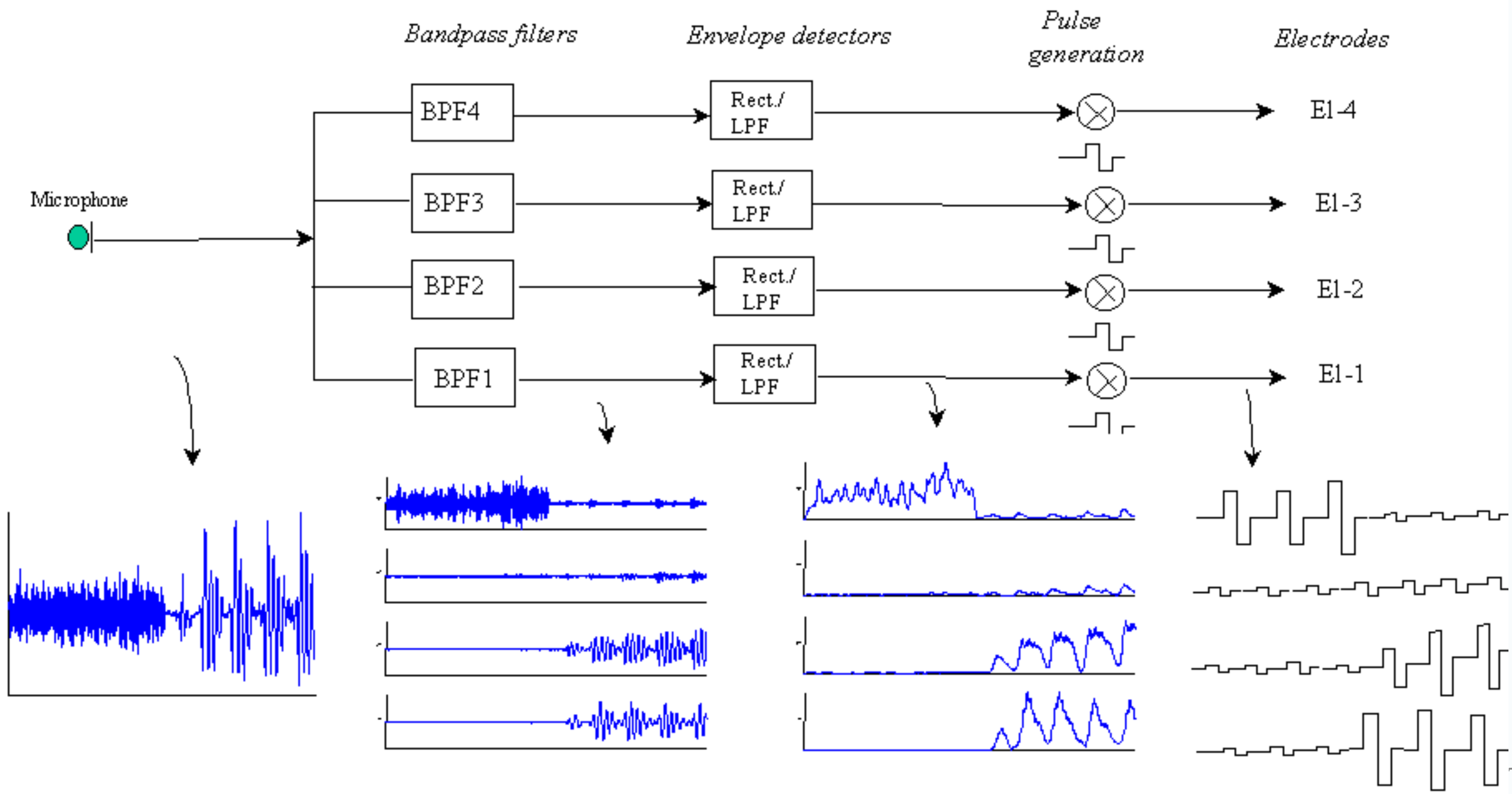
1. How it changes in frequency;

2. How it changes in time;

3. How it changes in intensity.

***"Mimicking the Human Ear" Philip Loizou, IEEE Signal Processing Magazine*, pages 101-130, September 1998.**





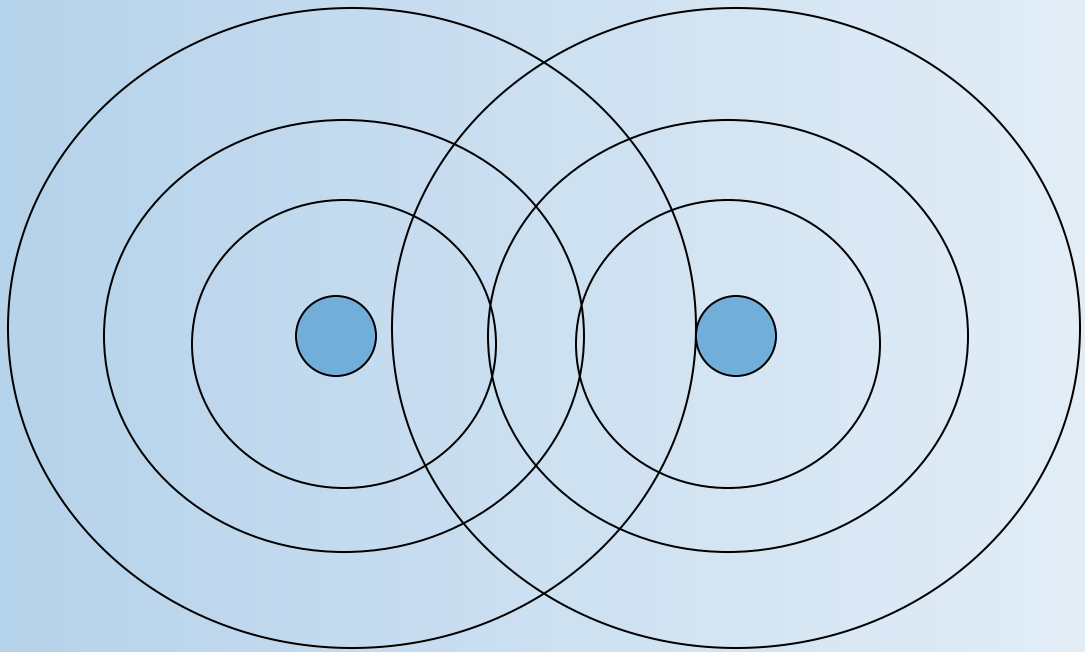
Channel-Interaction

When you stimulate two electrodes with information from two frequency regions, you want that information to remain separate, not to blend together.

