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« Simulating the bimodal spread of excitation
produced by bipolar stimulation in cochlear
implant:
Effects on speech intelligibility »

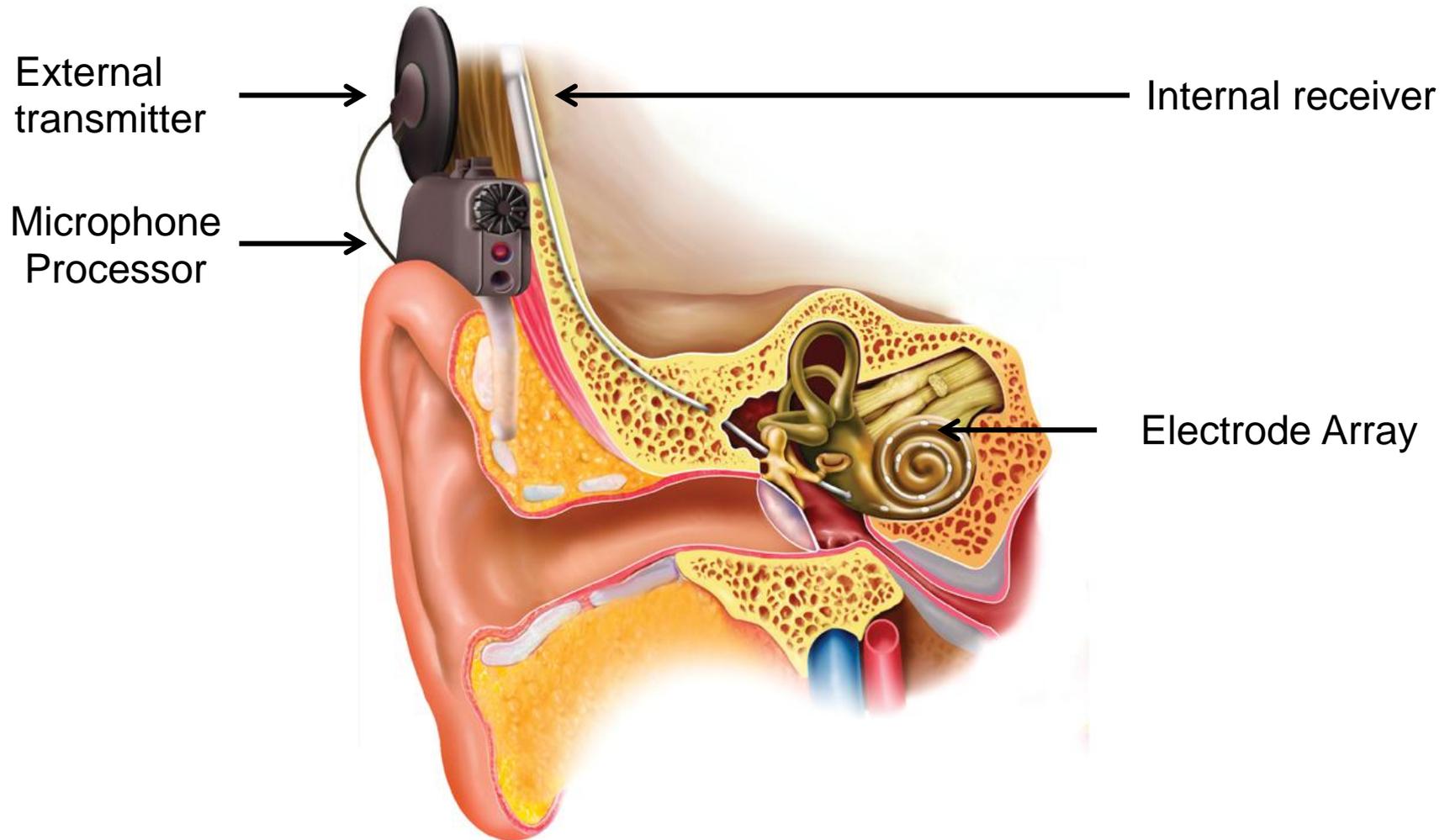
6th Workshop on Speech in Noise: Intelligibility and Quality
9/10 January 2014, Marseille, France



Cochlear implant



Restore an auditory perception by electrical stimulation of nerve fibers



Great performance for speech recognition in silence!

More than 200, 000 CI users worldwide!

Remaining limitations



- Performance drops dramatically in the presence of noise or concurrent speech
- Music appreciation remains highly variable across subjects

Not enough cues, too much sensitivity to noise!!!

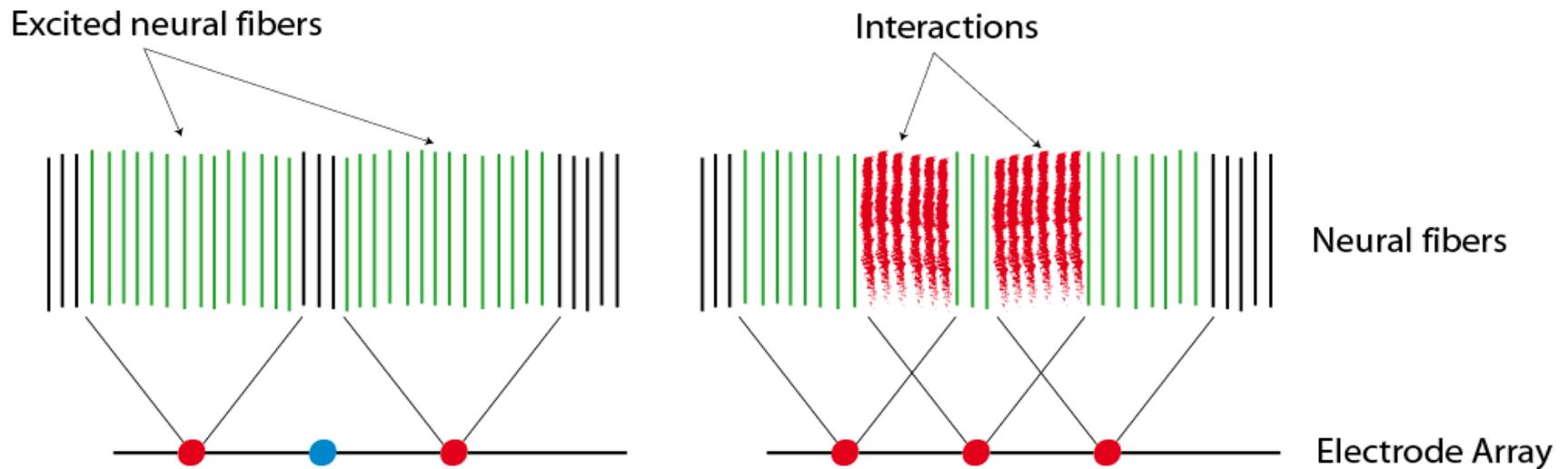
Increasing the **spectral resolution** should help going around these limitations...

- finer analysis
- more channels
- more electrodes

... better performance?



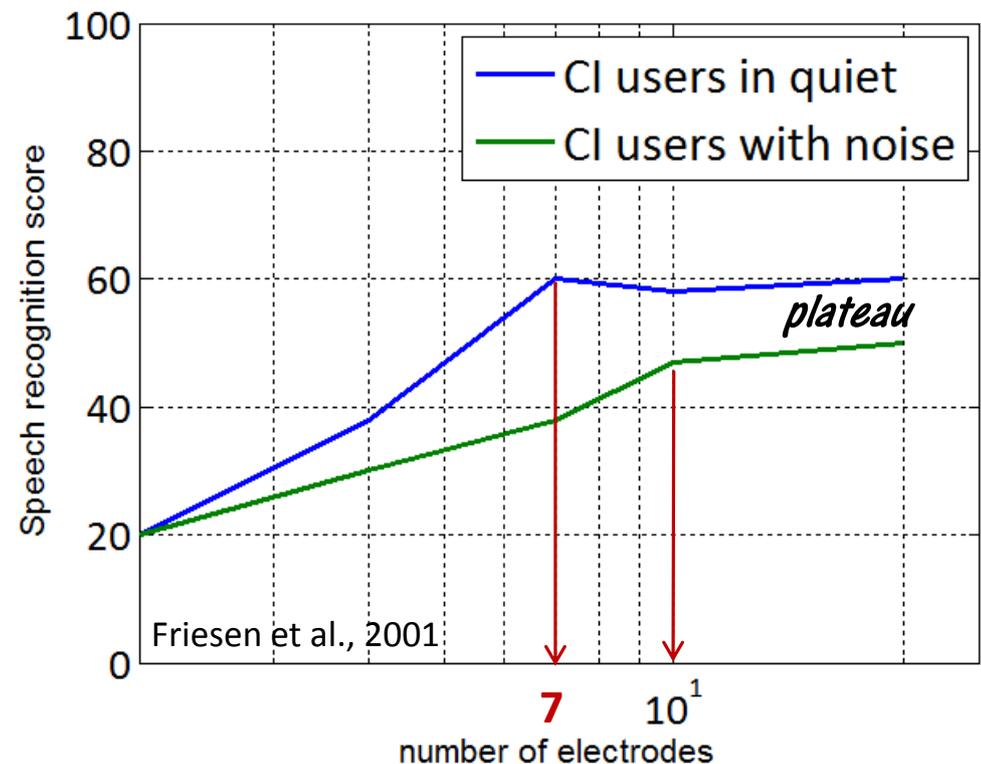
Remaining limitations: Channel interactions



