SPAU338
Hearing Aids II

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Introduction to Cochlear Implants:

- What are CI's?
- CI assessment and candidacy criteria for adults and paediatrics
- Outcomes from CI's
- Surgical and medical aspects of CI's
- **Basic terminology of cochlear implant programming**
- **Basic principles of cochlear implant programming**

Principles

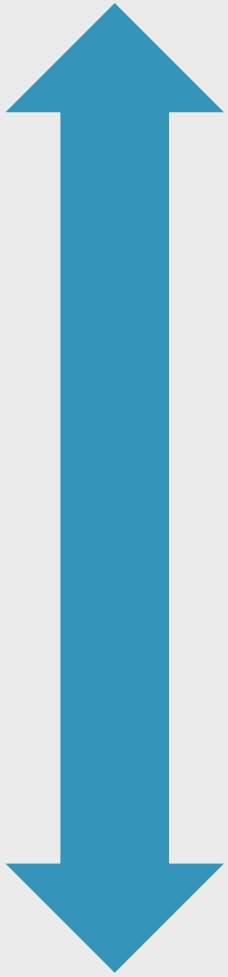
- Electrode array within scala tympani, first 1-2 turns of cochlea
- Tonotopicity preserved
- Electrode stimulation (frequency and intensity information coded and transmitted by speech processor)
- Stimulation of spiral ganglion cells
- Action potential generated within auditory nerve

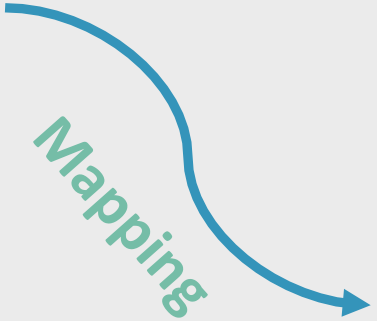
Pitch Perception

- Normal Ear
  - 20-20,000 Hz
  - Very precise pitch resolution
  - As many as 14,000 hair cells
- Cochlear Implant
  - 200-8000 Hz
  - Less precise pitch resolution
  - Number of electrode contacts varies from 12-22

CI Challenge

Normal auditory system has a dynamic range of ~ 120 dB



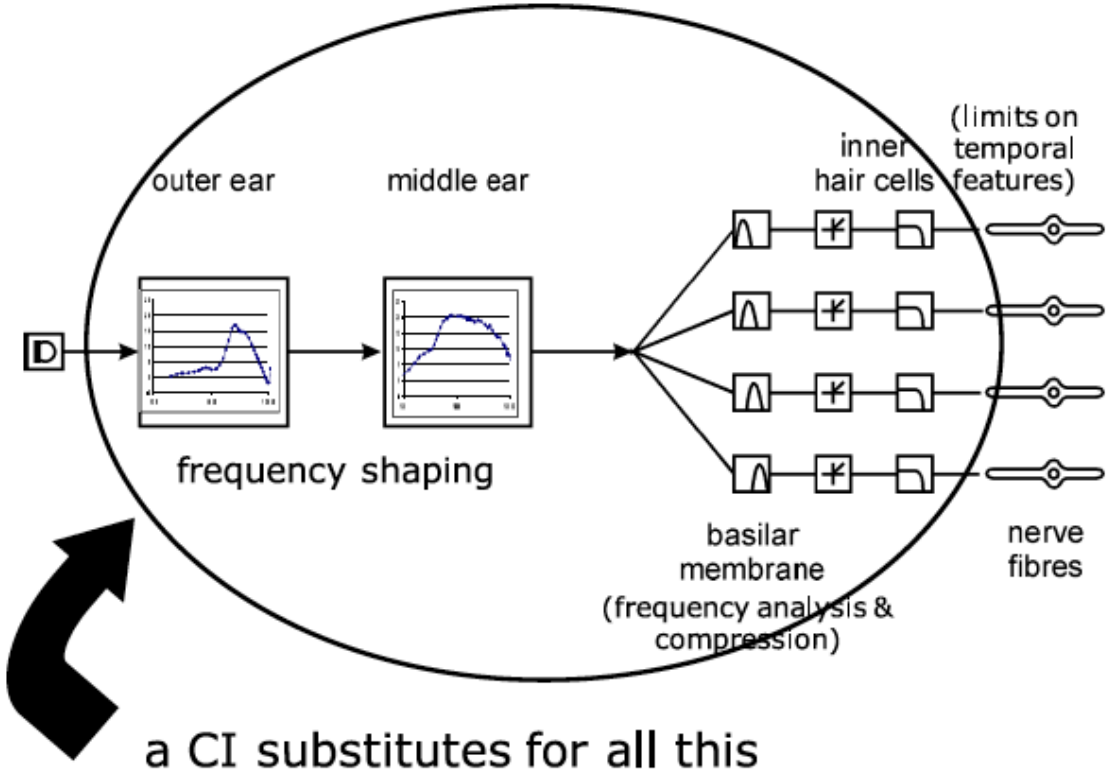


CI recipient has an electrical DR of 10-20 dB (universally)

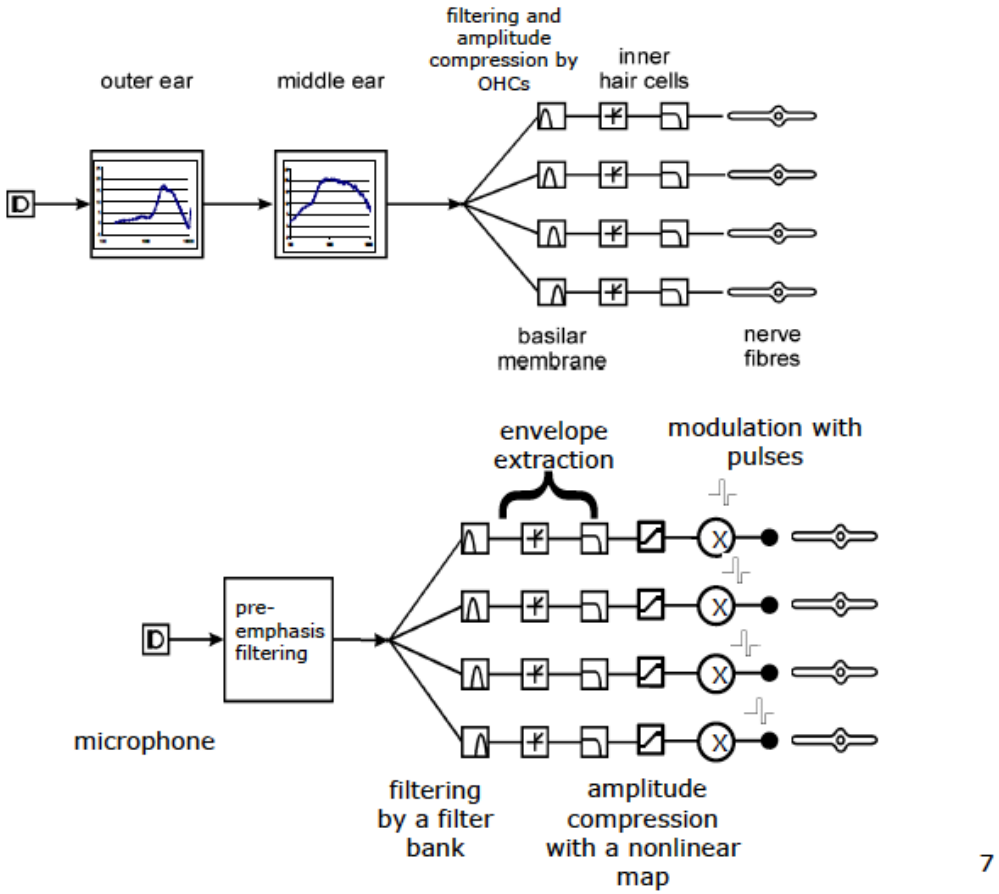
A physiological restriction of the auditory system