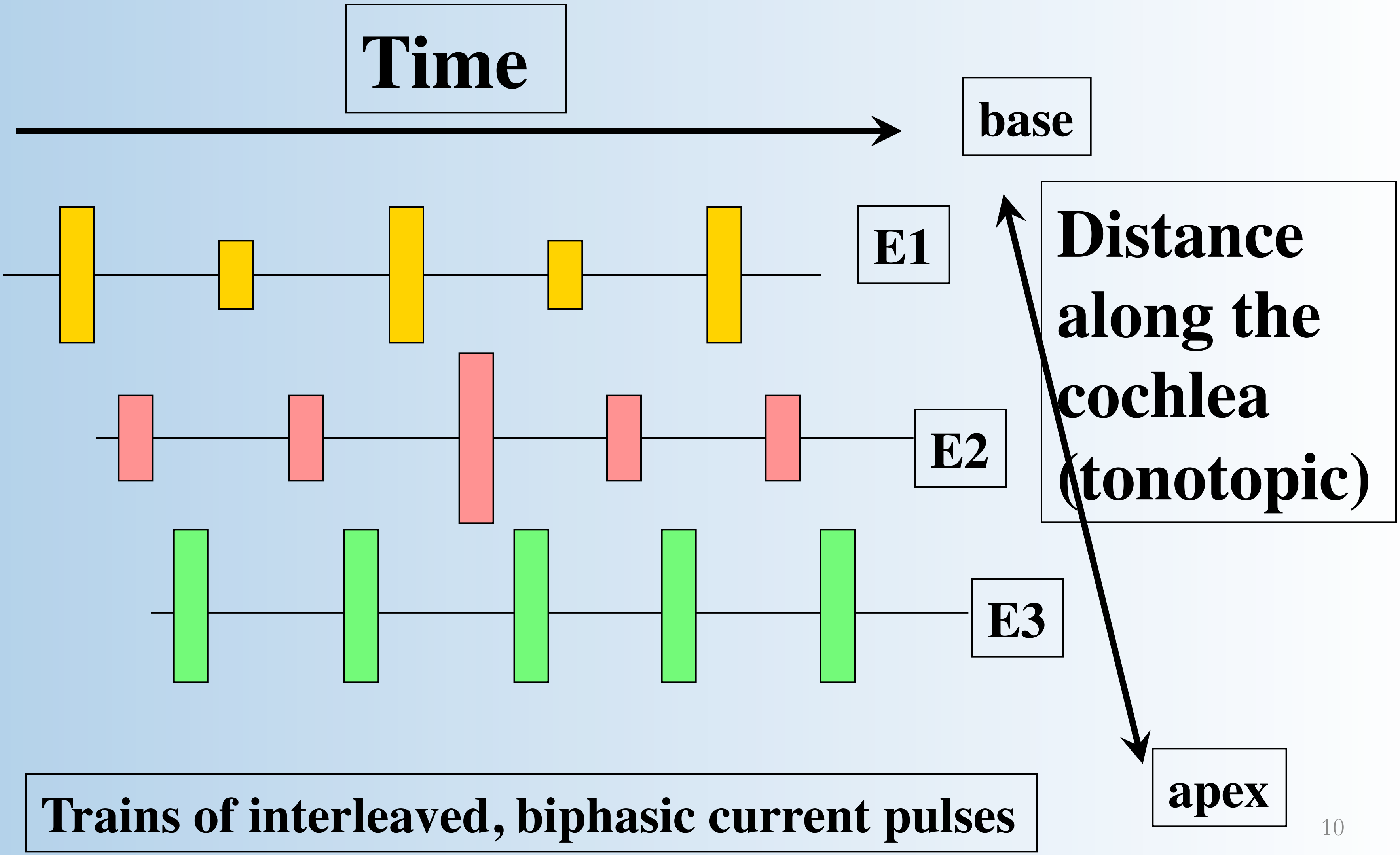
Channel-interaction means cross-talk between channels, when the electric fields overlap a lot spatially. This means that the neurons in the region of overlap are responding to both channels.

This blurs the spectral image being sent to the brain.

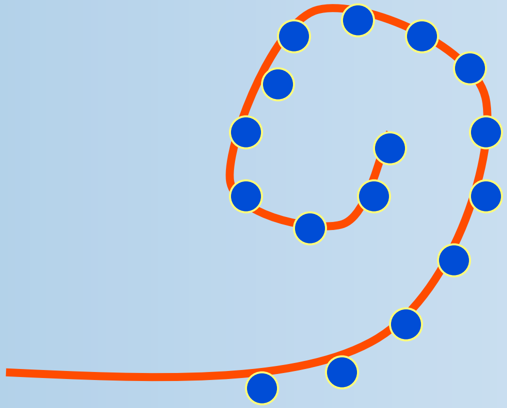
If signals are presented to two electrodes simultaneously, their currents can add and subtract, creating interference patterns just like overlapping sound fields. This distorts the signal going to the nerve.



Continuous-interleaved sampling avoids peripheral overlap



Channels and electrodes in cochlear implants



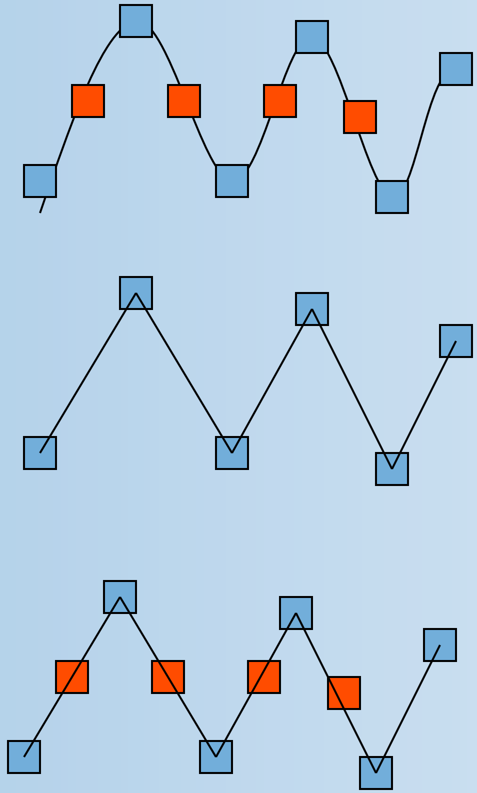
Question:

Does N electrodes = N channels of frequency information?

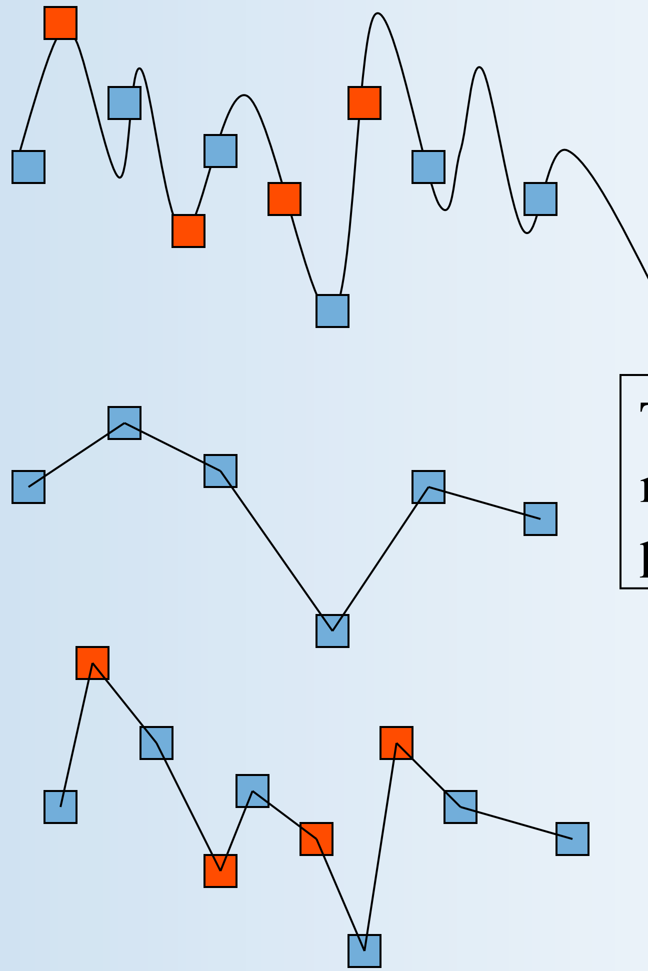
Yes ➔Loss-less system
No➔ Loss of information

Coding the frequency pattern

To generate a pattern, you need more than one point. If it’s a very detailed pattern, you need lots of points. How many you need depends on the pattern.



This pattern doesn’t need so many sampling points.



This pattern needs more sampling points.