- Active electrodes
- Inactive electrodes

Performance improves with the number of electrodes (i.e. Channels) until **7 or 8** (10 in background noise)

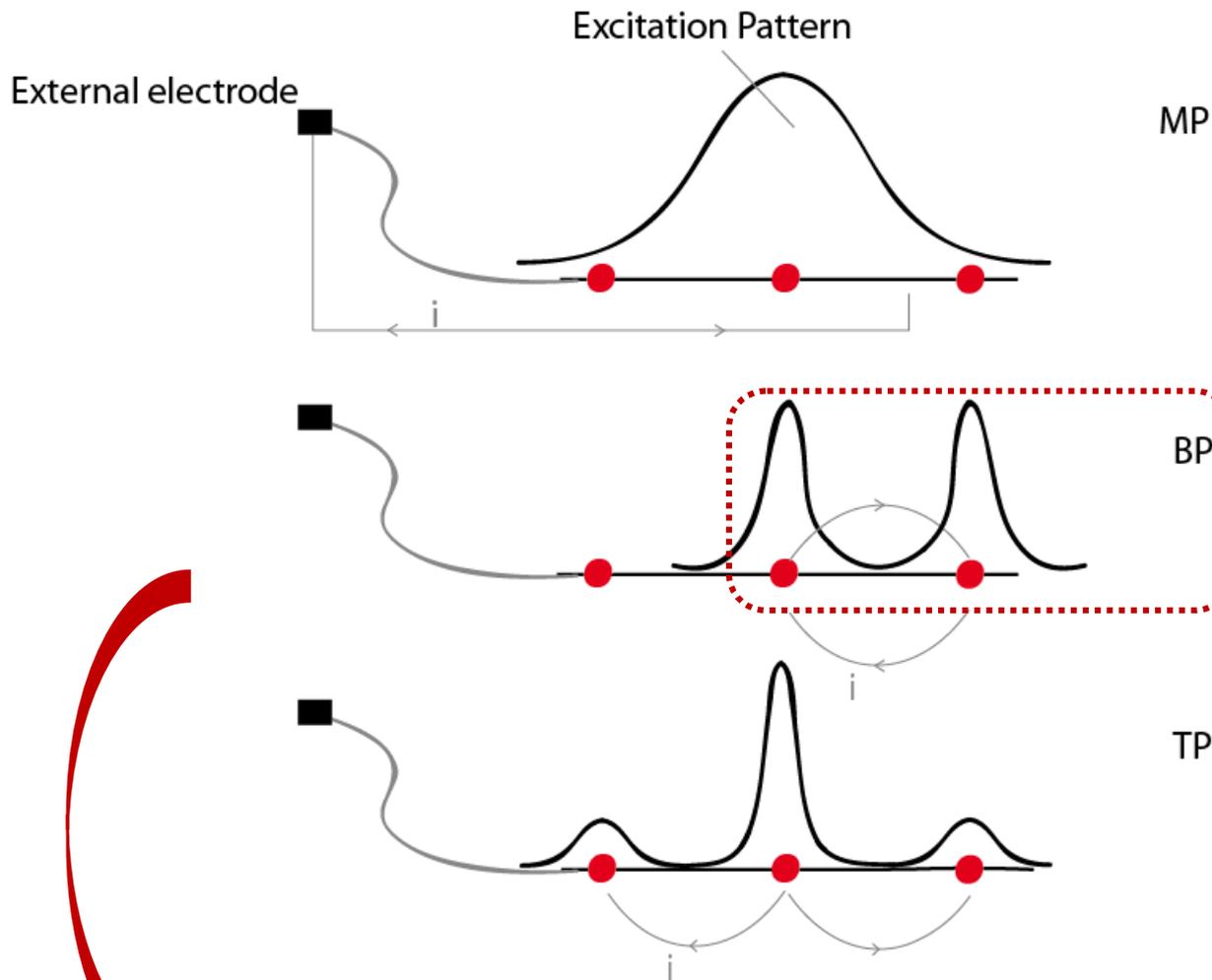
Inability to benefit from larger number of electrodes for CI users



Remaining limitations



Focused stimulation should improve **spatial selectivity** and help to reduce **channels interactions**.



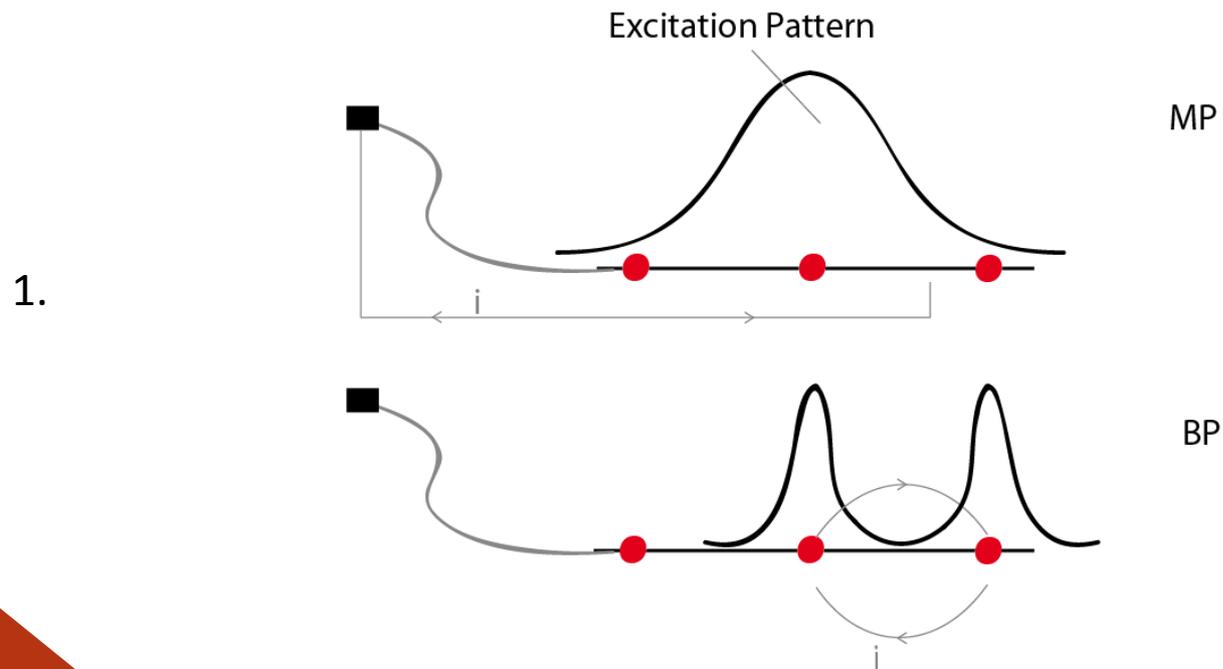
Why no better performance?

