NEURAL REPRESENTATION OF INTERAURAL TIME DIFFERENCES IN THE HUMAN BRAIN

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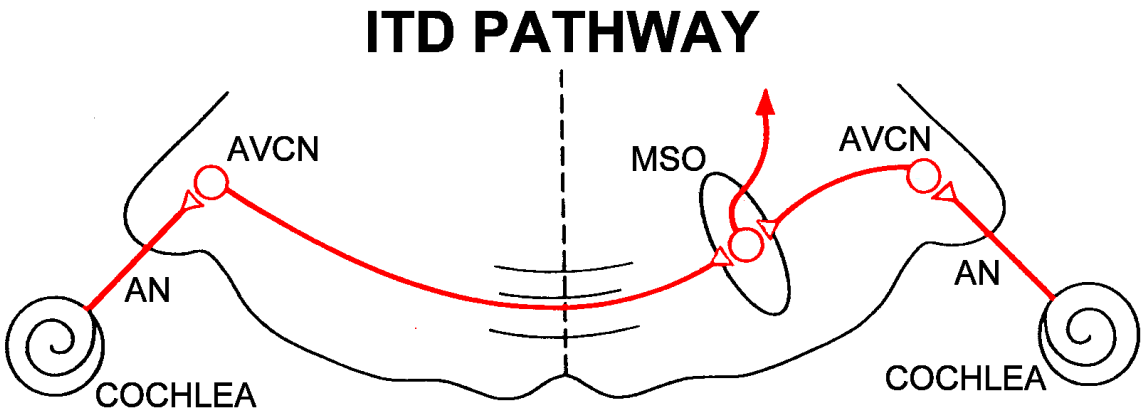
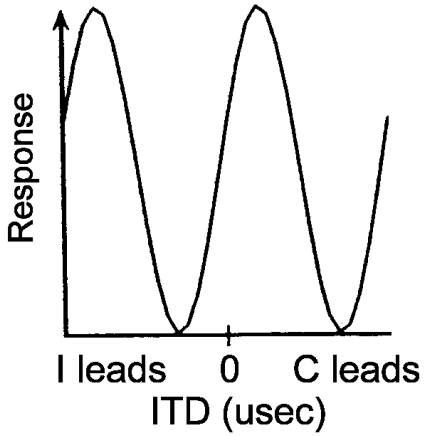
INTRODUCTION

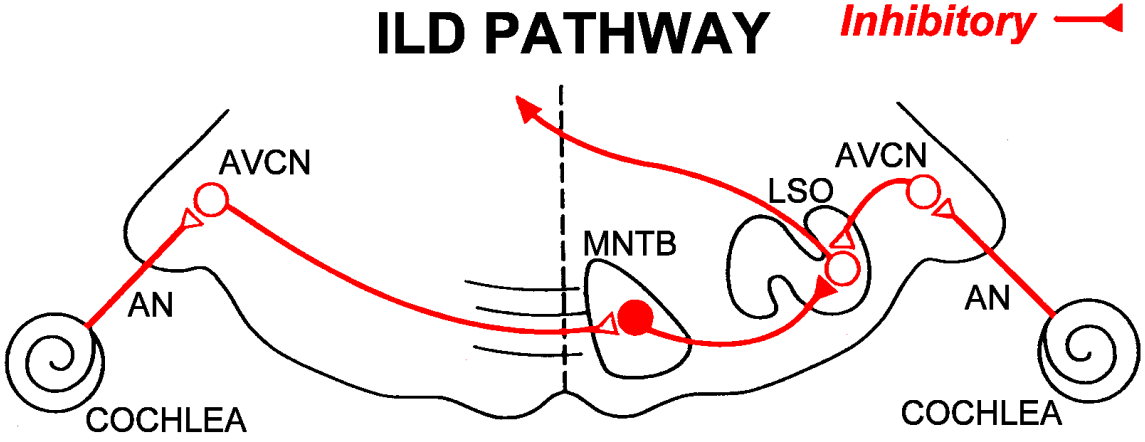
- Interaural time differences (ITDs) are the main cue used by humans and other mammals to determine the horizontal position below 1.5 kHz.
- ITD sensitivity is achieved by coincidence-detecting neurons in the superior olive - the first structure of binaural processing in the auditory pathway.