The larger the number of points, the better your resolution.

To sample finer-grained patterns, you need more resolution.

(This works for time patterns too – temporal resolution)

In cochlear implants, we have the problem of poor resolution because we have only a limited number of electrodes. Another problem is that the number of surviving neurons is unknown and varies from patient to patient.

To make matters worse, the current sent out by each electrode spreads out broadly, so our pattern is smeared out.

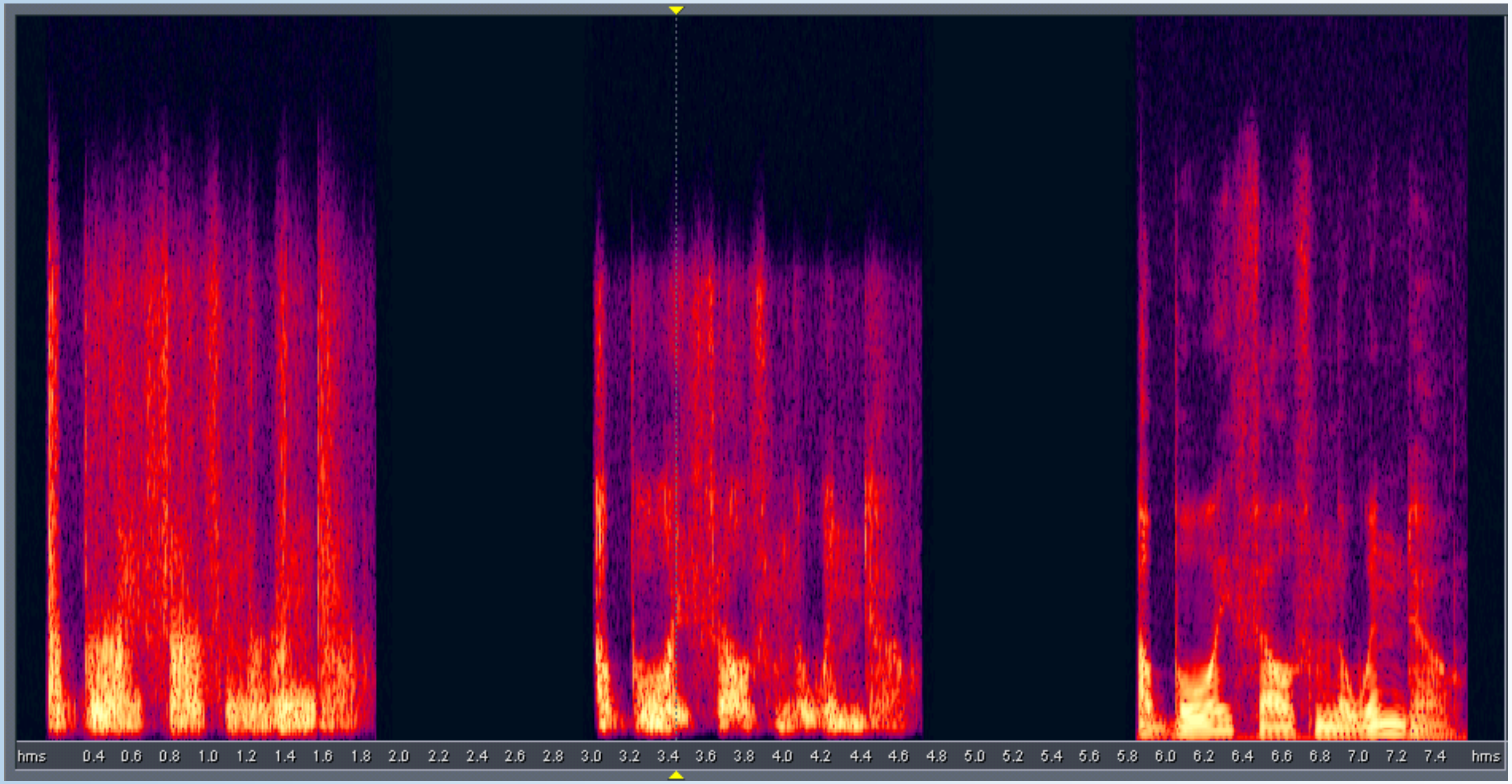
So you have a representation of the original spectrum that is

a) Poorly sampled and

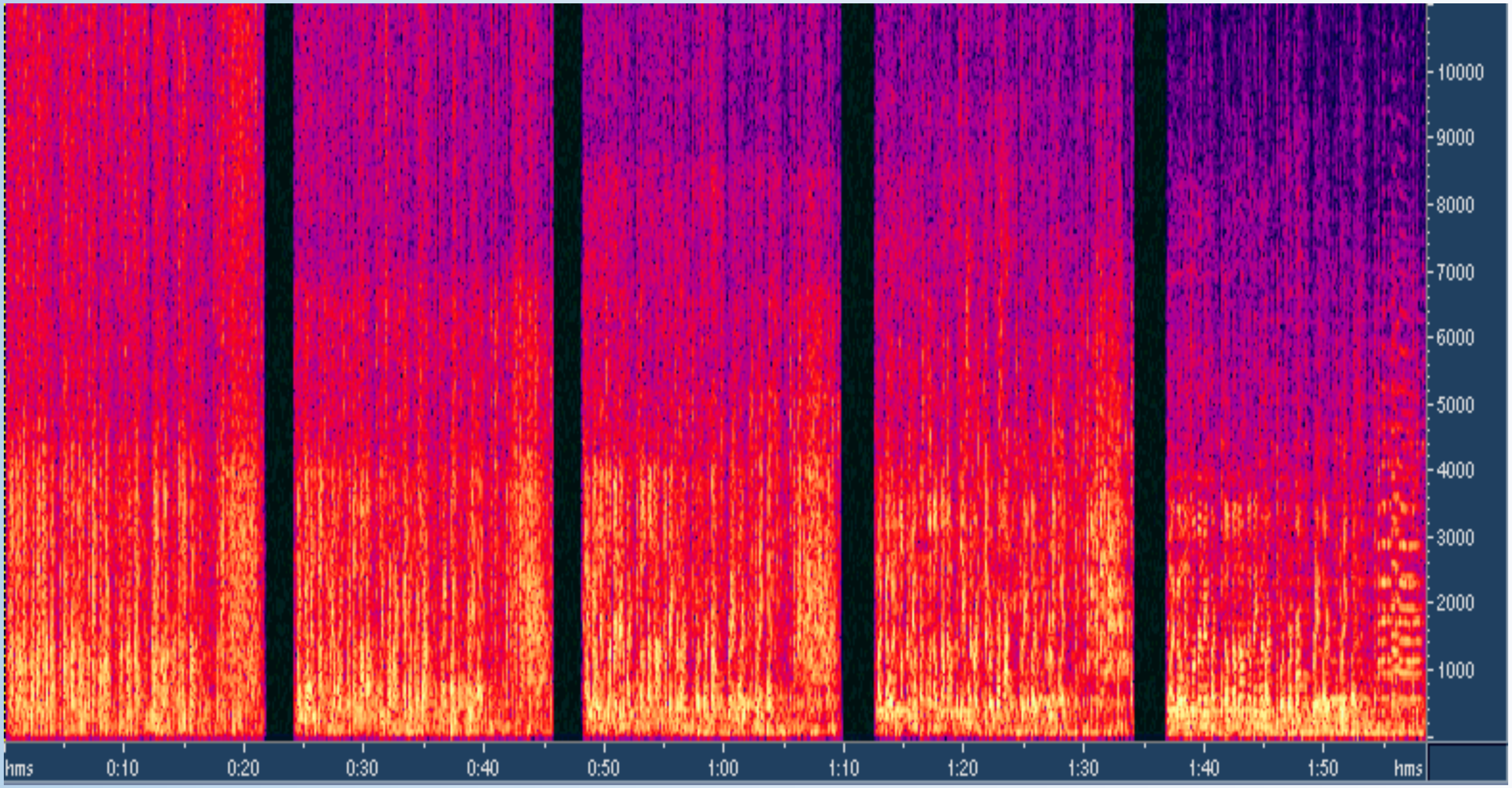
b) Smeared out, or blurred.