Better selectivity observed in animal studies
Contrary to expectations, no clear benefit for multi-electrode stimulation modes has been observed (BP even worse than MP)

Project outline:

Three experiments to better understand the poor performance obtained with BP stimulation:

1. Acoustic simulation of **monopolar** and **bipolar** stimulation modes
2. Testing the influence of the **bimodal excitation pattern**
3. Investigating the effects of **spacing between electrodes**

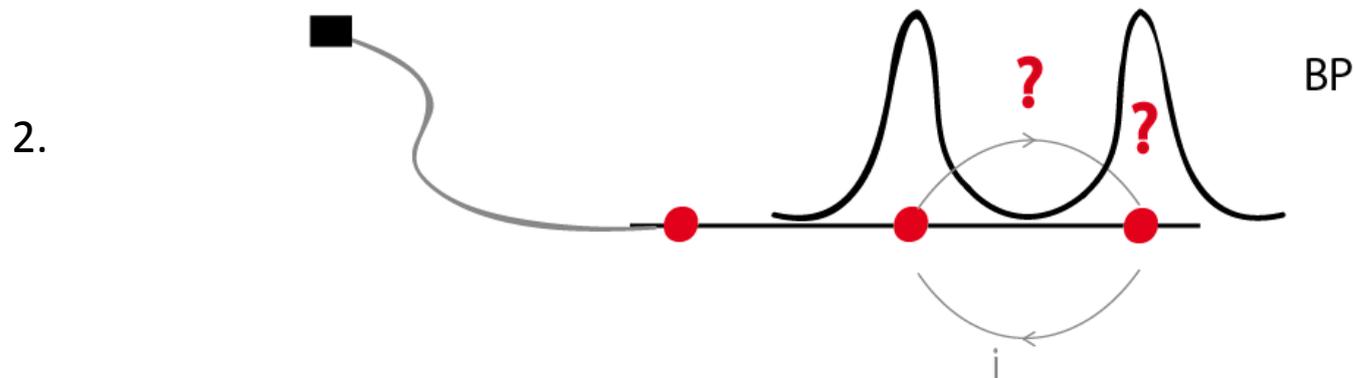


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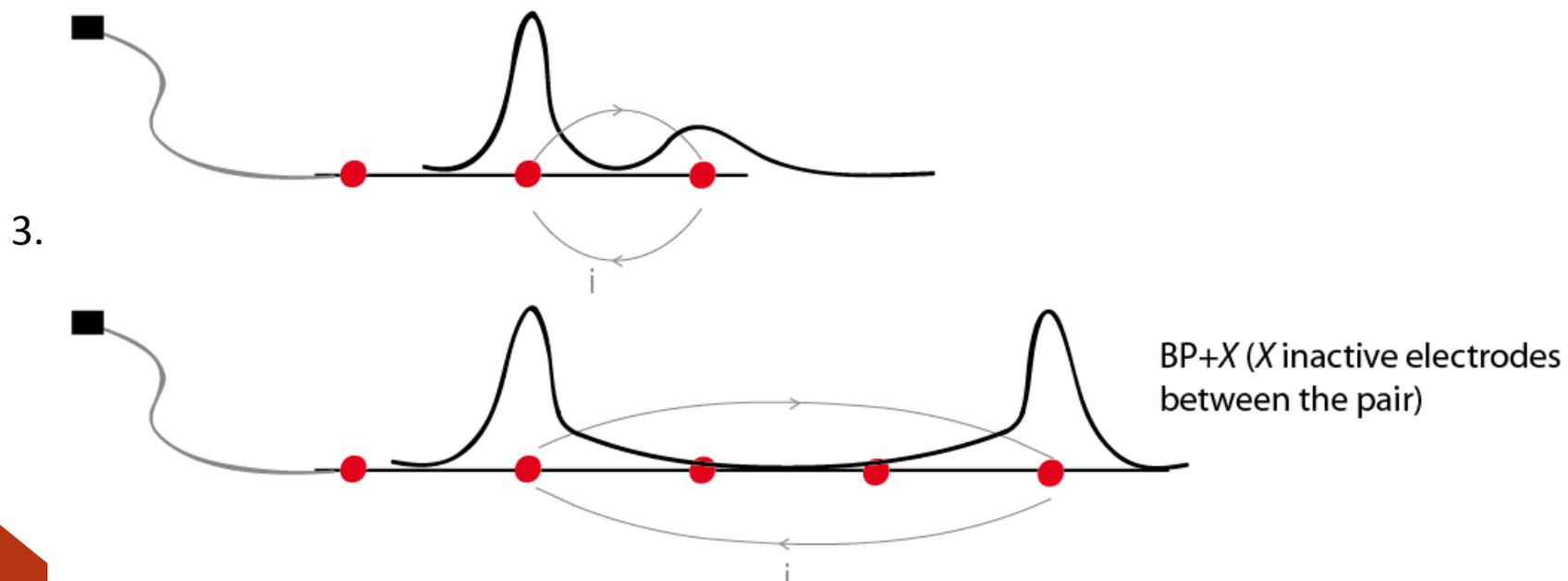


Project outline:

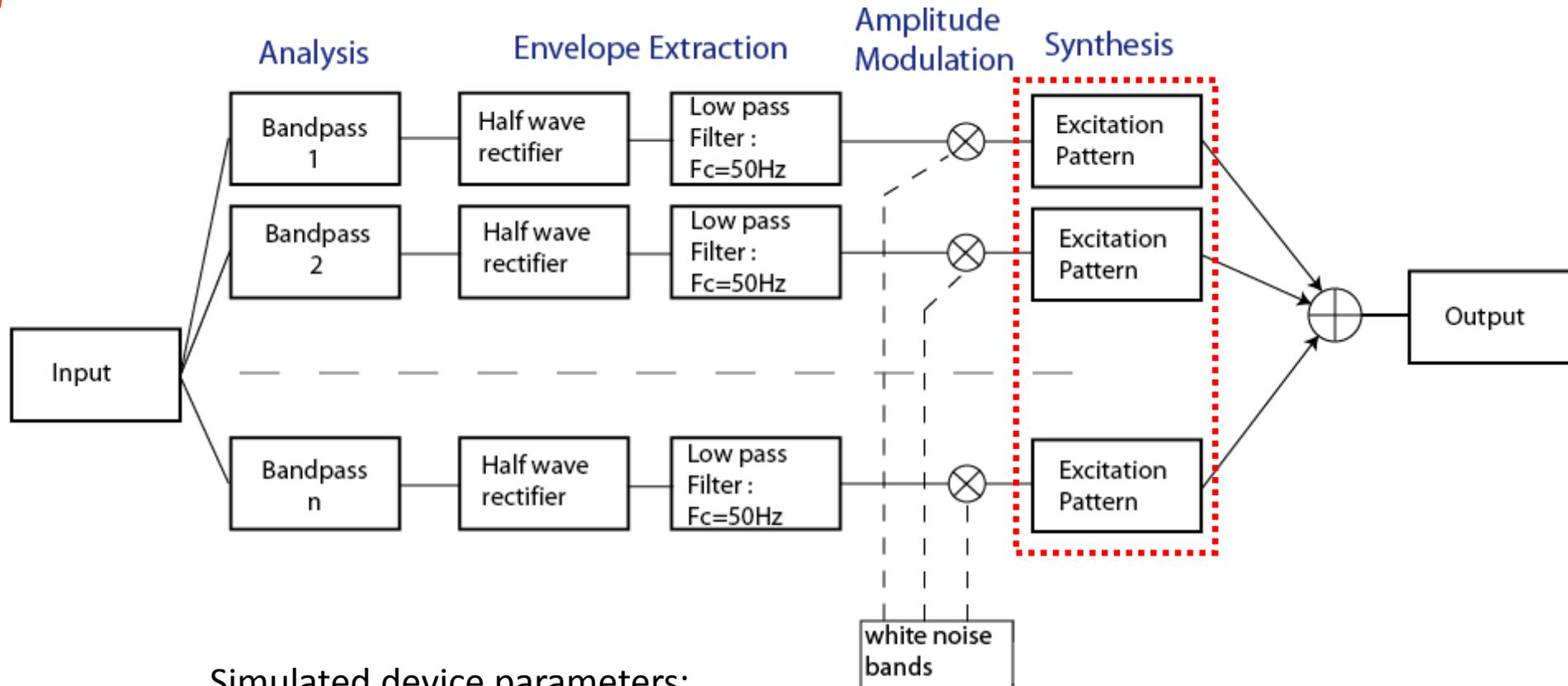


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Acoustic simulation: Vocoder



Simulated device parameters:

- Frequency range 250-5500Hz (Analysis filters = 6th order Butterworth filters)
- 17 electrodes array, (1,13 mm spacing)
- Various numbers of channels

Simulation of the spread of excitation

- White noise carriers
- **Synthesis filters design** (Bingabr et al., 2008, Friesen et al., 2001)

Test procedure



- Normal hearing subjects, 18-30 years old

- Speech recognition task: French Matrix Test (Jansen et al., 2011) closed-set identification, word scoring.