Principle of Electrical Stimulation

- Bypass the normal transduction mechanism in the intact inner ear
- There are limitations to reproducing coding of speech frequencies and intensities through electrical stimulation
  - Solution:
    - Analyze the most important speech info and optimize transmission
    - Use of multiple electrodes, front-end processing, post-processing enhancement



Rosen, S. (2017). Speech Processing Schemes for Cochlear Implants [Powerpoint slides]



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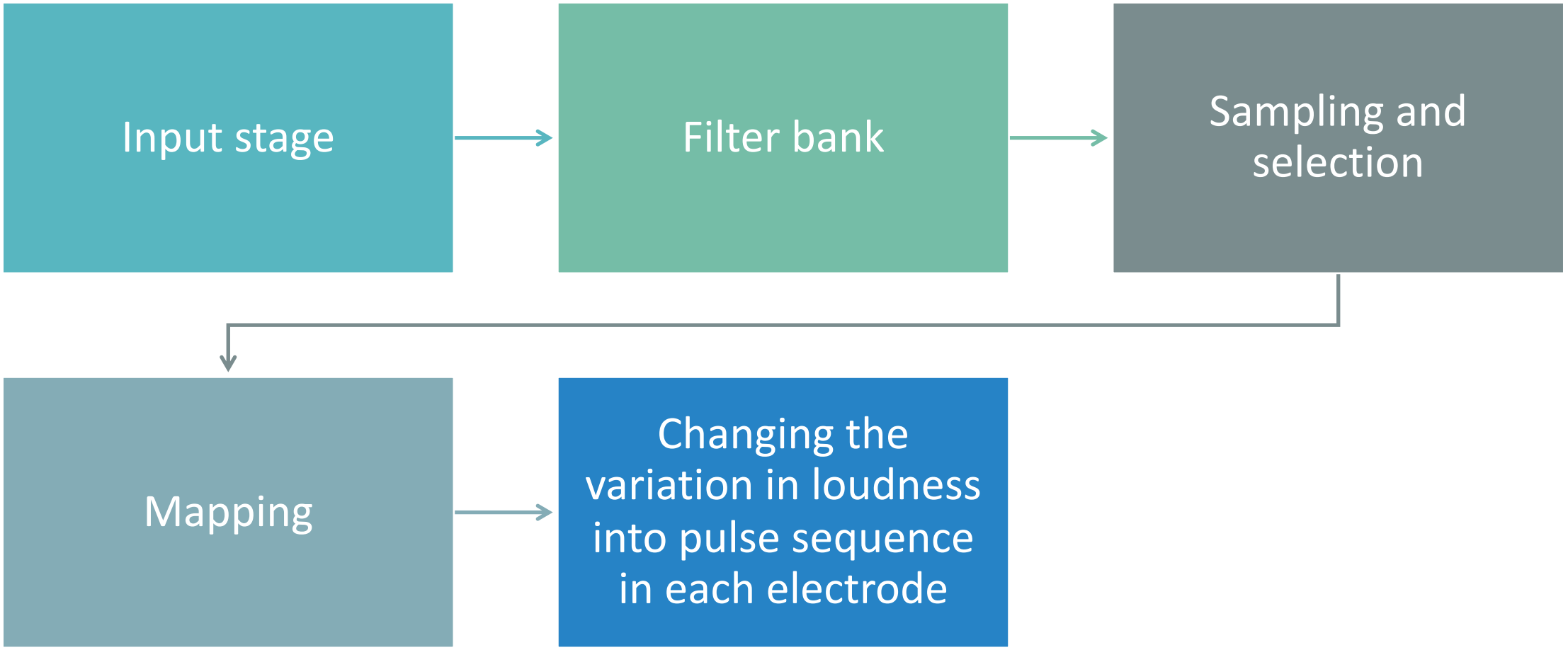
Rosen, S. (2017). The Psychophysics of Cochlear Implants [Powerpoint slides]

Signal processing stages in CI's

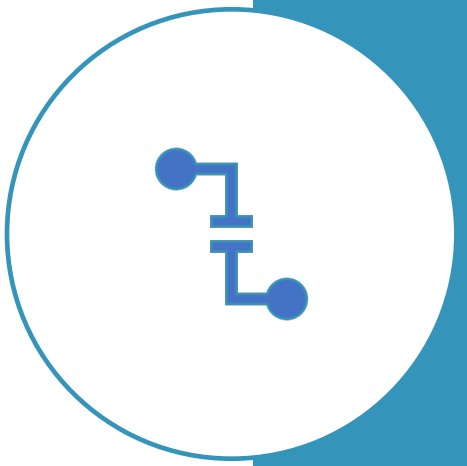


Input stage

- This stage takes place in the external signal processor
- Involves: Converting electricity into radio waves and amplification

Filter bank

- Electrical signal is converted into a number of frequency bands (typically one band per electrode)
- Band pass filters are involved in this conversion

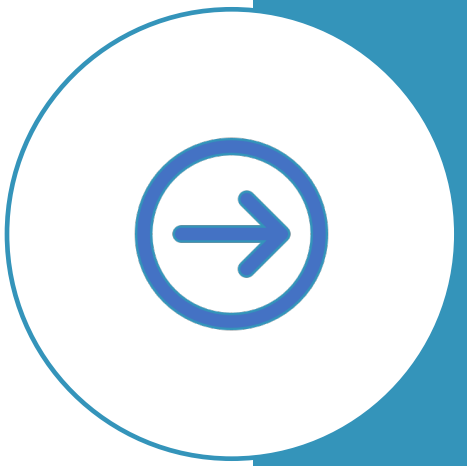


Sampling & selection

- The process of selecting which parts of the signal to convey
- May select all bands or only those with highest amplitude
- This is referred to as the coding strategy

Mapping

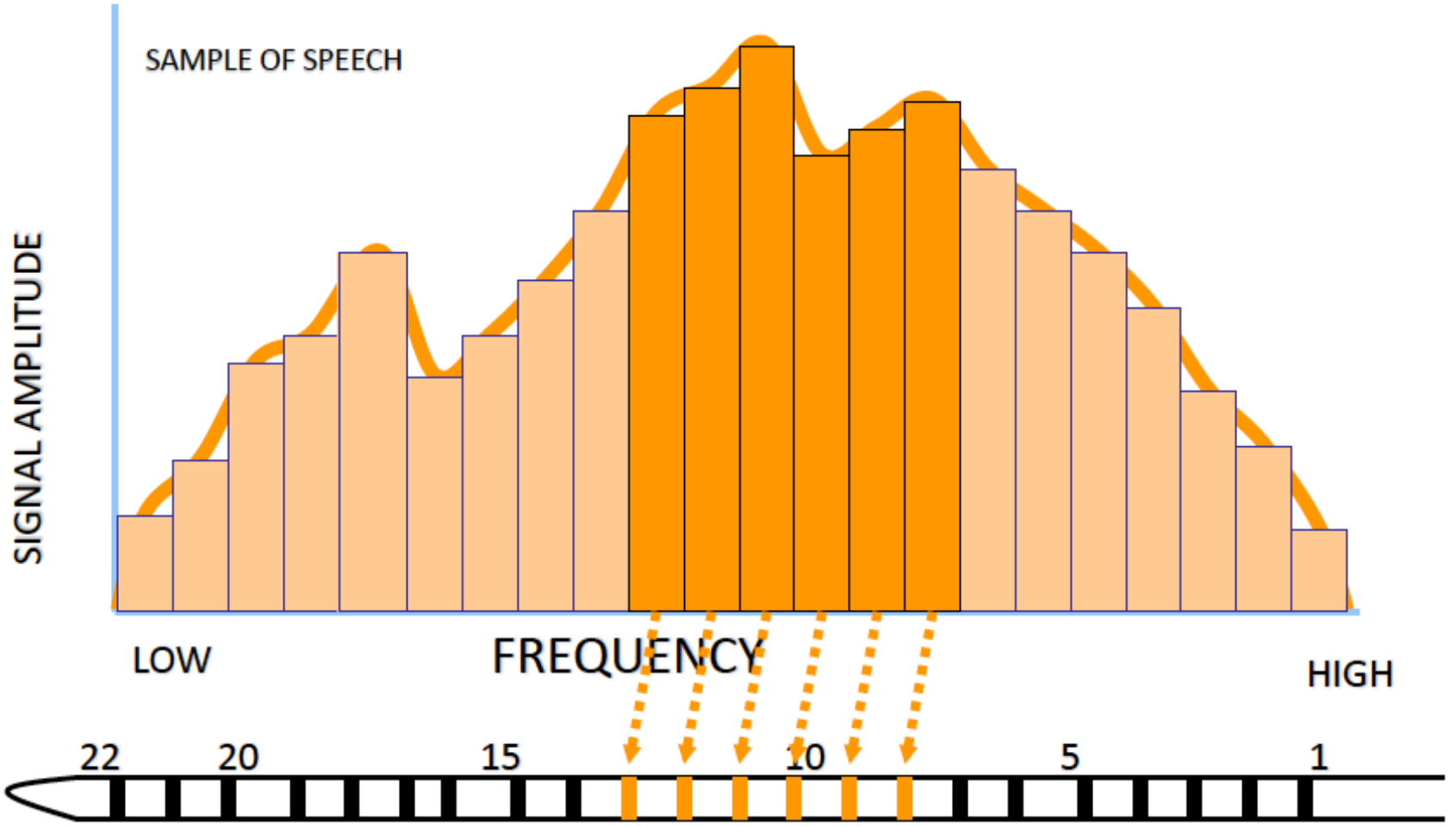
- The process in which range of amplitude values within each band are translated into electrode-specific dynamic ranges
- Performed for each individual frequency band / electrode
- Current ~ loudness