How would these distortions affect the perception of speech?

What about music?



4 ch **16 ch** **Unprocessed**



4 ch **8 ch** **16 ch** **32 ch** **Unprocessed**

So we see that speech is much easier to understand with only 4 channels than music.

Part of this has to do with speech itself, and its relationship to the brain. Important features of the speech pattern can withstand a lot of distortion.

On the other hand, the appreciation of music requires “getting” the fine details of the pattern (the “fine structure”).

Courtesy of Bob Shannon

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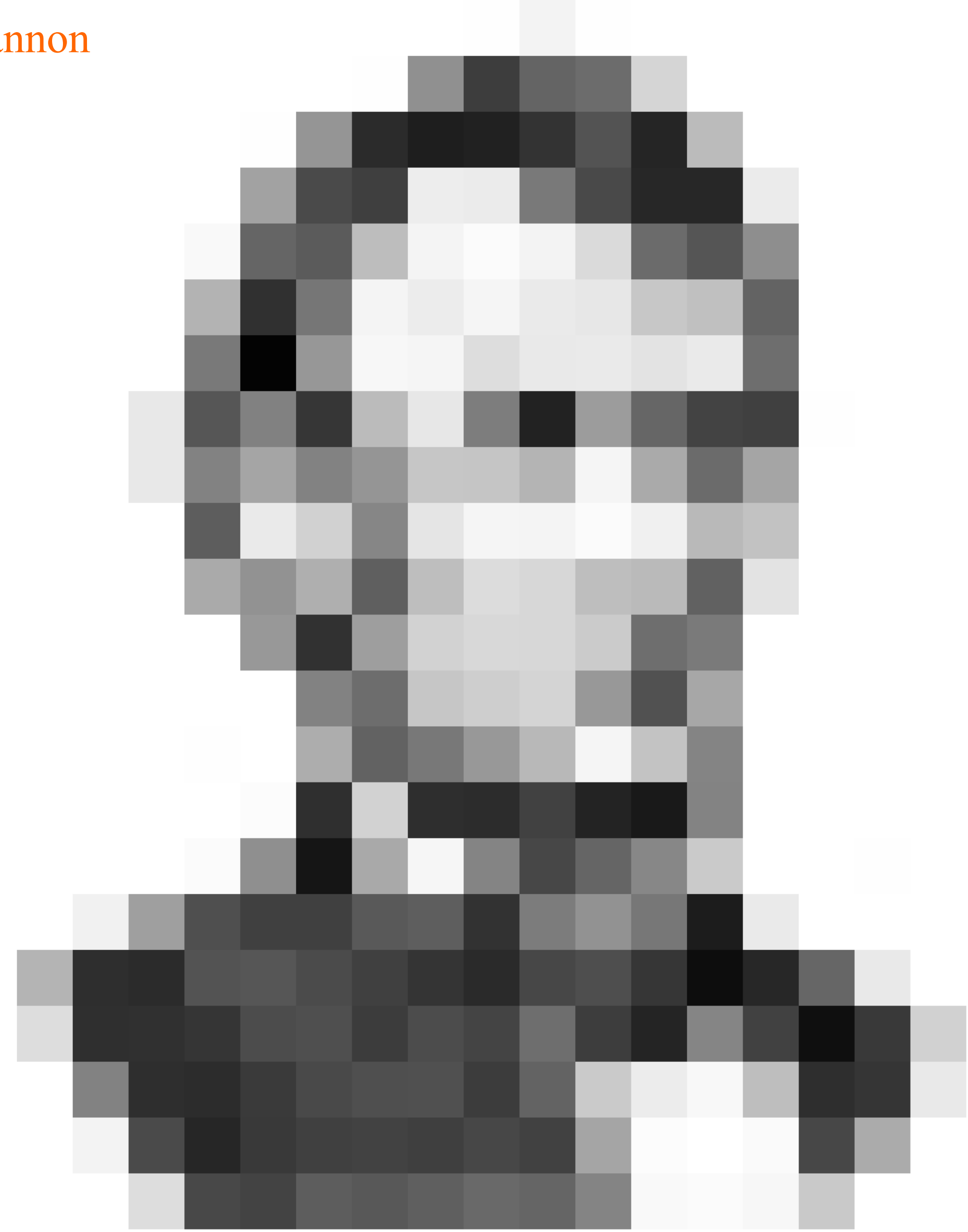