“Michel achète trois vélos bleus” ≈ “Michel buys three blue bicycles”

- Masker: time-reversed speech concatenated sentences extracted from the French Intelligibility Sentence Test corpus (FIST, Luts et al., 2008)

“troporéa'l ed éévirra erocne sap tse'n ellE ” ≈ “tey tropria eht morf devirra ton sah ehS”

- 2 target to masker ratios: +10dB and +5dB

- Substantial training : 40 sentences of passive listening (pop out) + 20 sentences of recognition task with feedback, per condition
- Each subject tested 150 words per condition
- Scores transformed in rationalized arcsine unit (Studebaker, 1985)

noms	verbes	nombres	objets	couleurs
Sophie	déplace	sept	pions	noirs
Charlotte	propose	cinq	rubans	gris
Félix	achète	six	anneaux	blancs
Eugène	reprend	neuf	ballons	roses
Michel	ramène	onze	jetons	mauves
Etienne	demande	douze	vélos	bleus
Julien	dessine	huit	piquets	bruns
Agnès	attrape	quinze	crayons	verts
Emile	voudrait	deux	livres	rouges
Jean-Luc	ramasse	trois	classeurs	jaunes

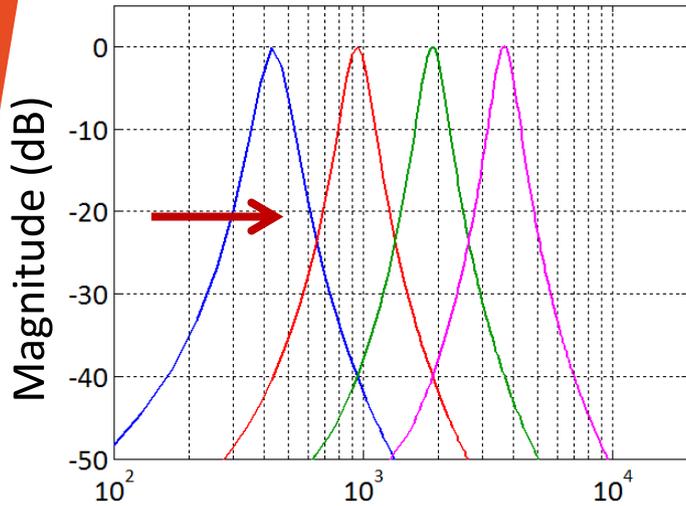
Experiment 1: Stimuli



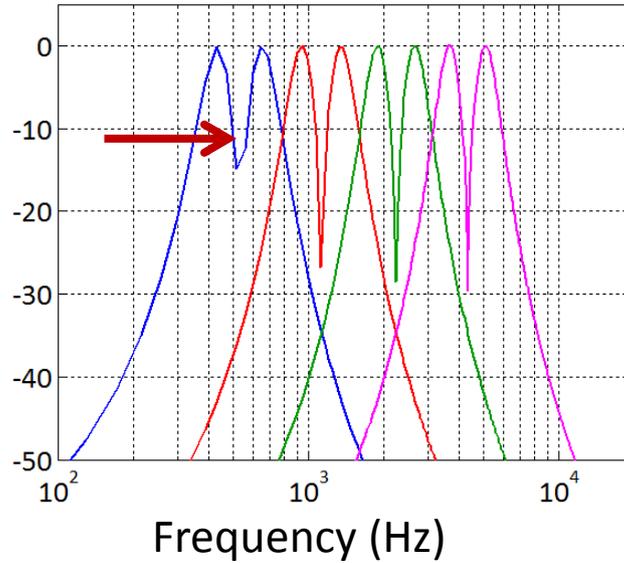
9 conditions: 3 Stimulation modes, 3 numbers of channels (4, 8 and 15)

3 stimulation modes = 3 synthesis filters

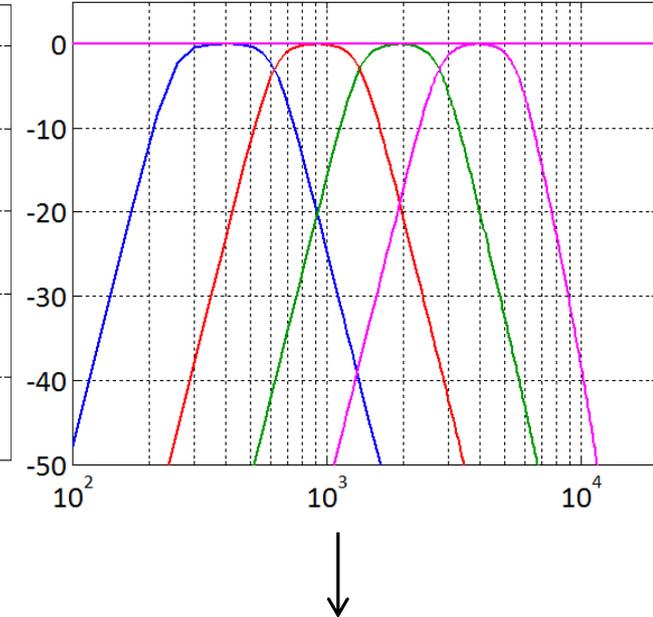
Monopolar (MP)



Bipolar (BP+I)



Control (CTRL)



Analysis filters = Synthesis filters

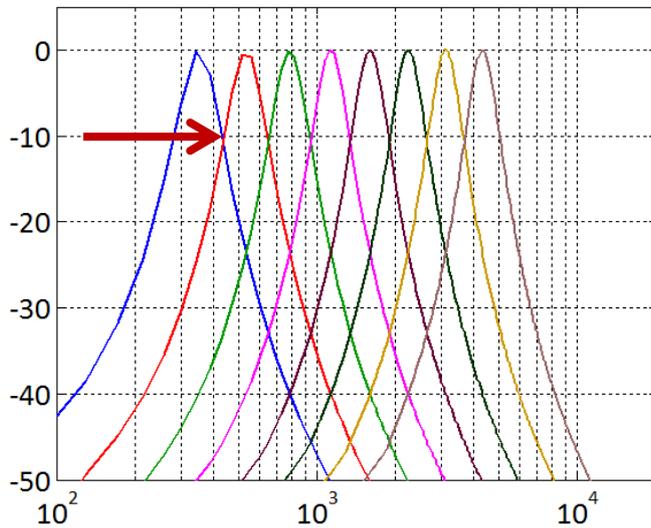
Experiment 1: Stimuli



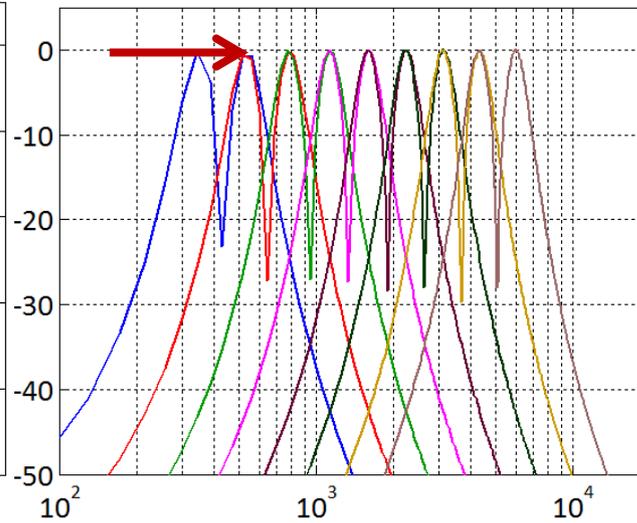
What is supposed to happen when N increases?

N=8 (figures below)

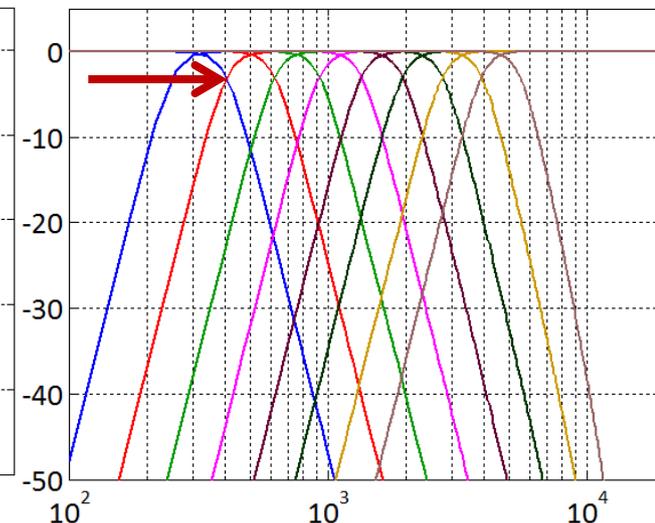
Lateral spread of excitation
≈ Constant shape (on a log scale)



Interactions increase with N



Perfect overlap of two peaks
from two synthesis filters



Bandwidth diminishes
with increasing N

Will simulation results match CI users' data reported in the literature ?

Experiment 1 : Results



9 subjects

3-way repeated measures ANOVA.

Interaction between
N and stimulation mode

=The evolution of performance with N is dependent on the stimulation mode !