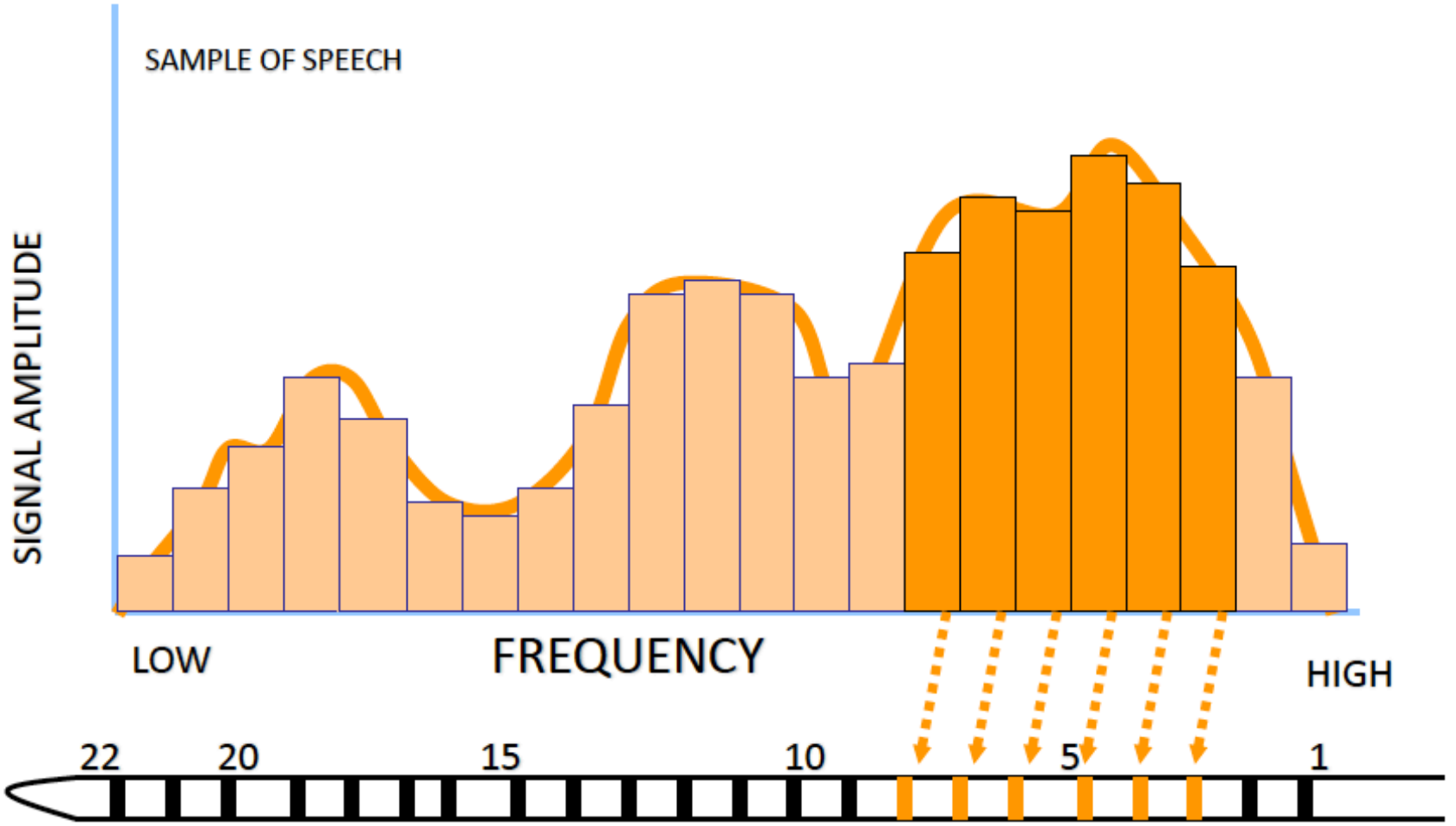
Loudness variation

- The variation in amplitudes of the signals transformed into pulse sequence in each electrode
- Aim: to represent changes in signal intensity over time