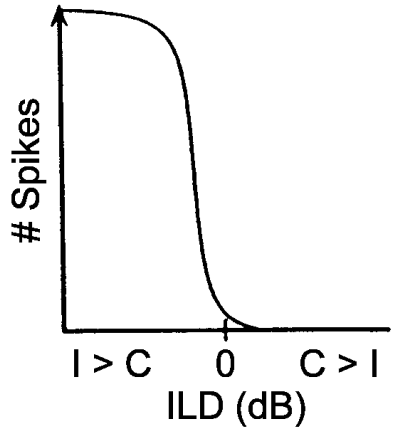




Excitatory

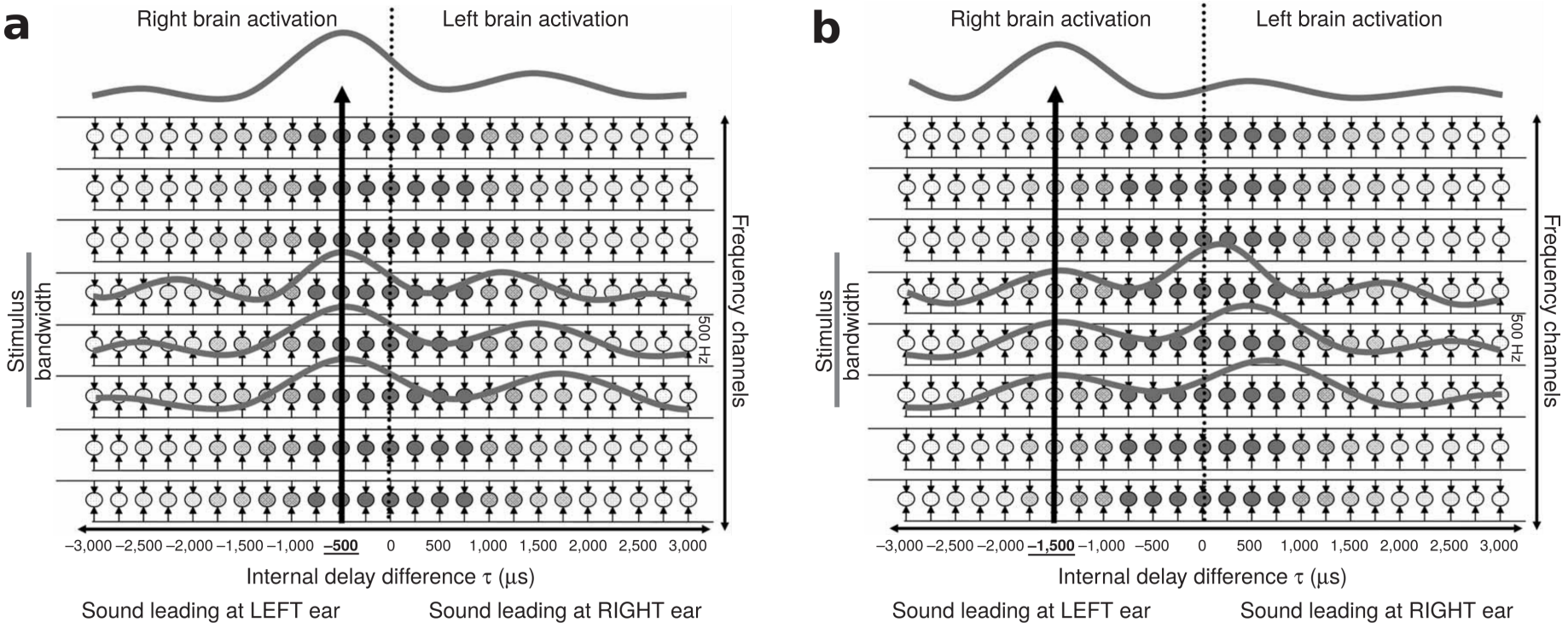
Inhibitory





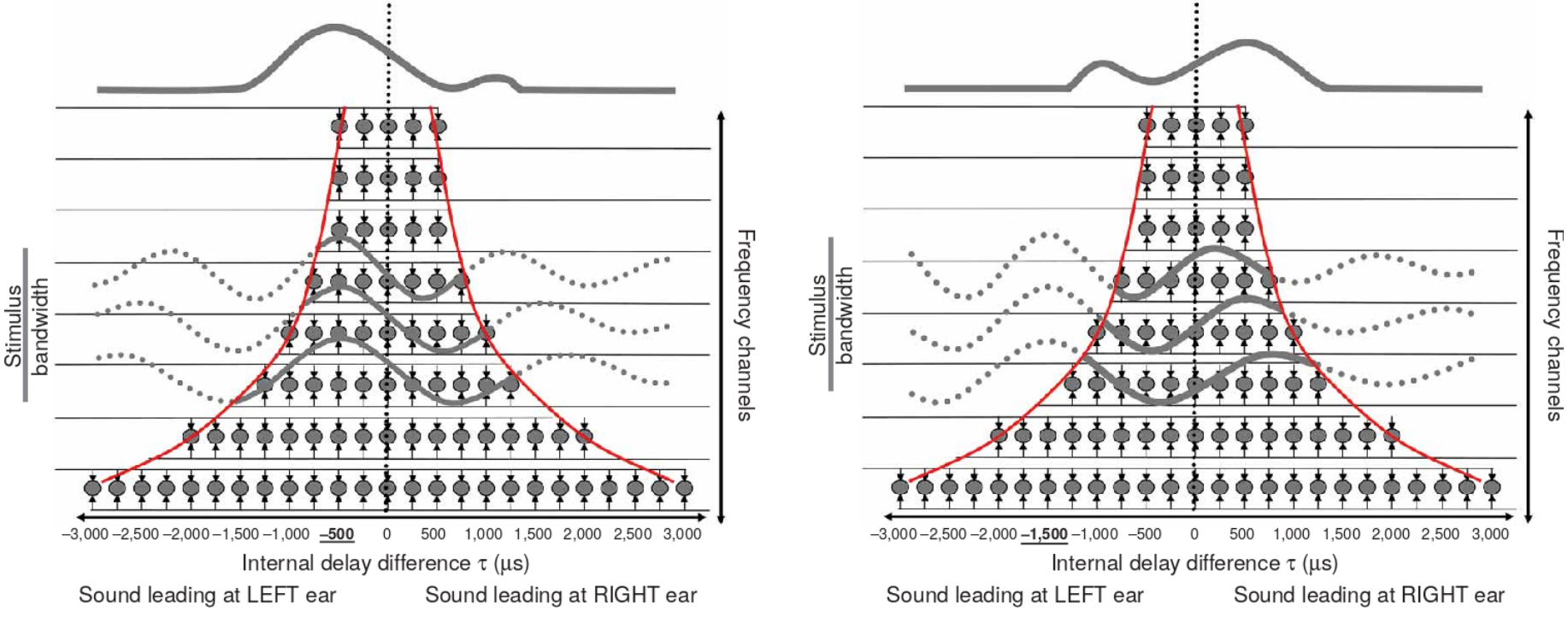
MODELS FOR ITD PROCESSING

STRAIGHTNESS WEIGHTING



