Measuring listening effort using pupil dilation: implications for management of hearing loss

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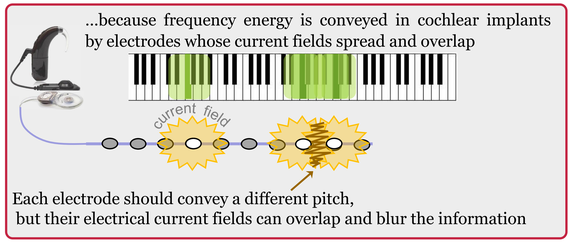
INTRODUCTION

Spectral resolution
(hearing sound frequency distinctions)

... is especially important for speech perception but is a major problem for cochlear implants (CIs).



...because frequency energy is conveyed in cochlear implants by electrodes whose current fields spread and overlap

Each electrode should convey a different pitch, but their electrical current fields can overlap and blur the information

Visual analogy:
hearing impairment causes blurring of fine details, similar to the loss of visual detail in a degraded image

CIs cause *severe* blurring and distortion of fine spectral details in sound, but CI listeners can still achieve considerable success

Poor spectral resolution results in m*ore listening effort* needed to understand speech,
leading to:

- more need for recovery time after work [1]
- increased incidence of stress-related sick leave [2]
- unemployment in young adults [3, 4]
- early retirement [5]
- feelings of social isolation [6]

A successful treatment for hearing loss should result in:

... better word recognition AND reduced listening effort

Goal of this study:

Build a paradigm to test whether a CI sound processing strategy can improve hearing *and* reduce listening effort

METHOD

PUPIL DILATION: an index of *listening effort* [7,8,9]

...also an index of *spectral resolution*

Pupil dilation increases with increased cognitive load.

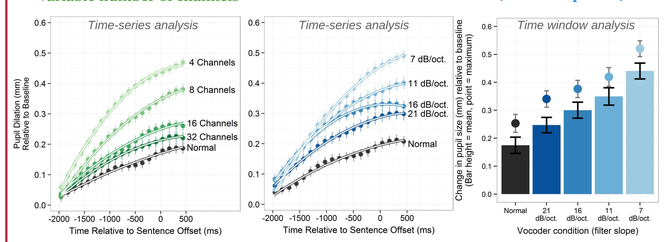
less effort

more effort

Hypothesis: poor spectral resolution results in greater effort needed to understand speech

Task: Listeners with normal hearing (NH) identify IEEE sentences degraded in one of two ways:

1. Noise vocoder with variable number of channels
2. Noise vocoder with variable carrier channel width ("current spread")

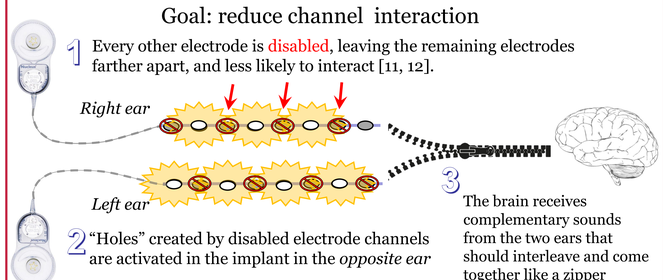


As spectral resolution becomes progressively poorer, pupil dilation increases.
Time-series growth curve analysis [10] reveals significant differences between each level in terms of slope of pupil dilation over time.

A CI listener regularly experiences poor spectral resolution;
If we can *improve* spectral resolution in a CI listener,
it should result in smaller pupil dilation

IMPROVEMENT OF SPECTRAL RESOLUTION

Goal: reduce channel interaction



1 Every other electrode is disabled, leaving the remaining electrodes farther apart, and less likely to interact [11, 12].

2 "Holes" created by disabled electrode channels are activated in the implant in the *opposite ear*

3 The brain receives complementary sounds from the two ears that should interleave and come together like a zipper

Details:

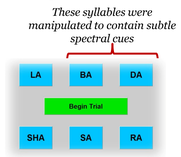
There is no guarantee that frequencies will align *correctly* in the implanted ears, but the frequency-channel allocation was kept the same as that used for each patient's everyday clinical map. Channel current was set to zero, but not physically de-activated, thus leaving all channels eligible for peak-picking

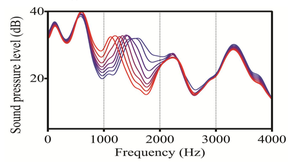
PROCEDURES

A **Monosyllabic word recognition**
(e.g. "boat", "time", "keep")
Open-set response.
More words correct indicate the success of the strategy

B **Spectral cue sensitivity**
Perception of a spectral cue in a BA-DA continuum was embedded in a six-syllable identification task including LA, RA, SA, SHA, BA, DA.