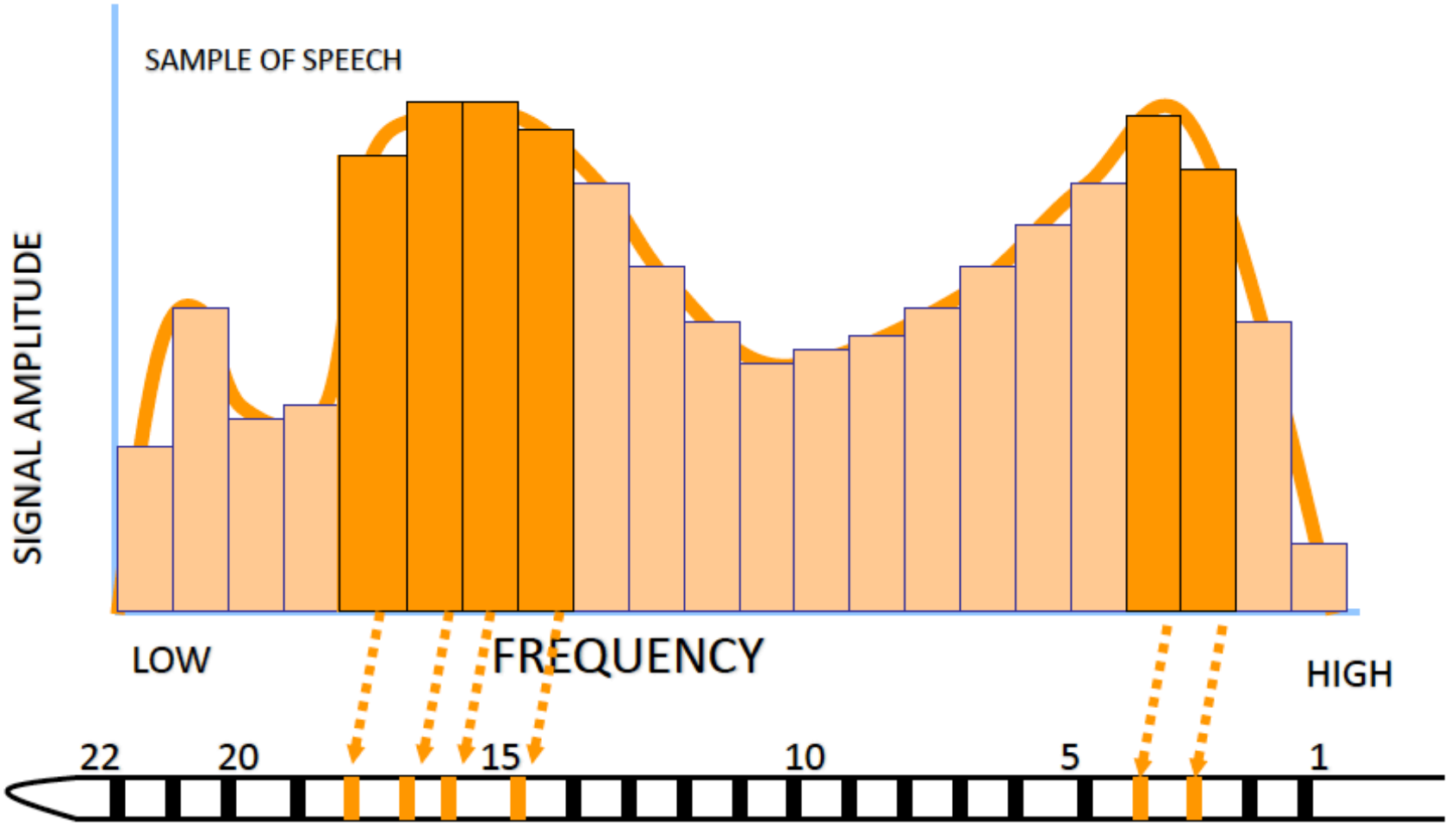
Speech Processing

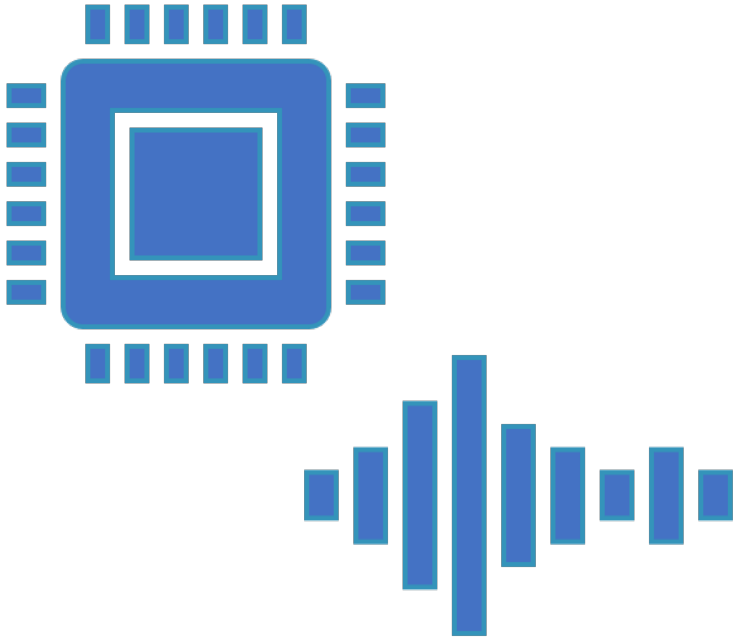


Speech Processing



Speech Processing





Programming a Cochlear Implant

Mapping (MAPping)

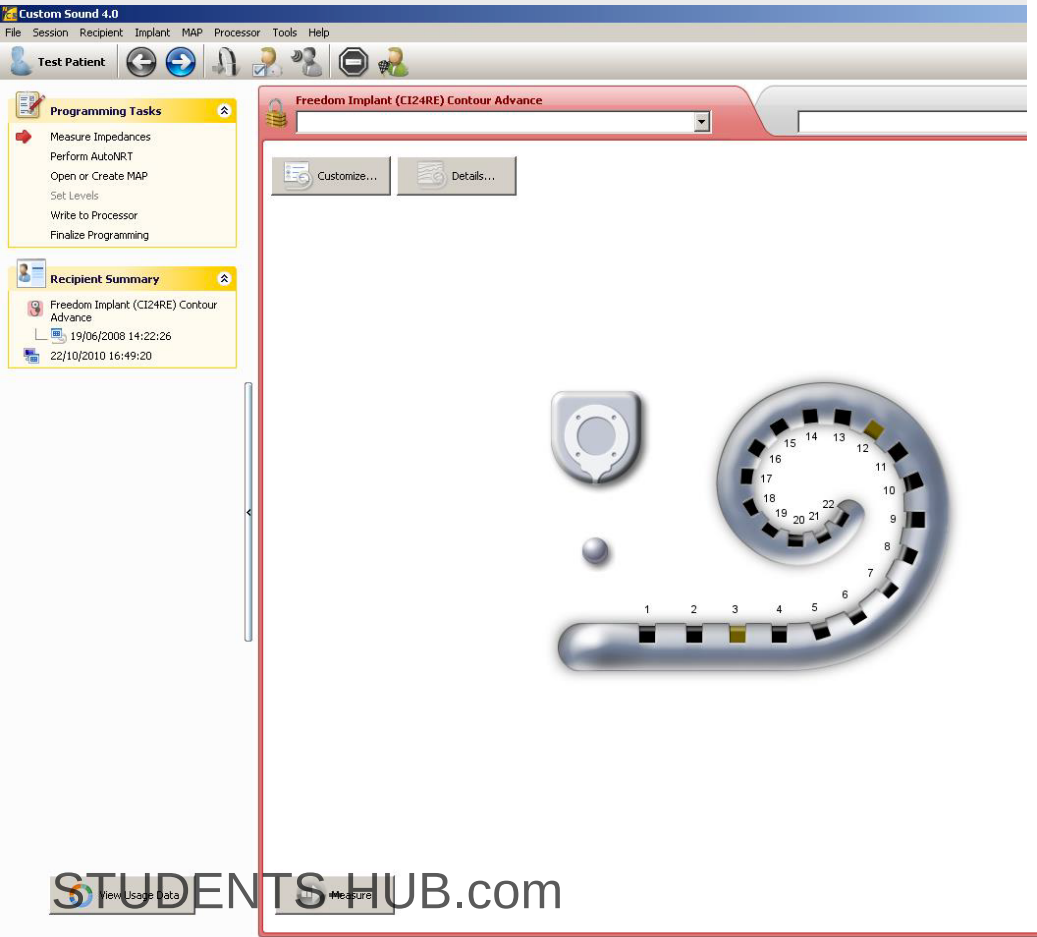
- the term for programming a cochlear implant to the specifications and needs of its user
- Combination of electrical parameters required to stimulate patient's CI