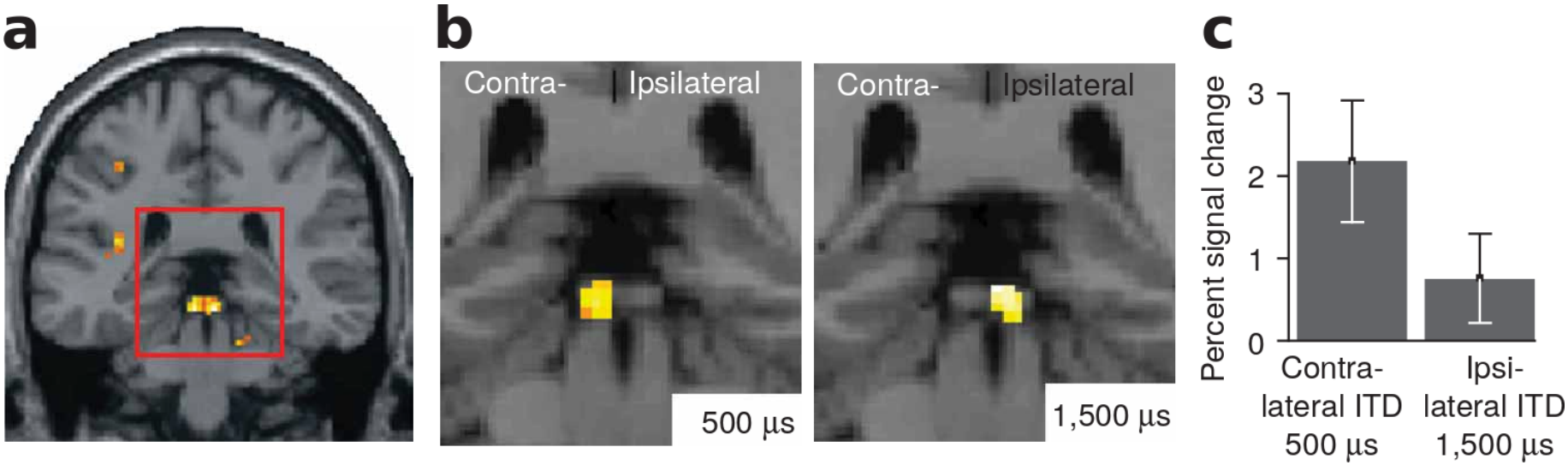
- Peaks of the cross-correlograms at –1.5 ms < peaks closer to 0 - central weighting.
- Correct localization estimated from second processing level (in the inferior colliculus, gray curve on top of each panel).