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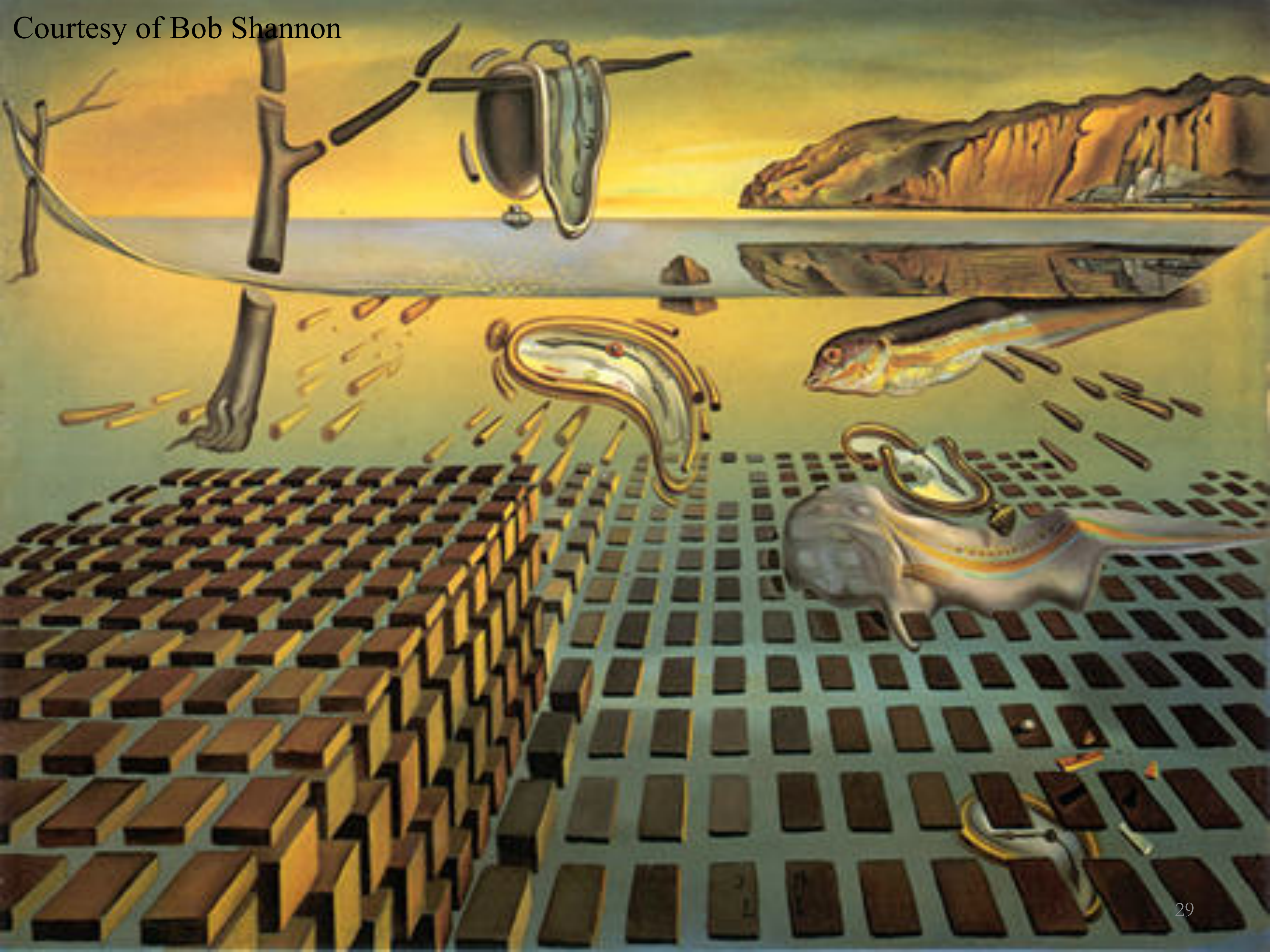
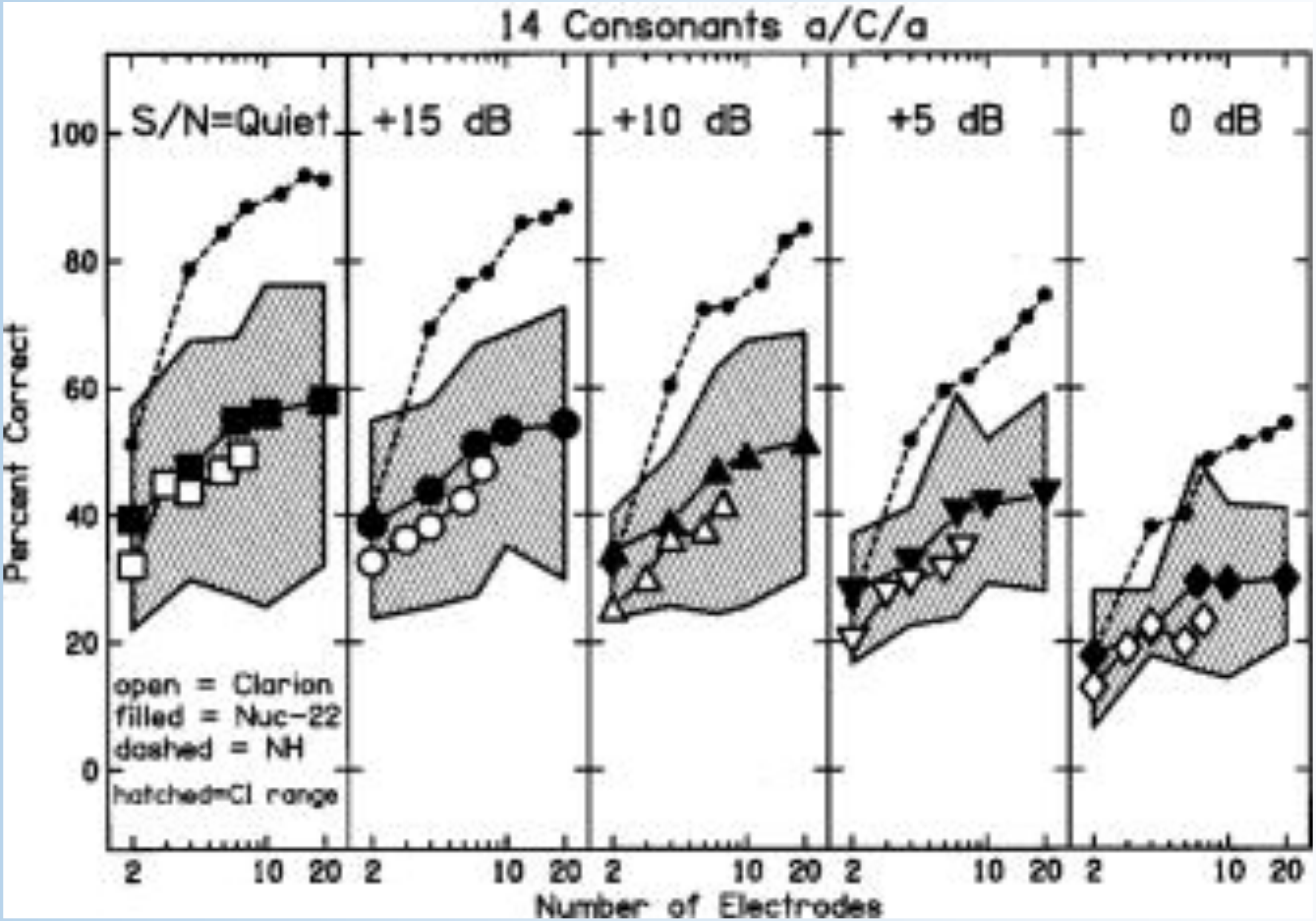




Friesen, Shannon, Baskent and Wang (2001, JASA 110(2), 1150-1163)

The normal cochlea has something like 3,500 inner hair cells. Compare that with 16 – 22 electrodes, or sampling points.

Notice that even with speech that can be understood, the quality is really degraded with a small number of channels. The larger the number of channels, the better the quality.

These problems are even more exacerbated when listening in background noise, which is a major challenge for cochlear implant listeners.

CI patients likely expend significant cognitive effort in reconstructing the spoken message.

Adaptation and brain plasticity, and prelingual deafness

The **duration of profound deafness** prior to implantation is an important factor in success with a cochlear implant.

A big factor in the success of CIs is the **adaptability of the brain**.

This takes:

i) some previous experience with hearing – the brain has to have an idea of what it's looking for (pre-lingually deaf adult CI recipients who have had no experience with sounds growing up face a greater challenge than post-lingually deaf CI recipients) and

ii) training with the device.

Age, Cognition, Language: top-down and bottom-up interactions

Developing children (prelingually deaf)

- ***Neural plasticity and adaptation – age, device experience, linguistic environment***
- ***Cognitive and linguistic development***

Middle-aged and older adults (post-lingually deaf)

- ***Reduced neural plasticity***
- ***Cognitive decline***
- ***Decline in auditory coding***
- ***Strong linguistic skills***

Voice pitch or F0…the final frontier?

Cochlear implant listeners have basically two complaints:

1. The sound quality could stand to improve: music sounds bad.

2. Listening in noise is a major problem.

BOTH ISSUES MIGHT BE RESOLVED BY PROVIDING IMPROVED REPRESENTATION OF PITCH!