N=4: ≈Equivalent scores

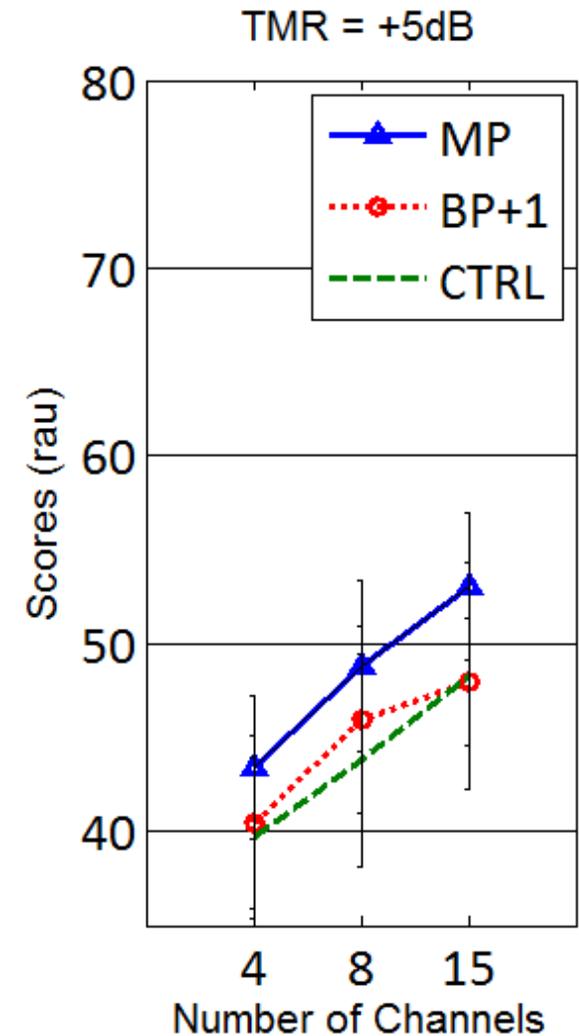
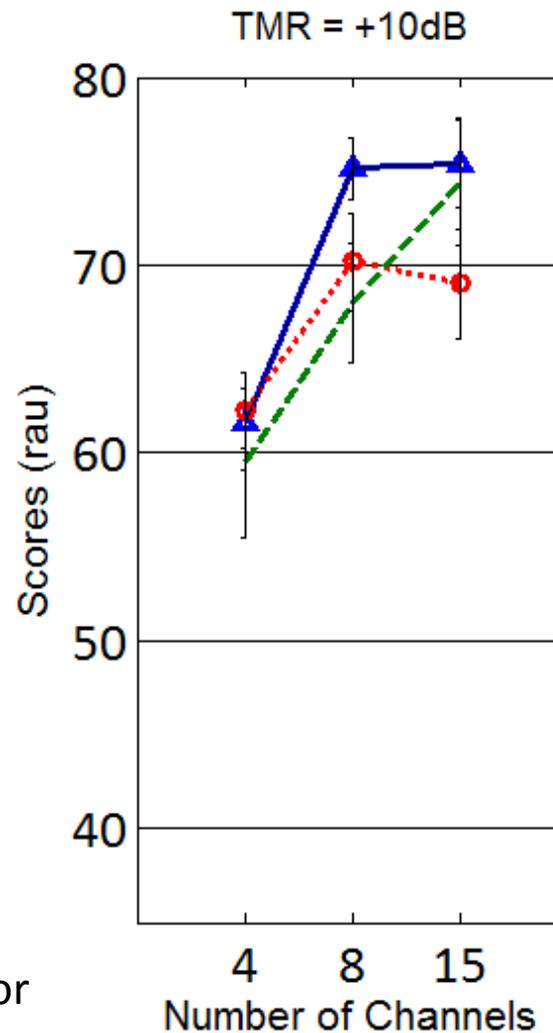
N=4 & 8: Improvement

Bigger improvement for **MP** than for **BP+1**

N=8 & 15:

No improvement for MP and BP+1 = plateau
CTRL keeps improving with N

☐ Consistent with CI users data



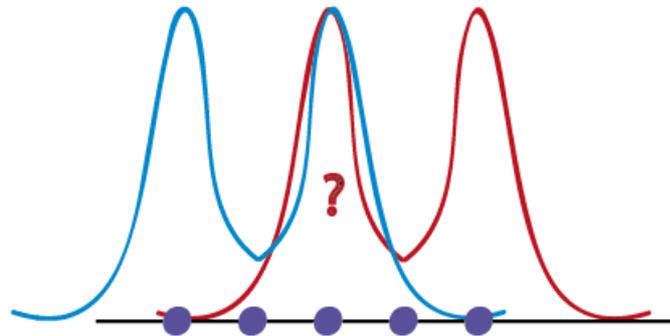
Experiment 1 : Discussion



A marked effect of **channel interactions** is suspected when simulating a lateral spread of excitation.

BP+1 seems to be even **more affected**...Scores 5 points lower than MP for 8 channels

many simulated electrodes act as the “active” electrode for one channel and as the “return” electrode for the neighboring channel



Apart from the amount of interactions,

Is the bimodal shape of the excitation of problem per se?

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1. Simulating **monopolar** and **bipolar** stimulation modes

☐ **Monopolar > Bipolar**, consistent with CI users' data

2. Testing the influence of the **bimodal excitation pattern**

3. Investigating the effects of **spacing between electrodes**

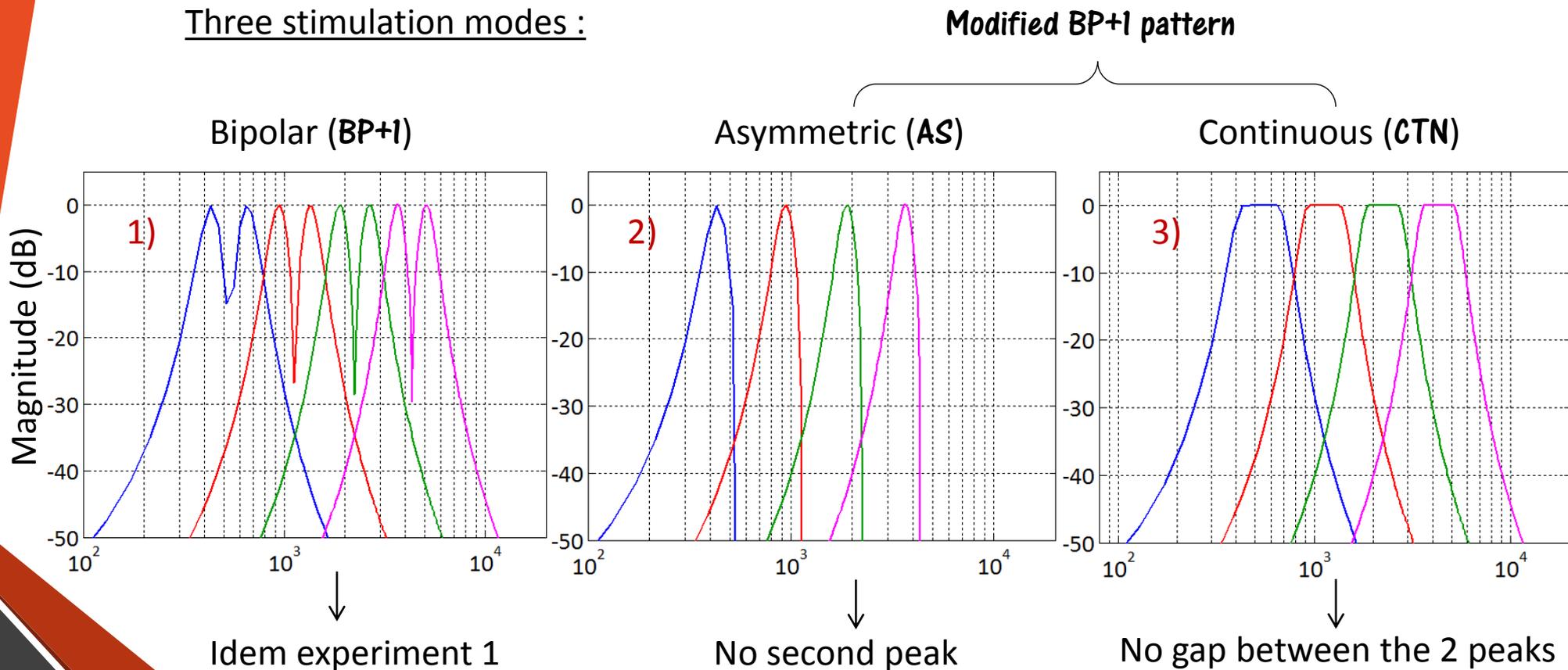
Experiment 2: Stimuli



Two main features related to the bimodality of the excitation pattern:

- Bipolar stimulation excites two distinct pools of neurons **1) vs. 2)**
Redundant information ?
- The excitation pattern is discontinuous. **1) vs. 3)**

Three stimulation modes :



Same protocole with these new filters

Experiment 2: Results



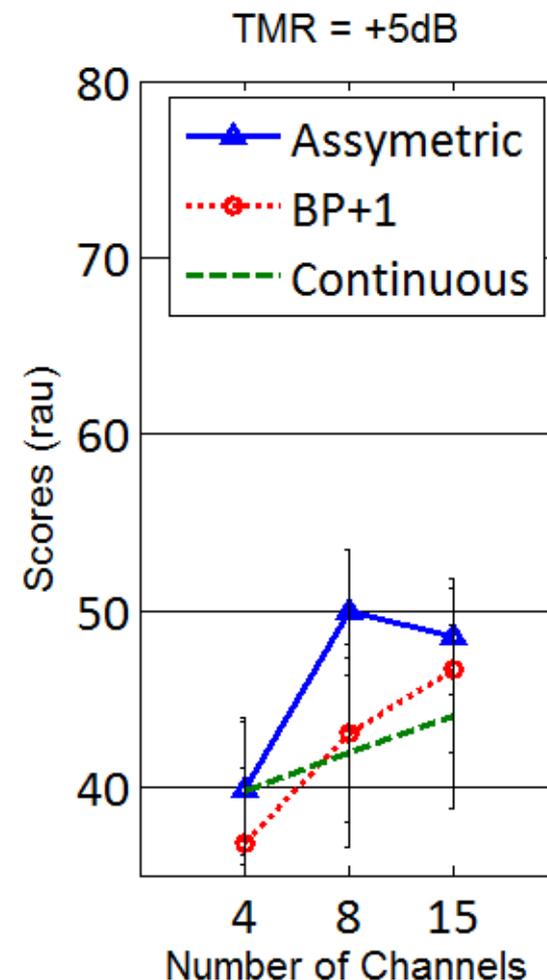
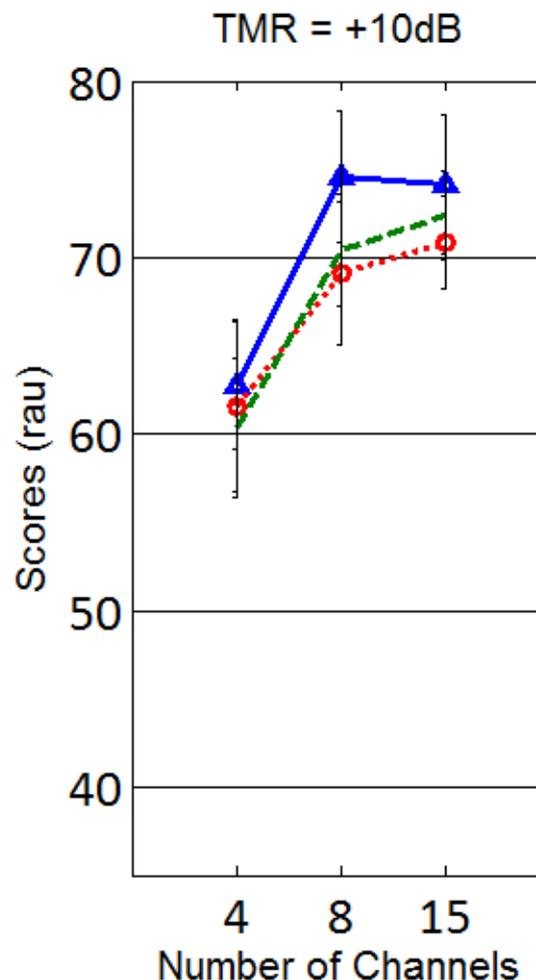
7 of the previous subjects

3 ways repeated measures ANOVA.

N=4: ≈Equivalent scores

N=4 & 8: Improvement
Bigger improvement for
Asymmetric than for **BP+1** and
Continuous

N=8 & 15:
Little improvement



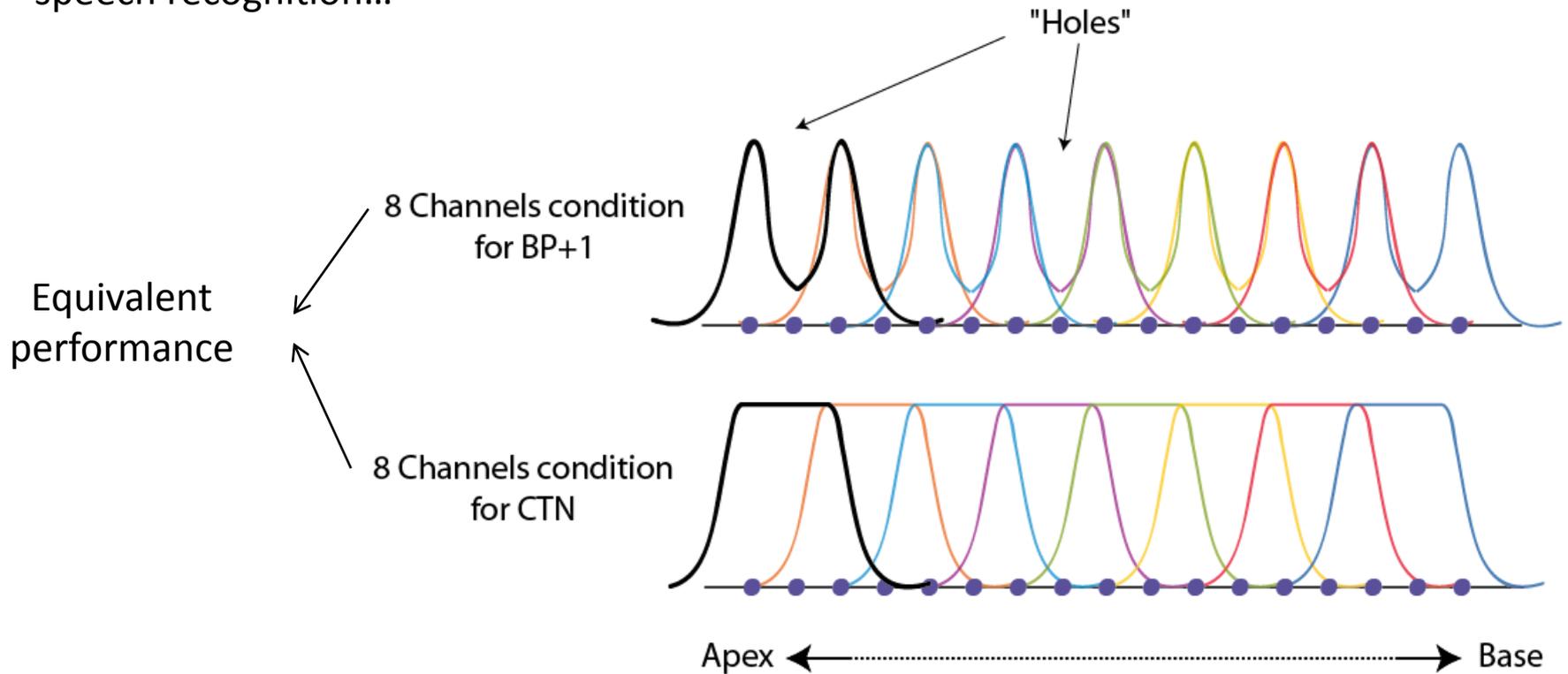
- **Asymmetric** more intelligible than **BP+1** and **CTN**

Significant benefit in removing the second peak = **Better selectivity**

- **BP+1** ≈ **CTN**

Experiment 2 : Discussion

Shannon et al., 2001: "Holes in hearing" up to 3 mm are supposed to have little effect on speech recognition...



Here we have **8 holes of 2.3mm** and still no deleterious effect!

This suggests that the effects of several gaps do not sum up

Experiment 2 : Discussion



This suggests that, for a given amount of interactions the bimodality is not a problem per se.

What if one varies the gap between the two peaks to reduce channel interactions ?