THE π-LIMIT



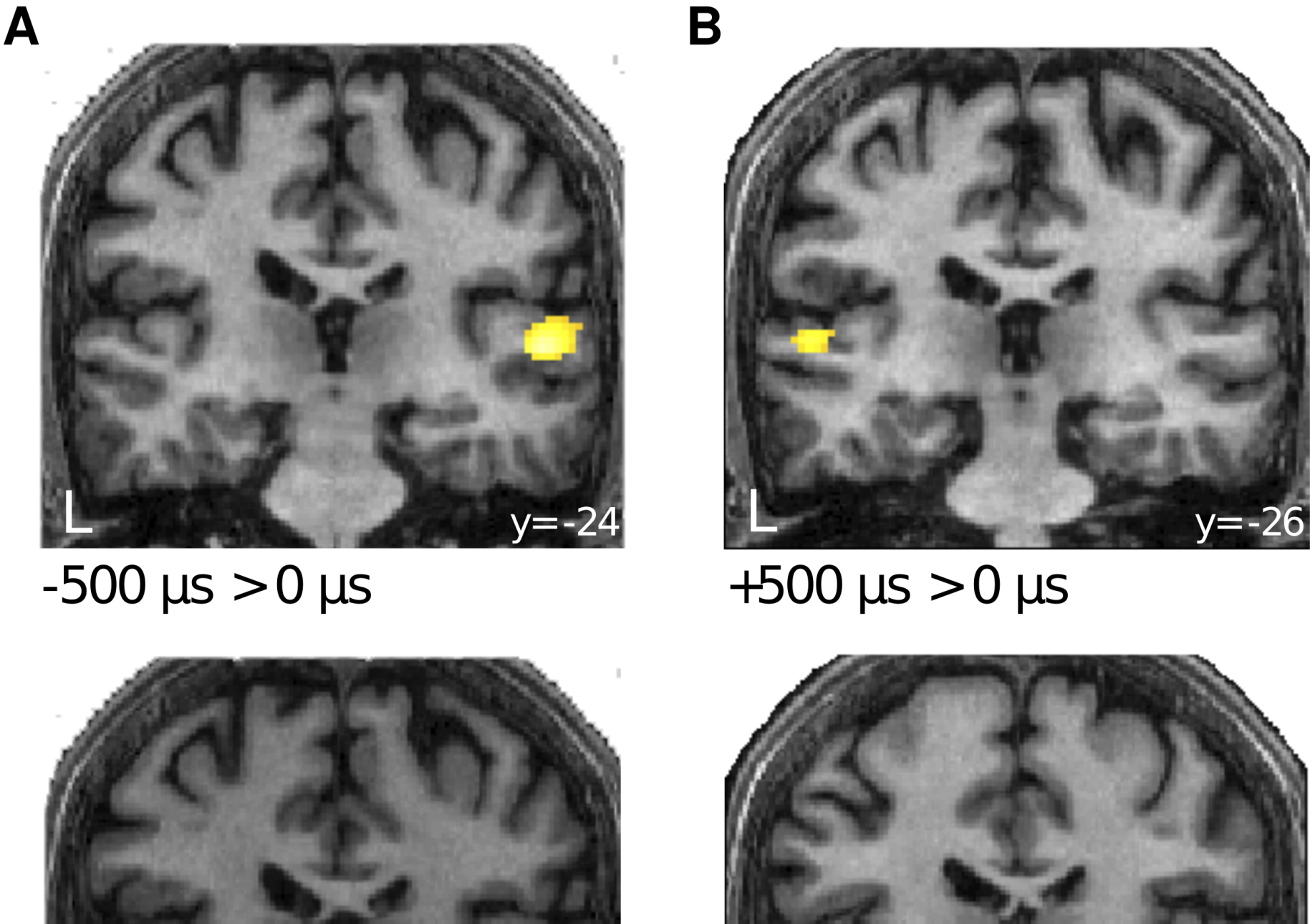
- ITD detectors in the mammalian brain restricted to $\approx$ half a cycle of best frequency.
- Frequency-dependent weighting for centrality