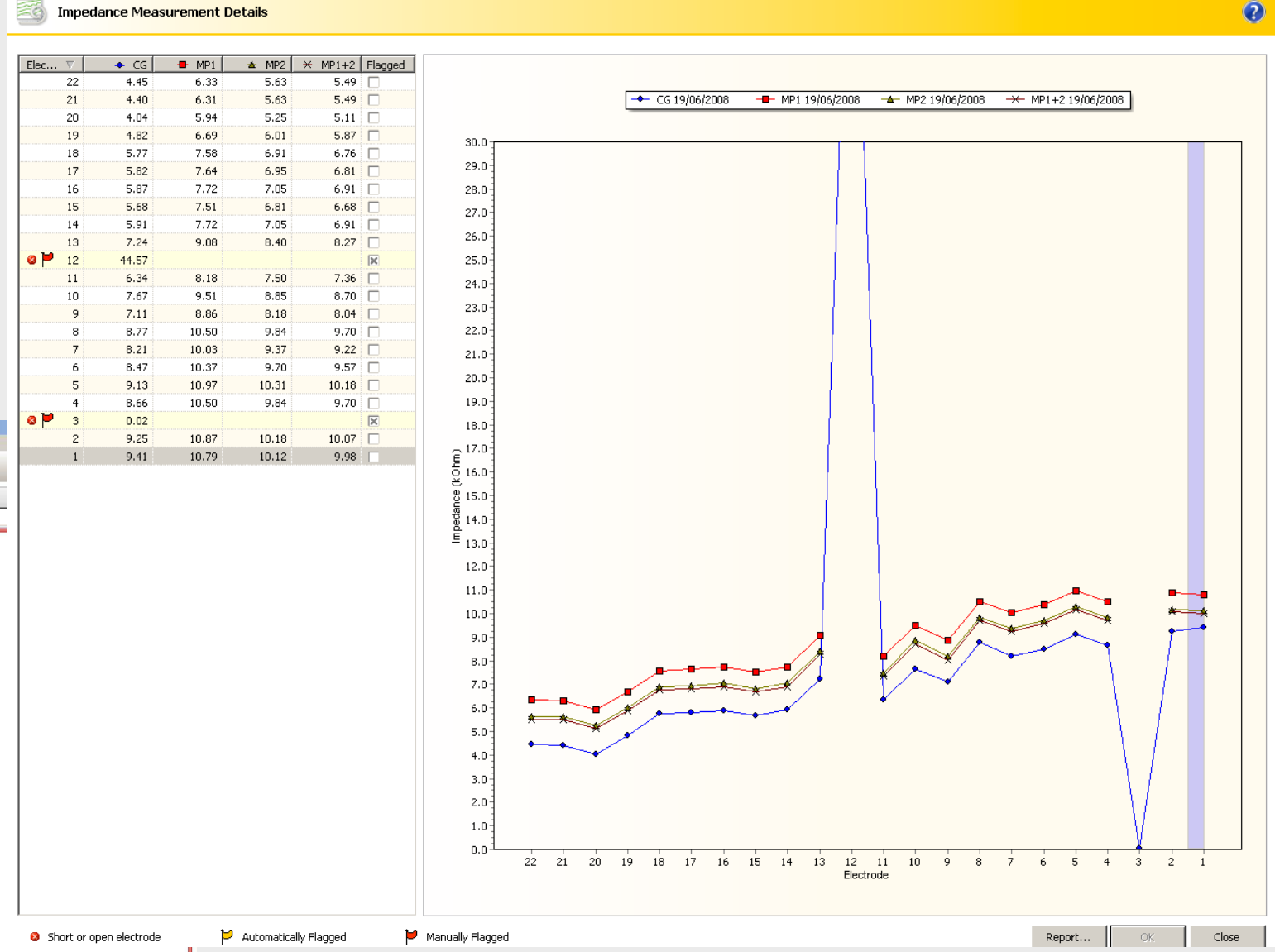
Switch on / initial activation

- Impedance telemetry
- Select speech processing strategy
- Set required electrical parameters

Impedance Telemetry

- Impedance: A measurement of the opposition to the flow of current surrounding the electrodes
- Provides information regarding the integrity of the electrodes along the array
- The software sends a signal to the electrodes and they respond, providing information about the status of the electrodes and the environment surrounding them
- We look to see if there are any changes over time
- Helps identify faulty electrodes (open / short)
- The transmitter coil and processor need to be in place
- Determines if enough voltage is available to deliver requested current
- Impedance levels will affect the output of the electrodes and will affect things like battery life as well





Electrical Parameters

T level

- Threshold level for electrical stimulation

M level

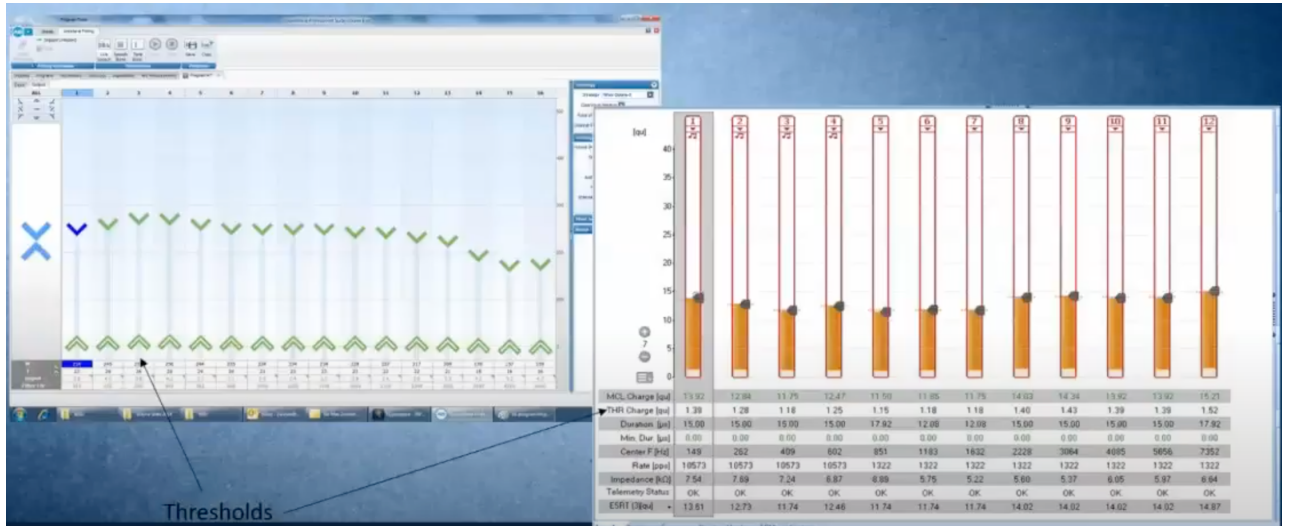
- Level of electrical stimulation which produces sound which is ‘Most Comfortable’

C level

- Level of electrical stimulation which produces the sensation ‘Loud but comfortable’

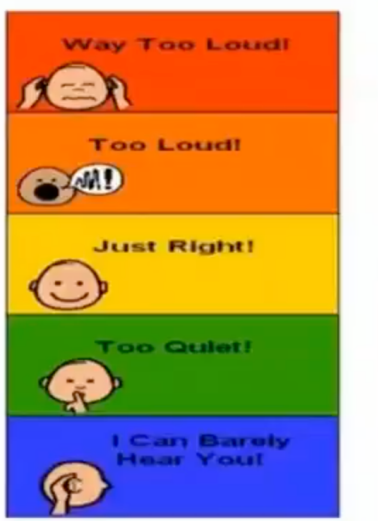
Threshold of Stimulation
(T-Levels)

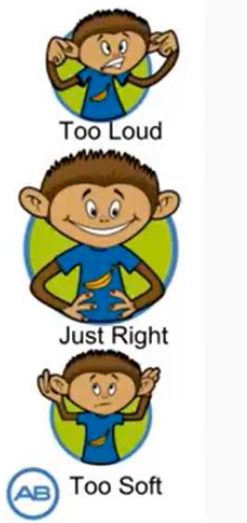
- The lowest level of electrical stimulation required at each electrode
- Allows the recipient to hear the softest sounds of speech and environment.
- Some devices don't require setting of T levels (AB & MED-EL) based on the design of the speech processing strategy that they use
- When they're required it's important to get them right:
  - If set too low: The child will miss out on soft sounds that should be audible
  - If set too high: Sounds that should be soft will sound louder, reducing important loudness cues and the child might hear background noise/ static in a quiet room.