- One consequence of the loss of voice pitch information: natural intonations in speech are degraded
- This affects emotional communications and lexical tone recognition

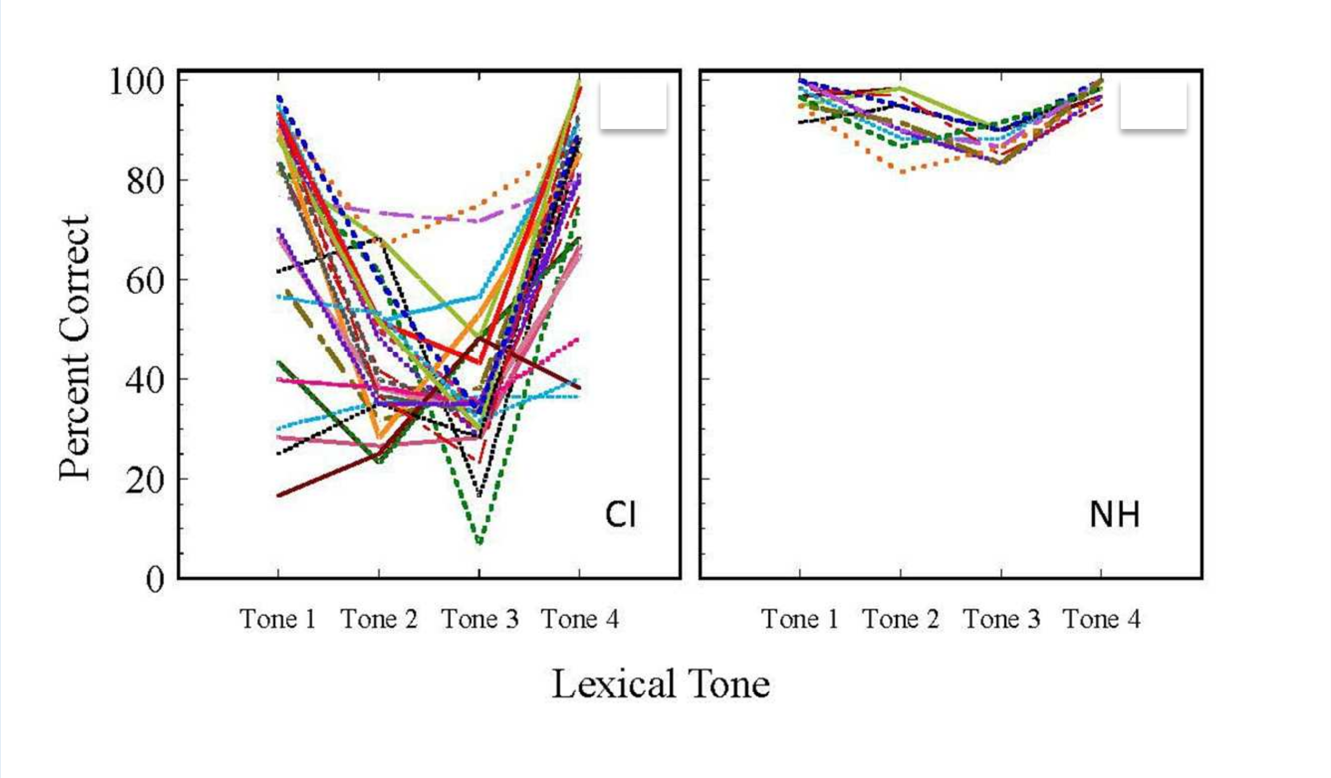
Examples of lexical tones

Tone	Lexical	Pin-Yin	Meaning	stimuli
T1	八	*ba*	‘eight’	
T2	拔	*ba* ´	‘pull out’	
T3	把	*ba* ˇ	‘to hold’	
T4	爸	*ba* `	‘father’	

Lexical-Tone-Driven Natural Word Recognition by Mandarin-Speaking Children in Taiwan

Peng et al., 2017 JSLHR

27 children with CIs
11 children with NH



A growing body of literature shows deficits in both perception and production of emotions by CI listeners

- Deficits in vocal emotion recognition by adults and children with CIs:
  - *Luo et al., 2007; Hopyan-Misakyan et al., 2009; Schorr et al., 2005; Most & Aviner, 2009; Most & Michaelis, 2012; Chatterjee et al, 2015*

- Facial emotion recognition/Emotion Understanding in children with CIs:
  - *Hopyan-Misakyan et al, 2009; Wang et al., 2011; Wiefferink et al 2013; Fengler et al 2017*

- Imitative production of happy and sad vocal emotions by children with CIs
  - *Nakata et al., 2012; Wang et al., 2013*

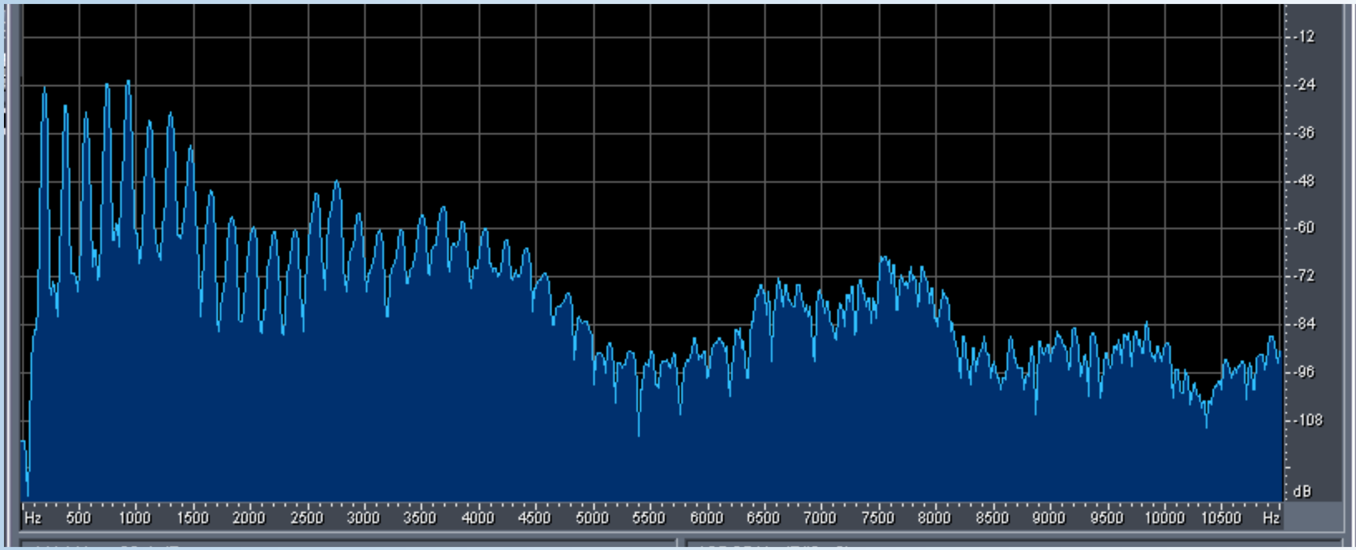
Vocal Emotion Recognition

- 12 sentences, 5 emotion each: *happy, angry, sad, neutral, scared (child-directed speech)*
- *1 female and 1 male talker (selected from pilot with 4 talkers)*