These syllables were manipulated to contain subtle spectral cues





Perception of spectral cues was modeled using logistic regression.

Higher logistic coefficients indicate better use of spectral cues in speech.

C **Pupil dilation**

Pupil dilation was measured as listeners heard & repeated sentences while alternating between their regular processor strategy and the interleaved strategy.

Mean & maximum pupil dilation was measured at the end of each sentence

Pupil dilation was modeled over time using growth curve analysis

Smaller pupil dilation indicated reduced effort and better success in this task.

Pupil diameter measured using Tobii T60XL distal eye-tracker

PARTICIPANTS

18 Listeners with bilateral cochlear implants

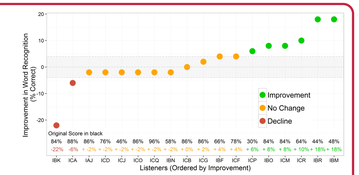
Code	Sex	Age	Years CI exp	Years BiCI exp	Implant Type (Left)	Implant Type (Right)	Processor (Left)	Processor (Right)
IAJ *	F	67	16	9	Nucleus 24 Straight	Nucleus 24 Contour	N5	N5
IBF	F	62	7	5	Freedom Cont. Adv.	Freedom Cont. Avd.	Freedom	Freedom
IBK	M	72	9	3	Nucleus 24 Contour	Freedom Cont. Avd.	Freedom	N5
IBM	F	59	7	3	CI512 (N5)	Freedom Cont. Avd.	N5	N5
IBN *	M	66	13	3	Freedom Cont. Adv.	Nucleus 24 Contour	Freedom	Freedom
IBO	F	46	6	3	CI512 (N5)	Freedom Cont. Avd.	N5	Freedom
IBR	F	57	9	5	CI512 (N5)	Freedom Cont. Avd.	N5	Freedom
ICA	F	52	10	3	Freedom Cont. Adv.	CI24R	N5	N5
ICB	F	61	8	6	Freedom Cont. Adv.	Nucleus 24 Contour	Freedom	N5
ICD *	F	54	9	3	Freedom Cont. Adv.	Nuc. 24 Cont.	Freedom	Freedom
ICF	F	70	1	1	CI512 (N5)	CI512 (N5)	N5	N5
ICG *	F	50	9	9	CI24R	CI24R	N5	N5
ICJ	F	63	1	3	CI512 (N5)	CI512 (N5)	N5	N5
ICM	F	59	1	1	CI512 (N5)	CI512 (N5)	N5	N5
ICO *	F	32	1	1	CI512 (N5)	CI512 (N5)	N5	N5
ICP *	M	50	6	3	Freedom Cont. Avd.	Freedom Cont. Avd.	N5	N5
ICQ *	M	19	15	1	Freedom Cont. Avd.	Nucleus 24 Straight	N5	N5
ICR	M	60	3	2	CI512 (N5)	CI512 (N5)	N5	N5

* Indicates hearing loss occurred before age 5

RESULTS

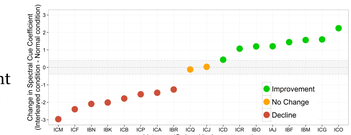
A Word Recognition

Few listeners showed substantial change.



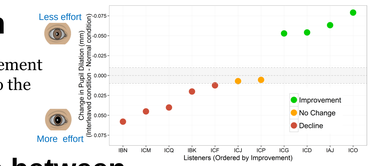
B Spectral Resolution

Wide range of improvement and decline, specific to the individual.



C Pupil Dilation

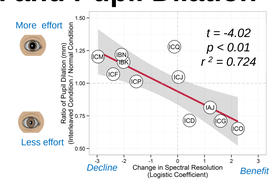
Wide range of improvement and decline, specific to the individual.



B:C Relationship between Spectral Resolution and Pupil Dilation

Improvement in spectral resolution corresponded with reduction in *listening effort* as indicated by less pupil dilation.

Change in effort with interleaved channels was better predicted by the spectral resolution test than by word recognition.



CONCLUSIONS

Degraded spectral resolution causes increased listening effort in NH listeners

Interleaved channels can be beneficial for individual bilateral CI users, in terms of improved spectral resolution and reduced listening effort.
•*Some individuals showed benefit, others showed decline*

Improvements in spectral resolution *correlated* with reduced listening effort in listeners with bilateral CIs.

Word recognition alone did not reveal much improvement or decline

Spectral resolution and listening effort are not accessible through conventional speech tests, but can be measured using pupillometry.

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