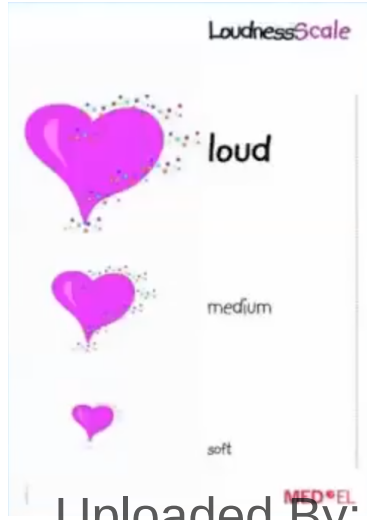


Upper-Stimulation Levels
(C-, M-, MCL- Levels)

- The maximum electrical stimulation level of sound that the recipient can comfortably tolerate at any given time
- Prevents sounds in the environment from being uncomfortably loud
- If set too high: Sounds may be uncomfortably loud or painful
- If set too low: Sounds that should be loud (loud clapping) are not perceived as loud but are perceived as medium or even soft
- In early appointments, we would set them conservatively (watch for any signs of disturbance), and then check the child's response to live speech and to louder noises to ensure comfort
- Early on, may provide progressive maps with gradual increases in C levels for later use as the child's tolerance increases

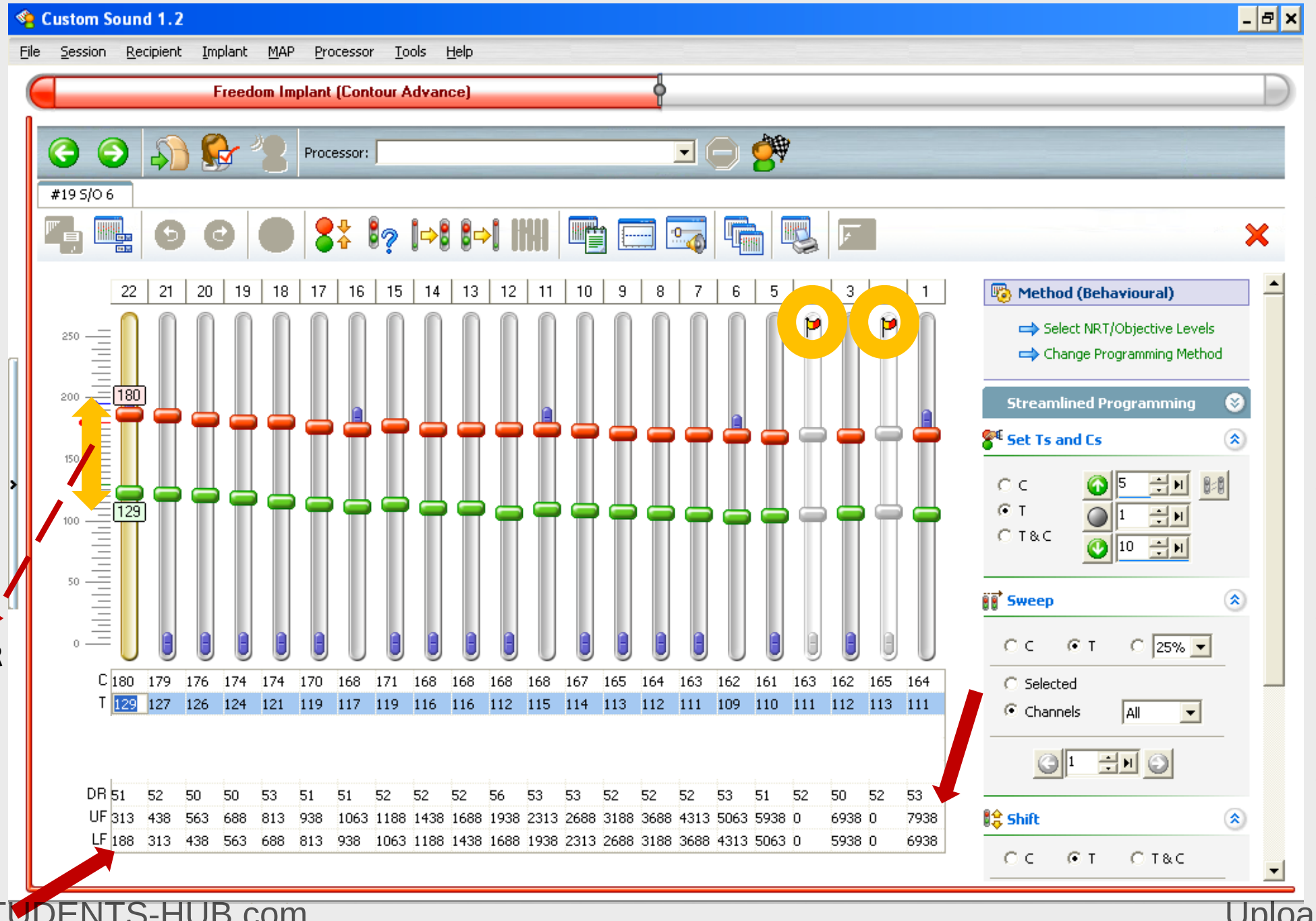






C-, M-, MCL-Levels

- The operational definition for the upper stimulation level also varies by CI manufacturer:
  - M-Level is similar to most comfortable level by AB - “Tell us when it’s most comfortable”
  - MCL, as in maximum comfortable levels, is used by MED-EL -“tell us when you can’t tolerate it anymore”
  - C-Levels referring to “loud but comfortable” are used by Cochlear - “tell us when you can’t tolerate it anymore”



- All active electrodes will have a T and a C level
- T & C levels are individualized
- Measured in current units, not decibels
- There's no relationship between T/C levels and pre-operative sound-field thresholds (residual hearing)
- There is no "target" threshold or comfort level
- T & C levels together determine the DR of electrical stimulation for each channel
- T & C levels may change overtime (especially in the first 3 – 6 months after implantation

Obtaining T and C / M levels

- **Objective**: EABR, ECAP (NRI, NRT, ART), ESRT (C-levels)
- **Subjective**: VRA/ CPA
- **Observational** (BOA): if the child cries, reaches out for mother's lap, blinks their eyes, pulls the coil out, etc.

- Early on, the level at which they respond is likely above the true T levels, so we often reduce them
- We continually reassess T's over time to verify level and to teach child how to respond

T-Levels

1. Patient counting the number of beeps which are randomly varied by the clinician
2. Loudness scaling approach-Threshold corresponds to “Very soft” or “barely audible”
3. Regular adaptive PTA threshold procedure

AB and MED-EL do not mandate measurement of electrical thresholds: Estimated thresholds may be used (e.g. 10% of maximum stimulation level)

C-, M-, MCL-Levels

- Loudness scaling cannot be used until 4-8 years old
- ESRTs are recommended for children
- If ESRTs cannot be measured, behavioral observations are used in preschool-aged and younger children
- Older children (≥ 4 years) may engage in simplified loudness scaling
- Children aged 8-9 years may engage in traditional loudness scaling that is used with adults

What if we can't obtain behavioral measurements?

ECAP

- Electrically-evoked Compound Action Potential
- Threshold represents lowest stimulus level (electrical current NOT intensity level) that elicits an auditory nerve response
- Implant processor delivers electrical stimulus and measures subsequent response
- Integrated into the software & sound processor
  - **AB**: Neural Response Imaging **(NRI)**
  - **Cochlear**: Neural Response Telemetry **(NRT)**
  - **MED-EL**: Auditory Nerve Response Testing **(ART)**