Happy Angry Neutral Sad Scared

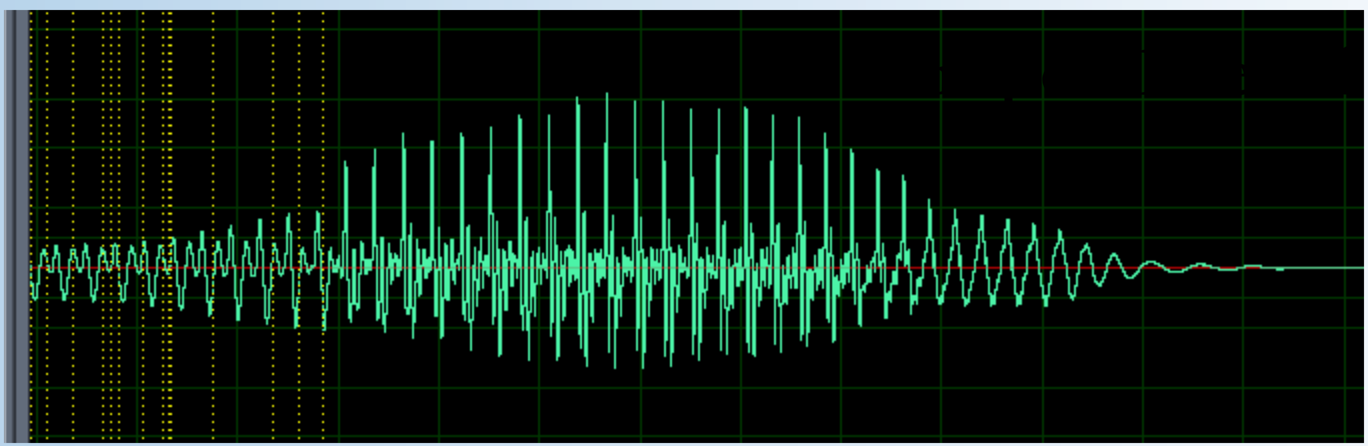
COMPLEX PITCH CUES IN NH AND CIs

Amplitude

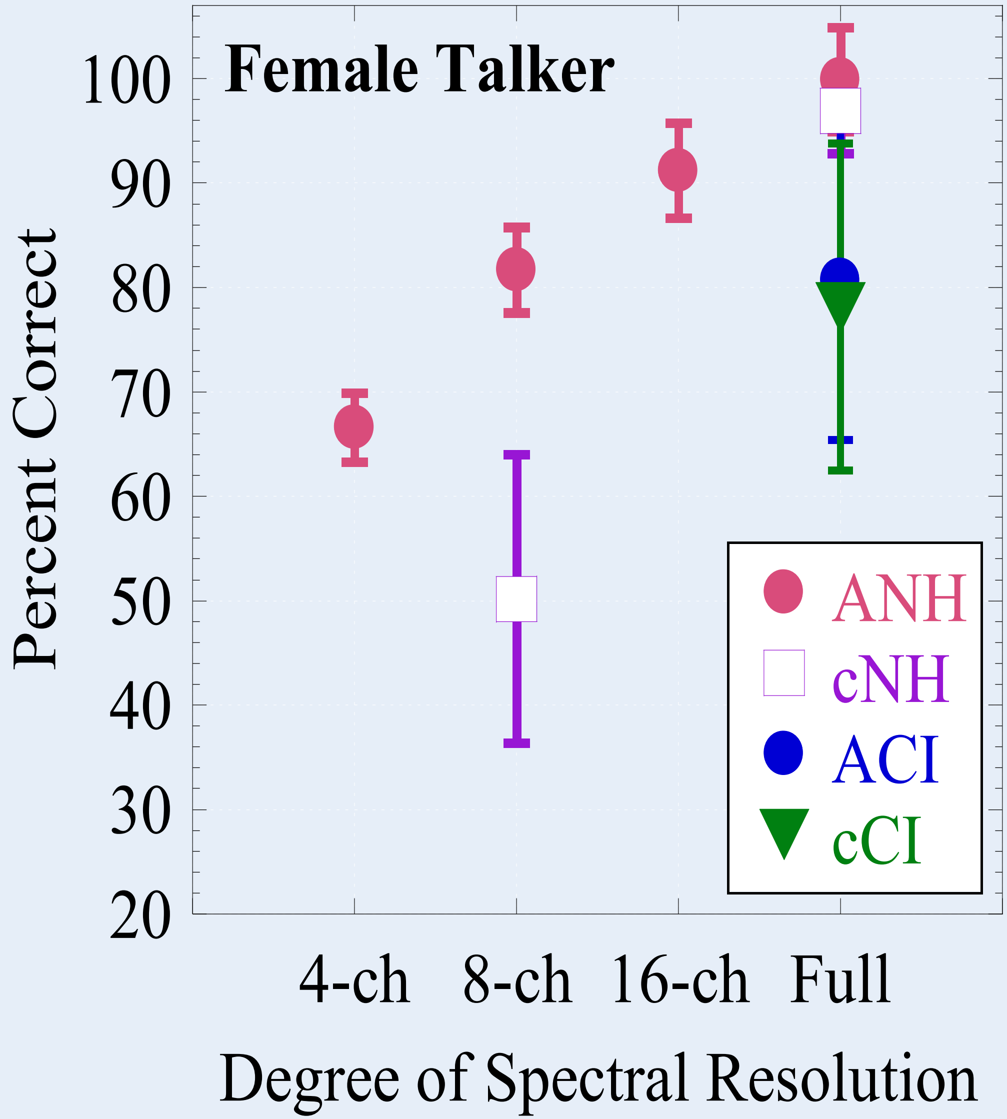


Frequency

Amplitude



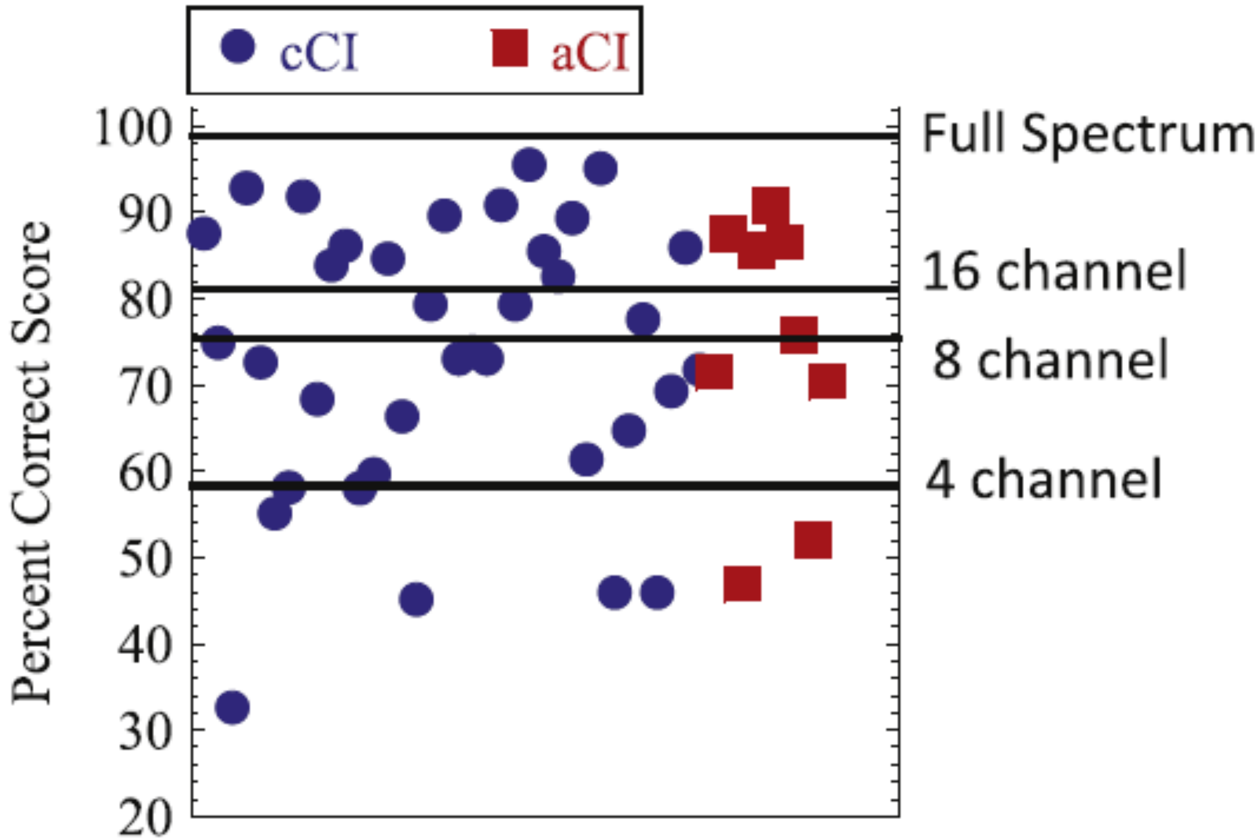
Time



- 10 NH adults
- 9 CI adults
- 31 NH children (6.38 – 18.76 years, mean age 10.76 years).
- 36 CI children (6.83 – 18.44 years, mean age 12. 15 yrs, mean dur. dev. 8.76 yrs.)