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Three **experiments** to better understand the poor performance obtained with BP stimulation:

1. Simulating **monopolar** and **bipolar** stimulation modes
 - ☐ **Monopolar** > **Bipolar**, consistent with CI users' data
2. Testing the influence of the **bimodal excitation pattern**
 - Bimodality does not seem to be a problem per se
3. Investigating the effects of **spacing between electrodes**

Experiment 3: Hypothesis



Previous results with CI users:

- **Wide BP \geq Narrow BP** Pfingst et al., 1997, 2001

Suggested explanations:

- Wide BP generates wider peaks of excitation
ie. **Activate more neurons** = more robust neural representation of the signal

a larger spacing should also:

- **reduce the amount of interactions** between channels
- **distribute the energy** on the whole frequency range

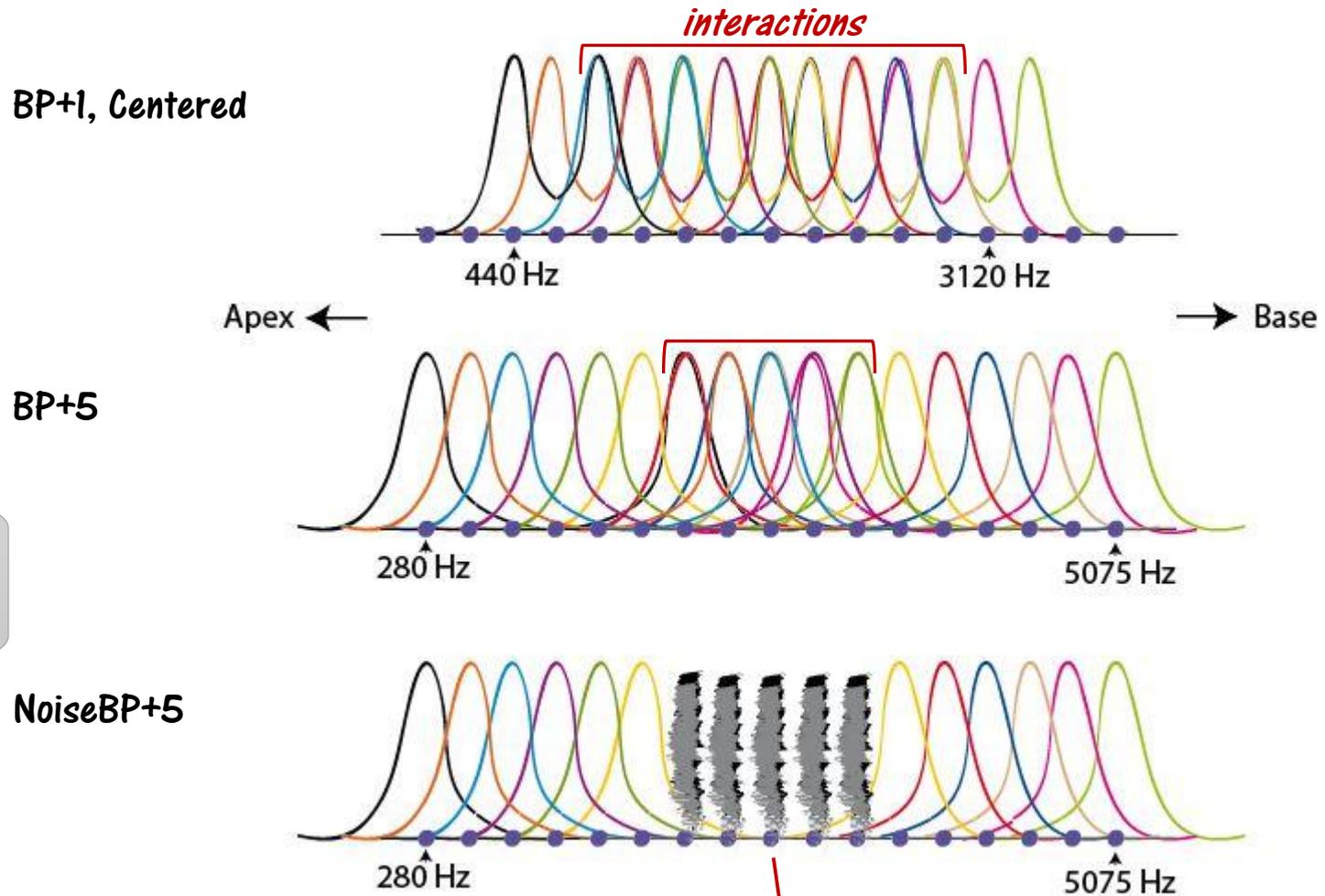
Simulation parameters:

- Analysis on the 250-5500Hz frequency range
- 11 synthesis channels
- 2 different spacings: BP+1 and BP+5

Experiment 3: Stimuli

Here we try to reproduce several conditions tested in Pfingst et al., 2001 with CI users...

3 conditions:



A vocoder is a pretty funny tool!

Interacting parts of the signal are removed and replaced by stationary noise restricted to the **same frequency range** (filtered by one peak only) and of the **same energy**

Experiment 3: Conditions & Expectations



3 conditions: 3 stimulation configurations (*Centered*, *BP+5*, *NoiseBP+5*)*2 TMR

We can expect:

$BP+5 \geq Centered$

And what about *NoiseBP+5* ?

Experiment 3: Results



8 new subjects

Effect of spacing:

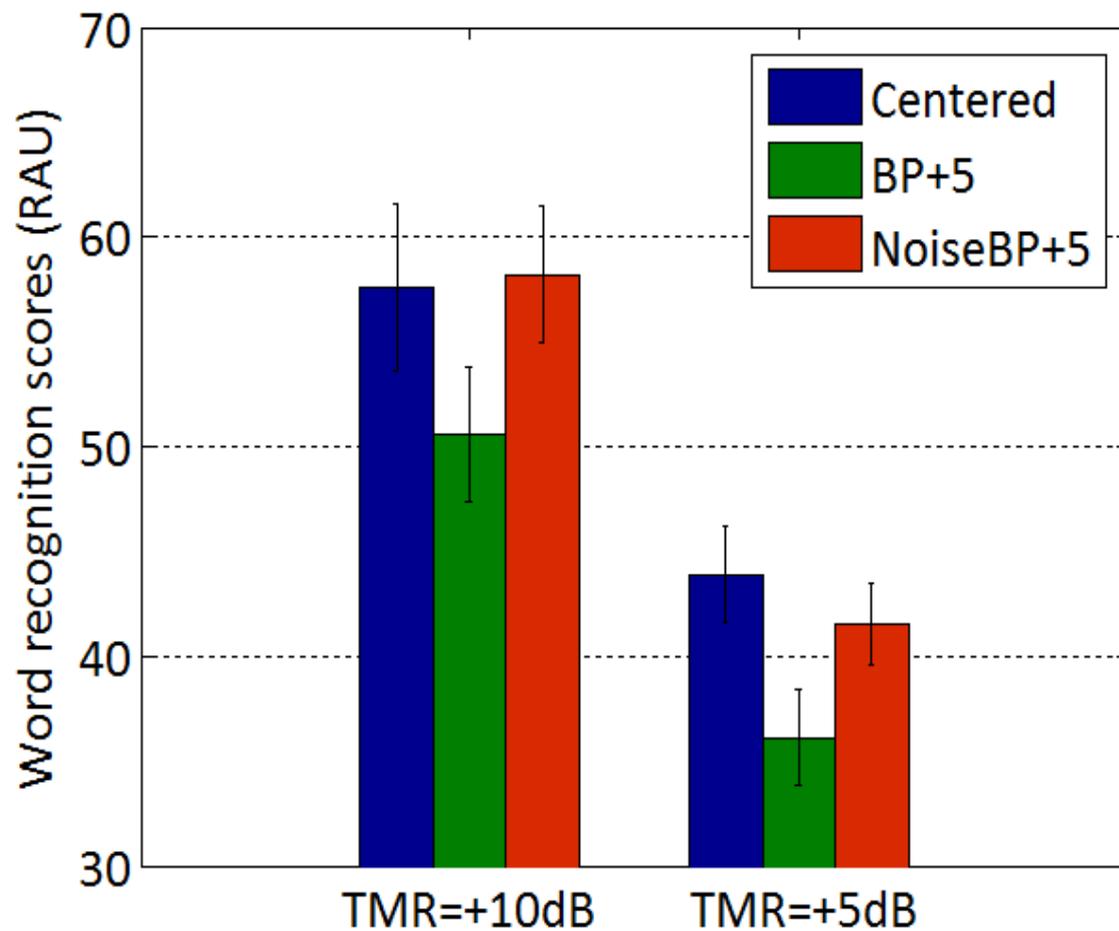
- **BP+5 < BP+1**

Opposite to Pfungst et al., 1997, 2001
with CI users !!