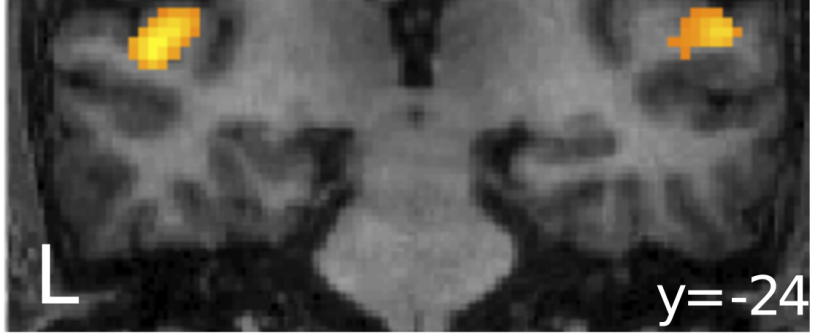
Thompson et al. (2006)



- Inferior colliculus consistent with the π-limit.
- Cortical responses to sounds with ITDs within the π-limit are in line with the predictions of both models.
- However, neural activation is bilateral for “long” ITDs, despite these being perceived as clearly lateralized
- Long ITDs leads to higher activation in cortex than processing of short ITDs.

Kriegstein et al. (2008)





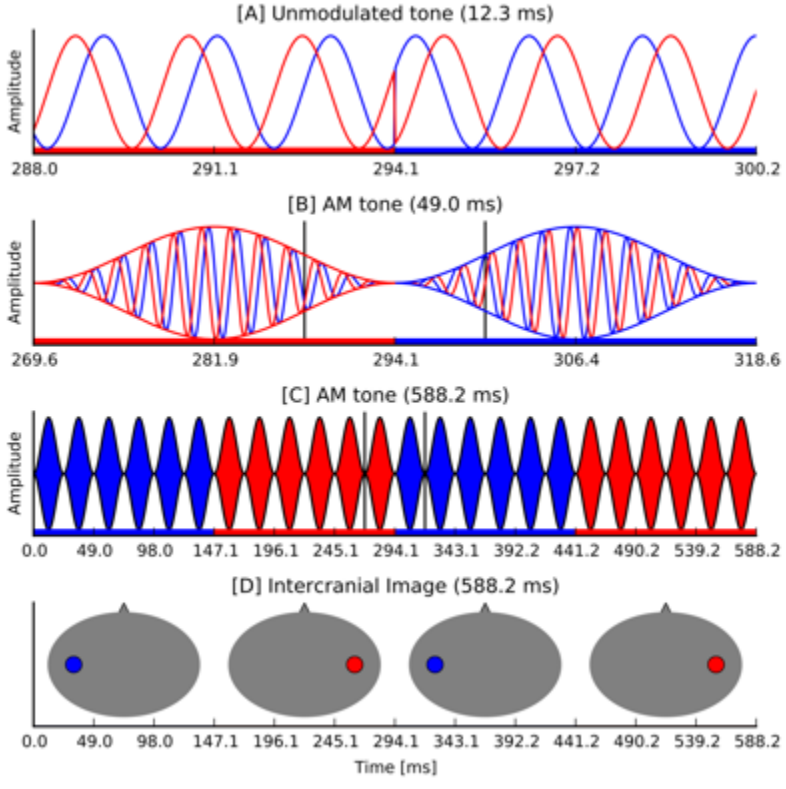
-1500 µs >0 µs

+1500 µs >0 µs

AIMS

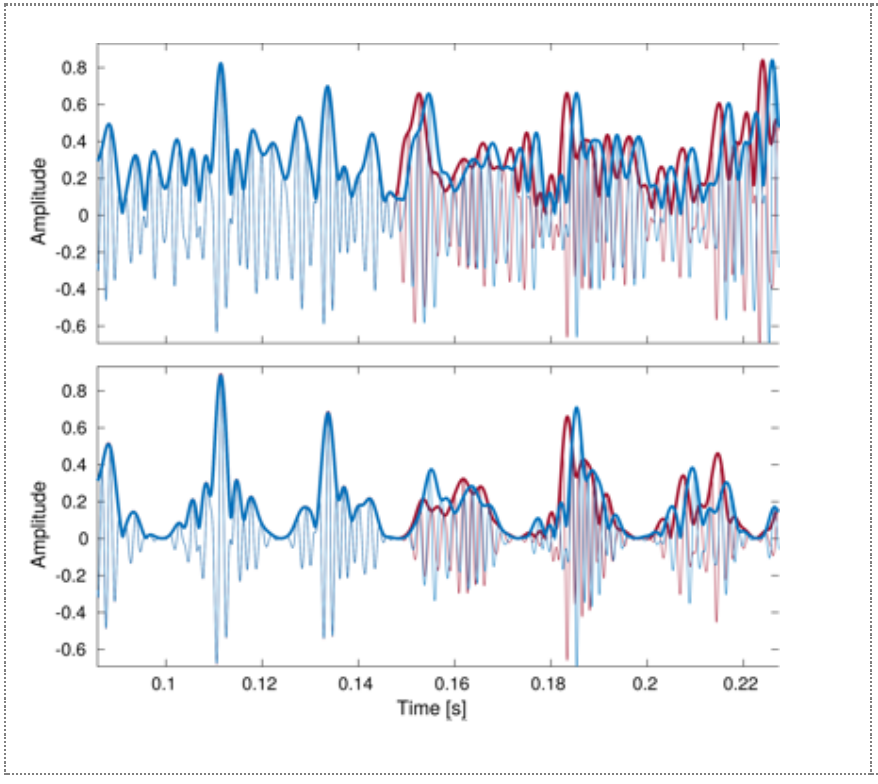
- to evaluate how short and long ITDs are processed in the human cortex using EEG recordings