eCAP

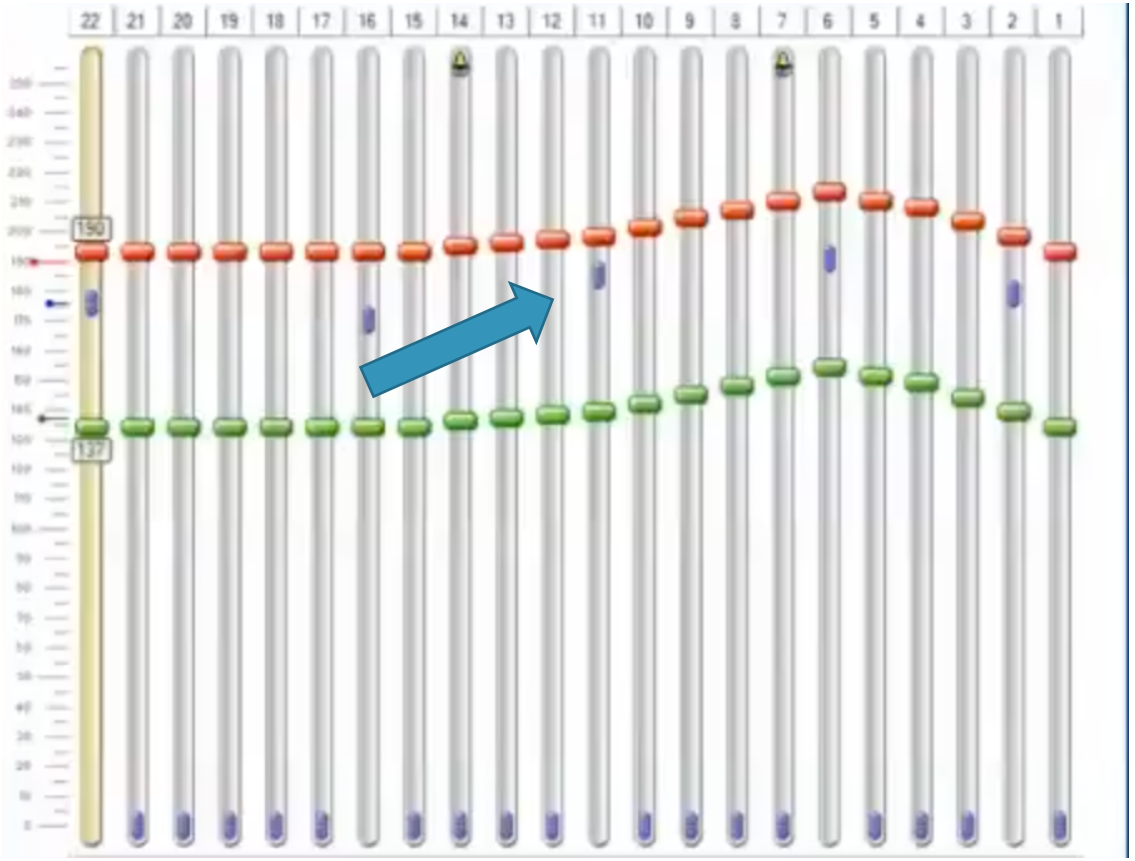
(NRT, NRI, ART)

- A signal is delivered to an electrode in the array, eliciting a response from the hearing nerve
- The response is then recorded using the other electrodes in the array
- If we see a response, we know the sound is audible!
- Ideally used in conjunction with behavioral measurements

eCAP

- Used to:
  1) Help program young children
  2) Verify behavioral responses
  3) Provide information regarding the status of the auditory nerve

- We import the ECAP thresholds into the child's map to see where they fall (they should fall somewhere between the T's and the C's)

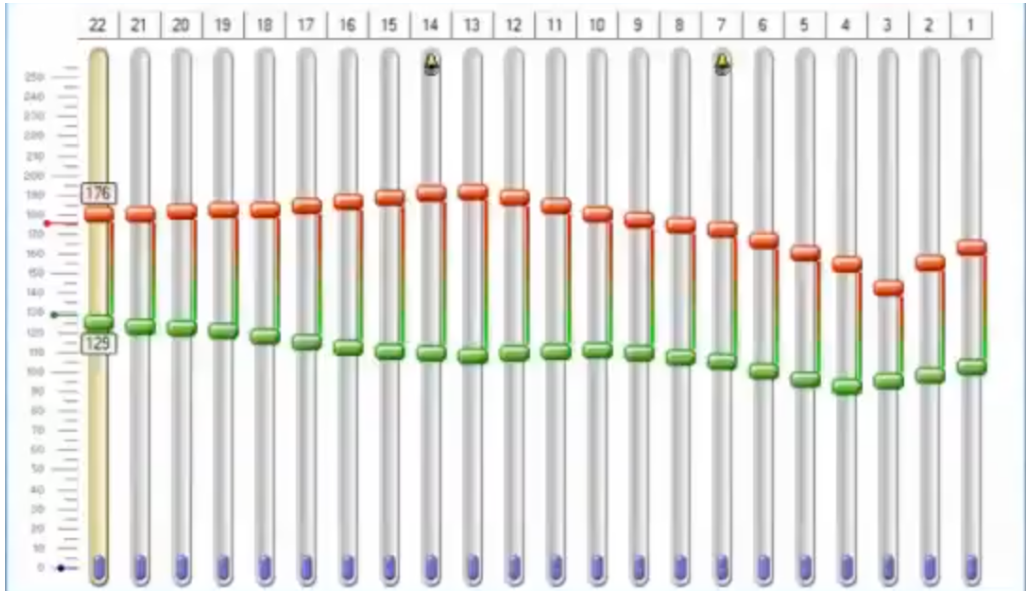


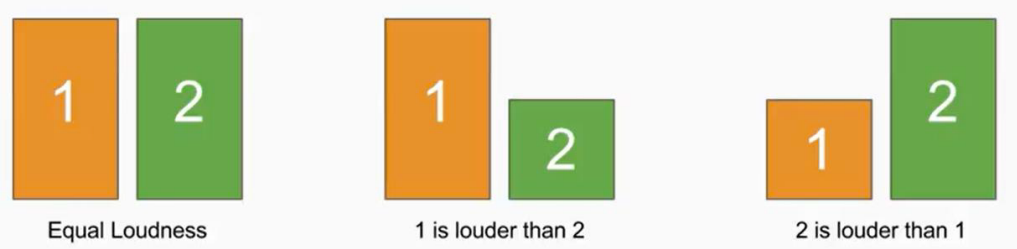
Interpolation

- Not every electrode needs to be measured
- Software will “fill in the blanks” for electrodes that are not tested
- This is possible since adjacent electrode measurements are very similar

Loudness balancing/ sweeping

- If possible, we want to ensure all C/M levels are the same loudness
- “You will hear 2 tones. The tones may be different in pitch, but are the two tones equally loud?”





Speech processing strategies

- Each CI manufacturer has a default coding strategy
- Determining optimum stimulation levels are a greater concern than the particular signal coding strategy in the initial weeks after implantation

Speech processing strategies

- After selection of speech coding strategy, additional parameters may be adjusted:
  - Pulse width: (Stimulus duration)
  - Frequency Allocation
  - Stimulus rate

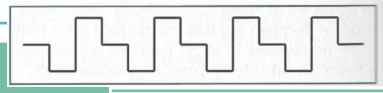
Table 12–1. Current Speech-Coding Strategies Available

Manufacturer	*Advanced Bionics*	*Cochlear Corporation*	*MED-EL Corporation*
Default Coding Strategy	HiRes S	ACE	FSP
Alternate Coding Strategies Available	HiRes P HiRes S with Fidelity 120 HiRes P with Fidelity 120 CIS MPS	CIS Speak	HCCIS CIS+

After selection of speech coding strategy, additional parameters may be adjusted:

Pulse width (stimulus duration)

- May be fixed/ varying across electrodes
- More pulse width = bigger intensity



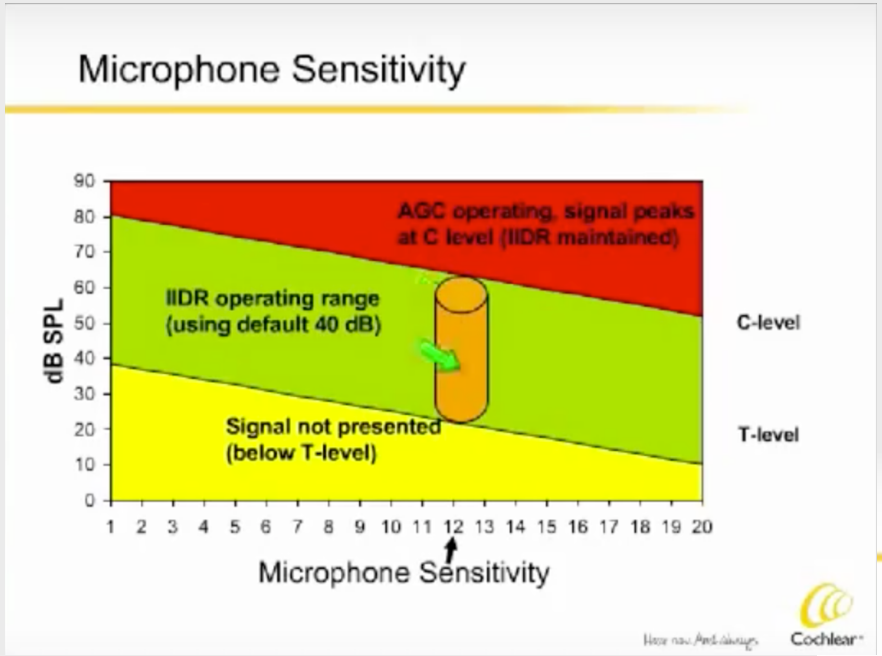
Stimulus Rate

- Number of electrical impulses per second (pps) that are delivered to the electrode array
- Optimal stimulation rates varies between individuals
- Faster rates = louder signal perception = higher pitch perception
- Increasing stimulation rates may also increase the risk of channel interaction
- Higher stimulation rates may evoke Tinnitus/ worsen sound quality
- Slower stimulation rates may be better for those with 8th nerve dysfunction (e.g. ANSD / the elderly)