- **NoiseBP+5 > BP+5**

Possible explanation:

Interactions in BP+1 or BP+5 are **not**
equally deleterious



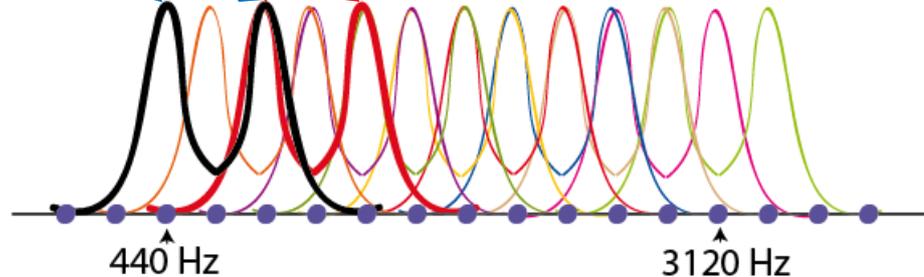
Experiment 3: Discussion

Interactions = superposition of 2 **temporal envelopes** from remote parts of the input signal's spectrum

Analysis bands



BP+1

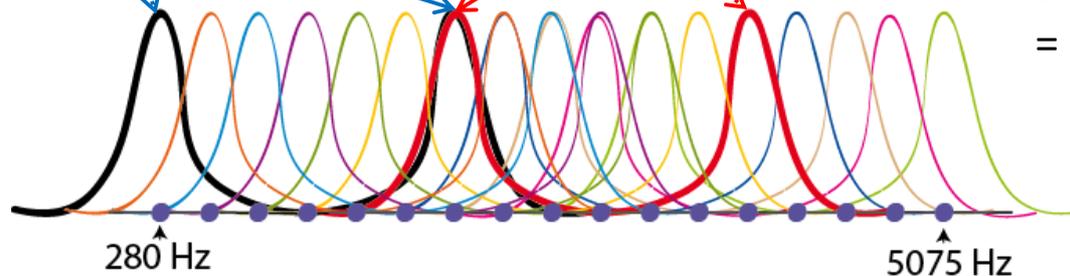


Envelopes from the 1st and the 3rd analysis bands interfere
= **correlated envelopes**, $r=0,66$

Analysis bands



BP+5



Envelopes from the 1st and the 7th analysis bands interfere
= **poorly correlated envelopes**, $r=0,28$

↓
Fewer interactions but highly deleterious !

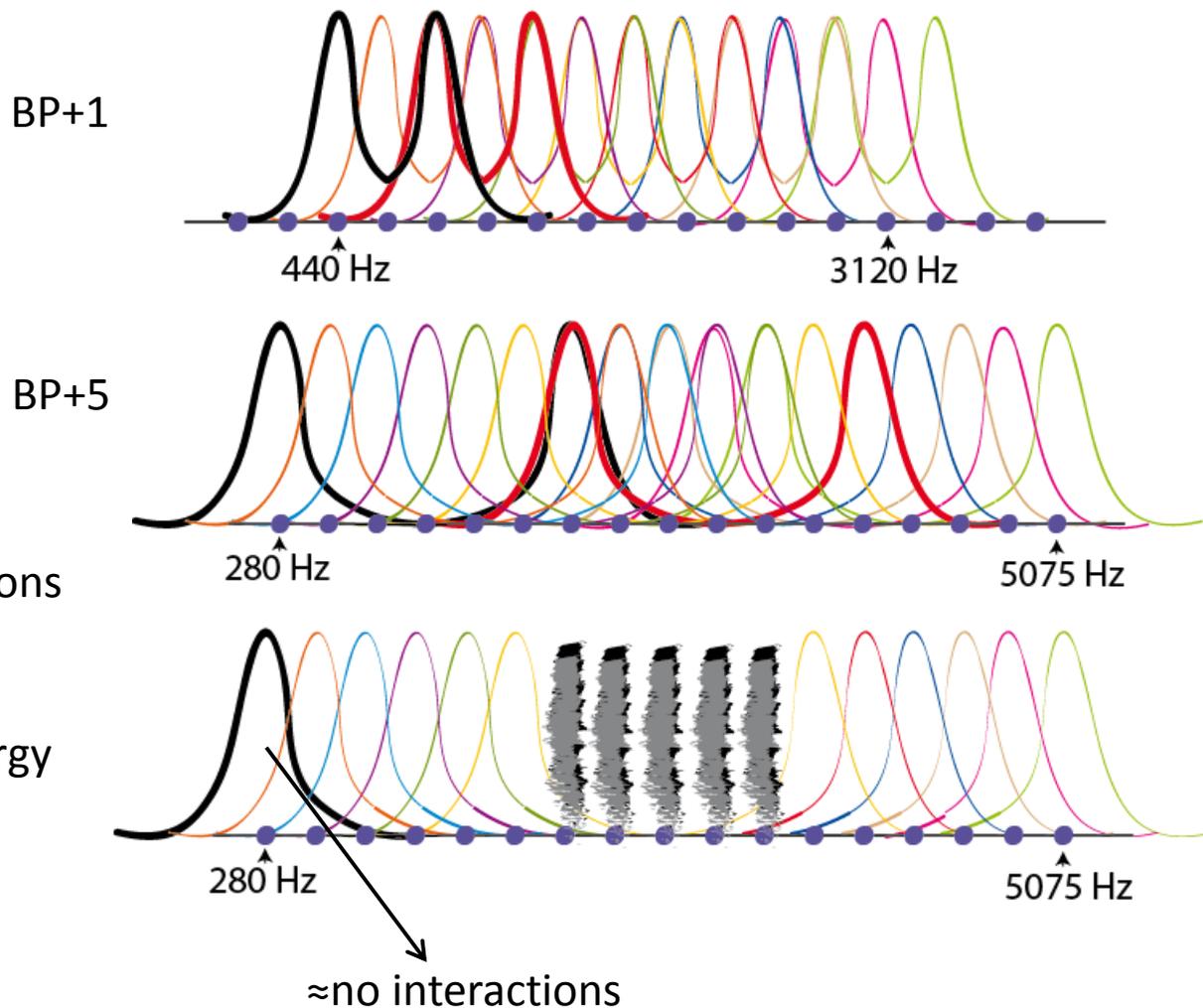
Experiment 3: Discussion



These interpretations are supported by the results of **NoiseBP+5**.

With **NoiseBP+5** main interactions are removed.

Better distribution of the energy



However: **NoiseBP+5** \approx *Centered BP+1*

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☐ Bimodality does not seem to be a problem per se

3. Investigating the effects of **spacing between electrodes**

→ Larger spacing did not improve speech recognition
Channel interactions in wide BP seem highly deleterious

General Conclusion

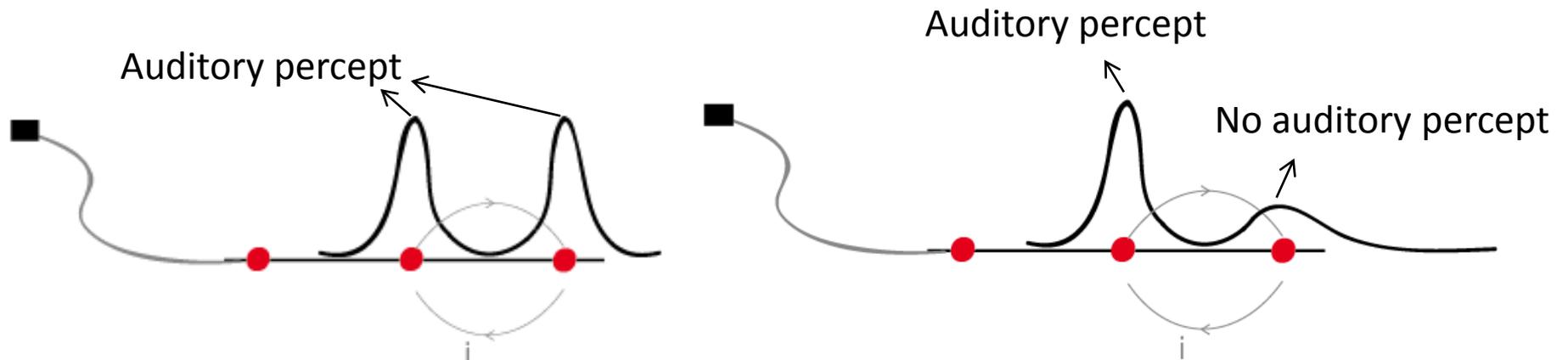


Those results seem to demonstrate that:

- BP stimulation is mainly limited by the fact it introduces channel interactions
- The influence of channel interactions depends on the correlation between the overlapped signals

□ The efficiency of focused stimulation depends on the influence of the return electrode.

(Using asymmetric pulse shapes could improve the performance of BP stimulation by reducing the influence of one of the excitation peaks)



This is supported by the last results obtained with **Partial Tripolar** stimulation



Thank you very much for your attention.

Special thanks to:

Olivier & Gaston for supervising me

The entire team

Sabine, Sophie, Jacques, Guy, Pierre and Michèle

For their help advice and for all the pleasant moments we can share

During this project

And hopefully for the next 3 years