Chatterjee et al., 2015 (Hearing Res)

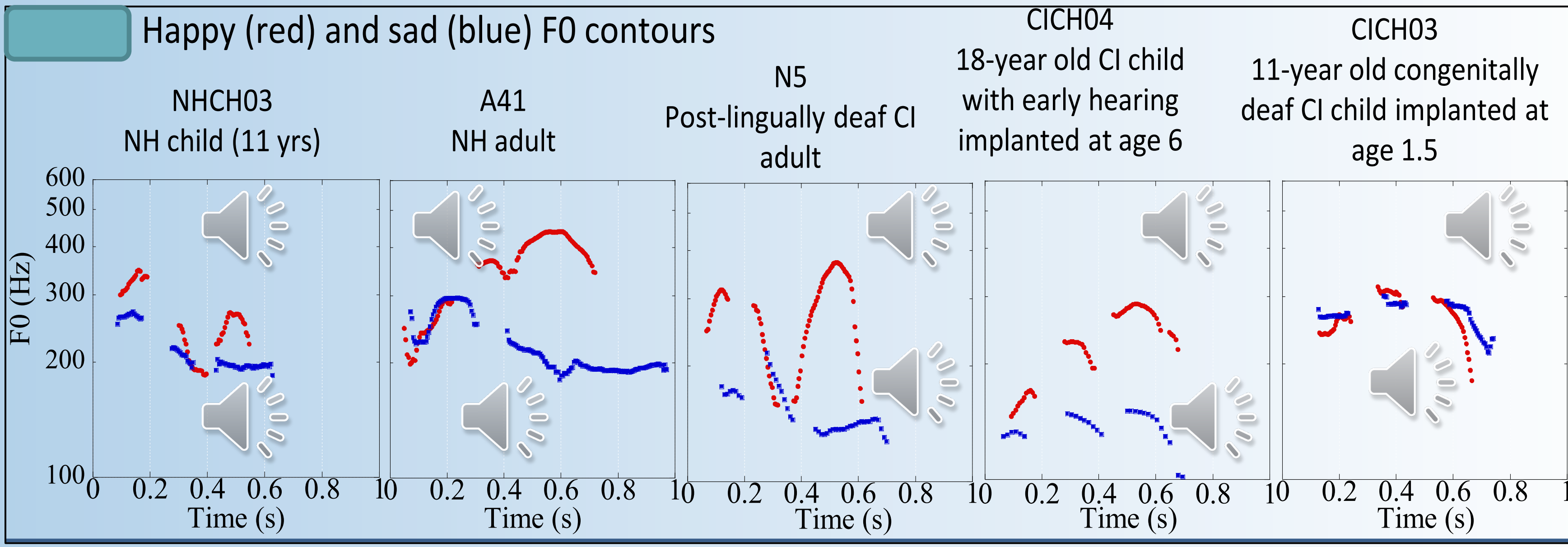
A Closer Look At Individual Data



Chatterjee et al., 2015 (Hearing Res)

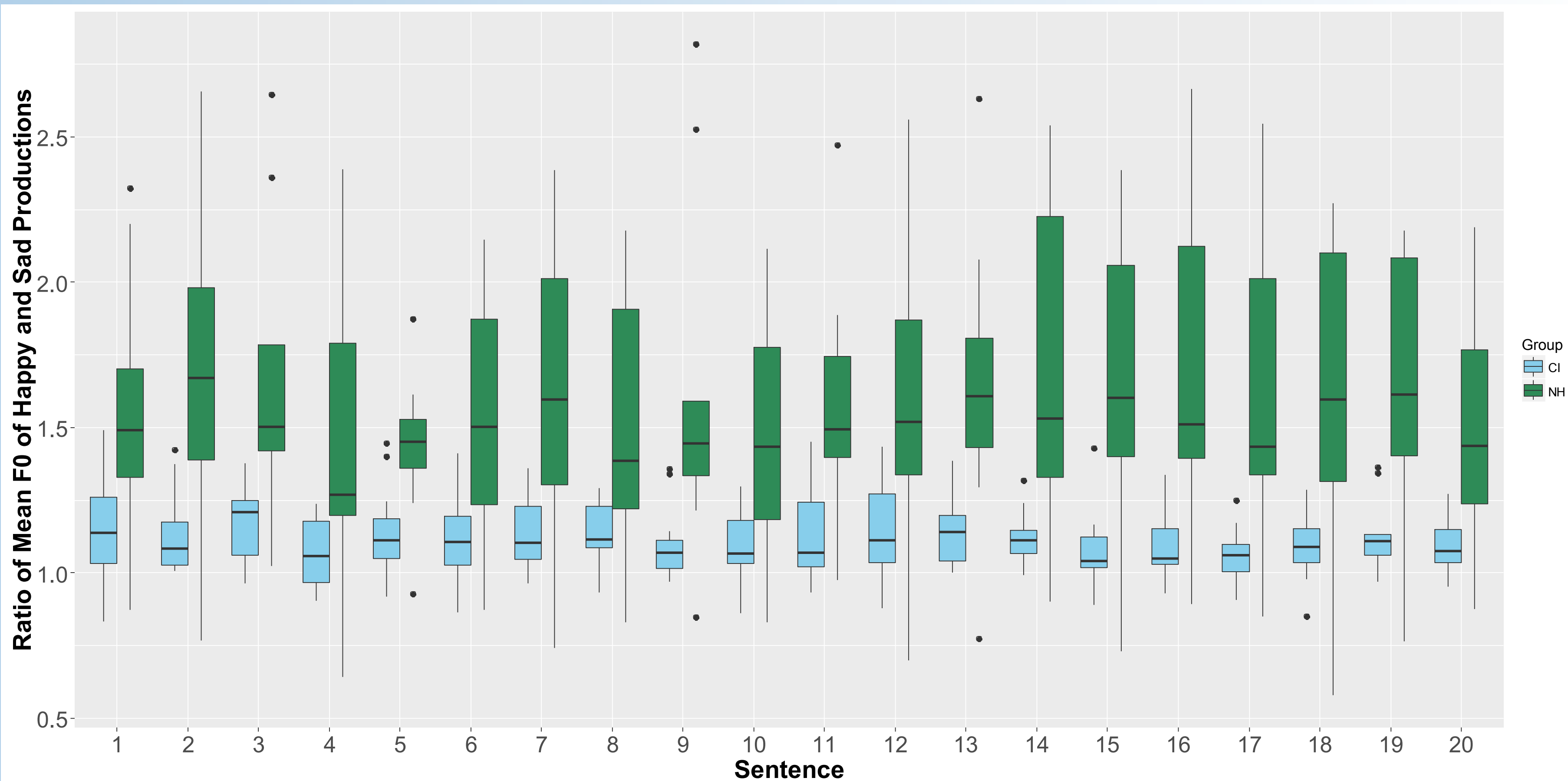
VOCAL EMOTION PRODUCTIONS BY CHILDREN WITH CIs: HAPPY and SAD

EXAMPLES…AND INSIGHTS



VOCAL EMOTION PRODUCTIONS BY CHILDREN WITH CI SHOW SMALLER ACOUSTIC CONTRASTS THAN CHILDREN WITH NH

Example: Mean F0 ratio [Happy/Sad]



Summary

- Cochlear implants require a minimum amount of spectro-temporal information to successfully transmit speech in quiet
- To improve pitch/music perception and listening in noise, we must find a way to improve spectral resolution in the transmitted auditory image
- The success of CIs is largely attributable to top-down processes by the brain
- The key advance that will move the field forward must involve improved coding of voice characteristics, particularly pitch.

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