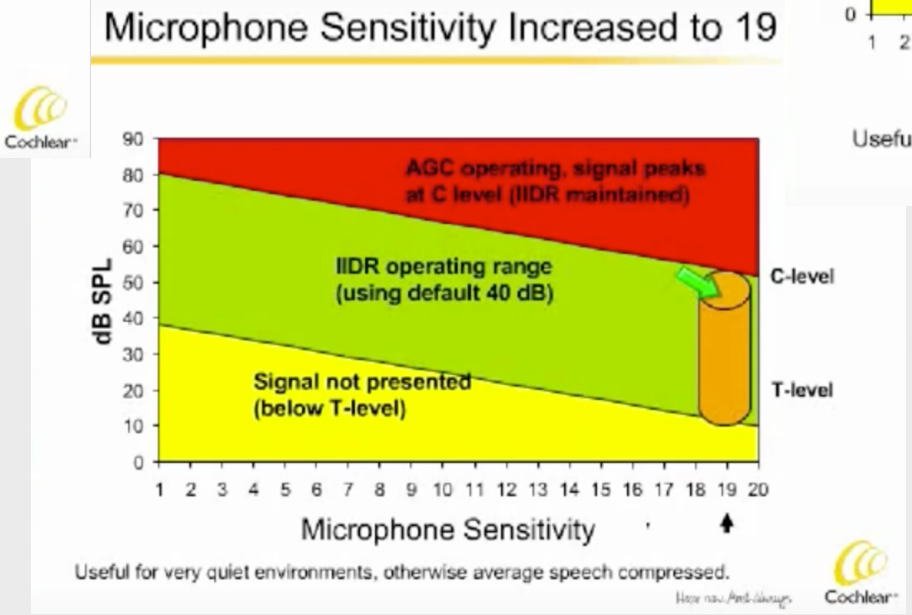
Frequency allocations

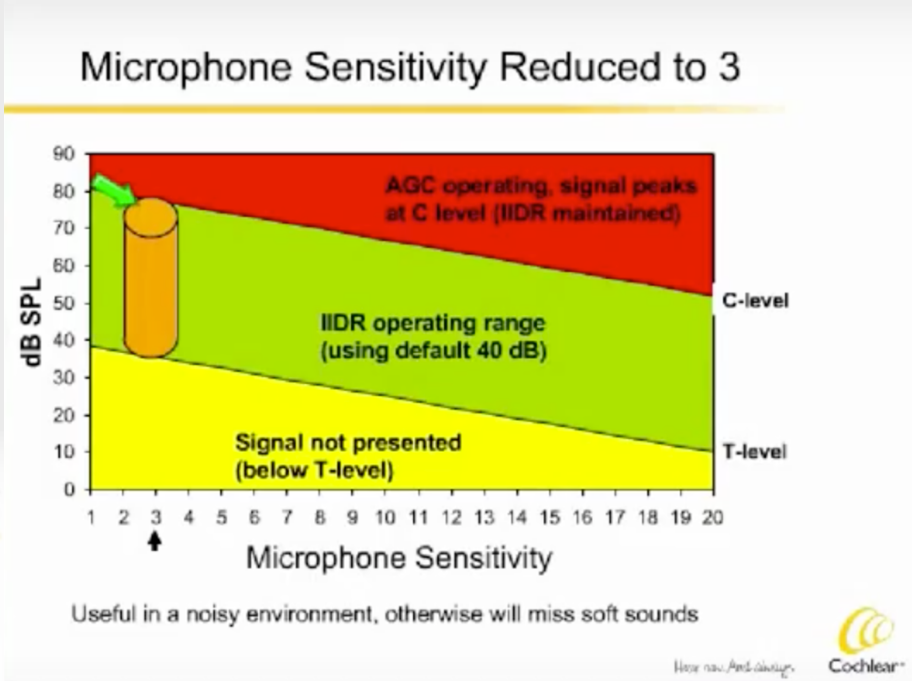
- Affects encoding in frequency domain
- Narrower channel bandwidths result in better spectral resolution which may improve speech recognition
- Frequency range is automatically assigned depending on number of active electrodes and chosen speech-coding strategy
- Some manufacturers (e.g. Cochlear) let you adjust these frequency allocation tables (LF – UF)

Microphone Sensitivity



- Controls the softest level of sound allowed in the processor
- Default is 12





Volume Control

- Controls loudness
- Globally reduces the C levels by a percent of the DR
- A volume of zero is not no sound, it’s about 20% reduction of the DR (depending on the volume range of the speech processor)

Speech coding strategies

- Purpose: Encode important intensity, frequency, and timing cues so that they can be perceptually utilized by patient.

Live Speech

- During live speech, the child is listening with the entire array
  - Initial responses to sound vary greatly
  - Further adjustments may be needed for comfort when volume is set to mid range
  - We adjust C levels up and down based on the child's response to sound
  - Loud sounds are used to check for possible discomfort
  - Ling sounds, numbers, colors, simple questions to verify the status of speech recognition

Activating device – initial reactions

Children:

- 90% - minimal reaction
- 5% - happy
- 5% - tears

Adults:

- Sound may seem robotic, electronic, underwater
- Speech may only be perceived as beeps at first

Baseline Measurements

- Baseline task to evaluate performance
  - Ling sounds
  - Closed-set spondees
  - Sound-field audiogram
  - Speech perception tasks
- Feedback from school personnel
- Daily listening checks
- Correct MAP settings

Change in Performance

Observe a decrease in:

- Auditory Responsiveness
- Speech becoming more slurred
- Ability to repeat the Ling sounds
- Vocal quality

Observe an increase in:

- Request to repeat
- Not wearing equipment
- Turning down the volume
- Negative behavior
- Increase in articulation errors

It’s not always the MAP

- Try to be aware of:
  - Changes at home or in the classroom
  - Rapid development of other skills
    - e.g. when some children begin to walk, their vocalizations decrease
  - Determining if both, perception and production are affected
  - “Selective listening”? Just having a bad day?

What else can go wrong?

- Physiological changes
  - Medication
  - Puberty (hormonal changes)
- Medical Issues
  - Electrode extrusion (does the postoperative x-ray show correct electrode-array position?)
  - Infection
  - Ongoing ossification
  - Otosclerosis

Current models of CI's

MAKE	Internal device	Speech processor	Speech processing strategies	Web page
Nucleus (Cochlear)	CI512 CI522 CI532	CP1000 (Nucleus 7) Kanso	ACE, SPEAK, CIS	www.cochlear.com
AB (Advanced Bionics)	HiRes 90K MidScala HiRes Ultra	Naida Q90 Neptune (BW)	HiRes120 Optima	www.bionicear.com
Med-El	Symphony Concerto	Sonnet Rondo 2	FS4 FS4p	www.medel.com
Oticon Medical	Neuro Zti	Neuro 2	n of m	www.oticonmedical.com

So, which CI brand is the best?

- Same principles
- Different signal- coding strategies
- The perfect CI doesn’t exist yet – All 4 CI companies are competing, the competition is good as it keeps the R&D going!

So, which CI brand is the best?

- Surgical reasoning (patient's anatomy)
- Audiological reasons
- Accessories (e.g. waterproofing)
- Connectivity (e.g. Bluetooth)
- Parents will usually choose the same CI brand they've seen on someone they know
- Current research
- Team's experiences (ease of use, reliability …)