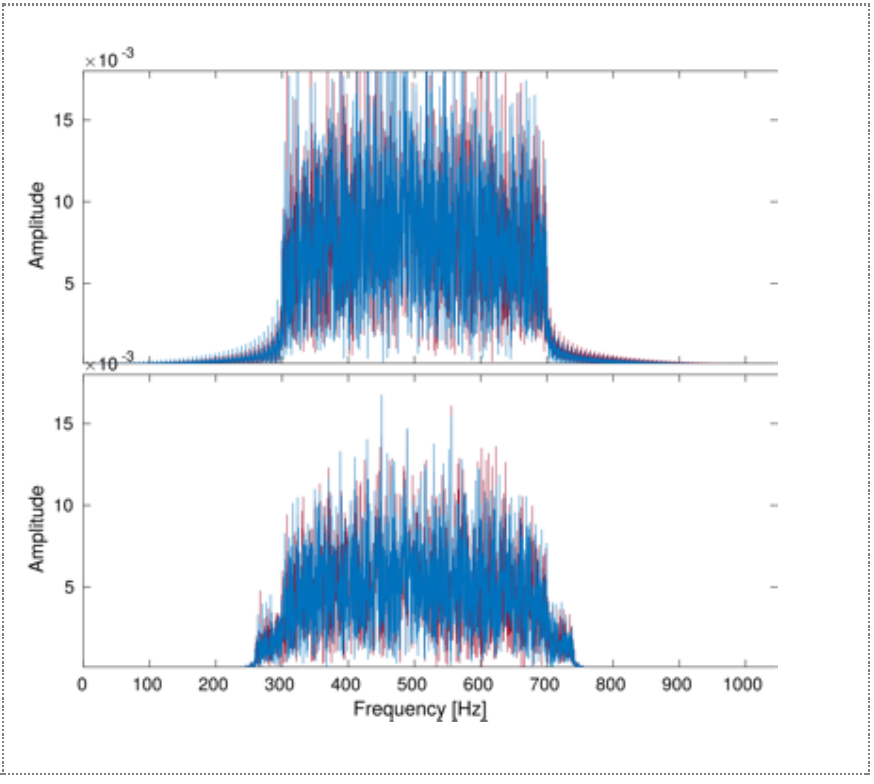
METHODS


[A] Unmodulated tone (12.3 ms)
Amplitude
288.0
291.1
294.1
297.2
300.2
[B] AM tone (49.0 ms)
Amplitude
269.6
281.9
294.1
306.4
318.6
[C] AM tone (588.2 ms)
Amplitude
0.0
49.0
98.0
147.1
196.1
245.1
294.1
343.1
392.2
441.2
490.2
539.2
588.2
[D] Intercranial Image (588.2 ms)
0.0
49.0
98.0
147.1
196.1
245.1
294.1
343.1
392.2
441.2
490.2
539.2
588.2
Time [ms]

STIMULI

- 500 Hz bandwidth modulated noise (40.4 Hz) centered at 500 Hz
- Periodics interaural time moulations at 6.7 Hz (ITM-FRs)





RECORDINGS

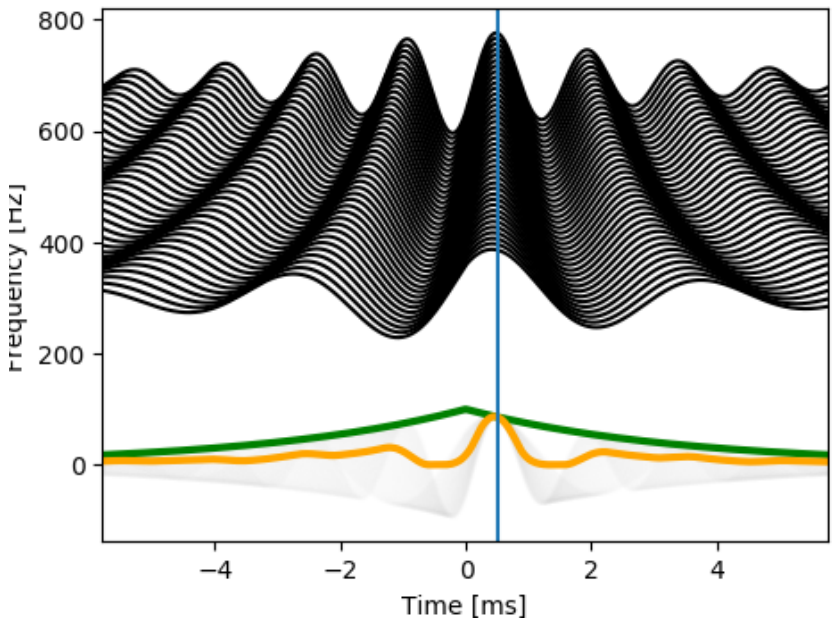
- 10 normal hearing participants
- 66 channels Biosemi active electrode system
- 5 minutes recordings

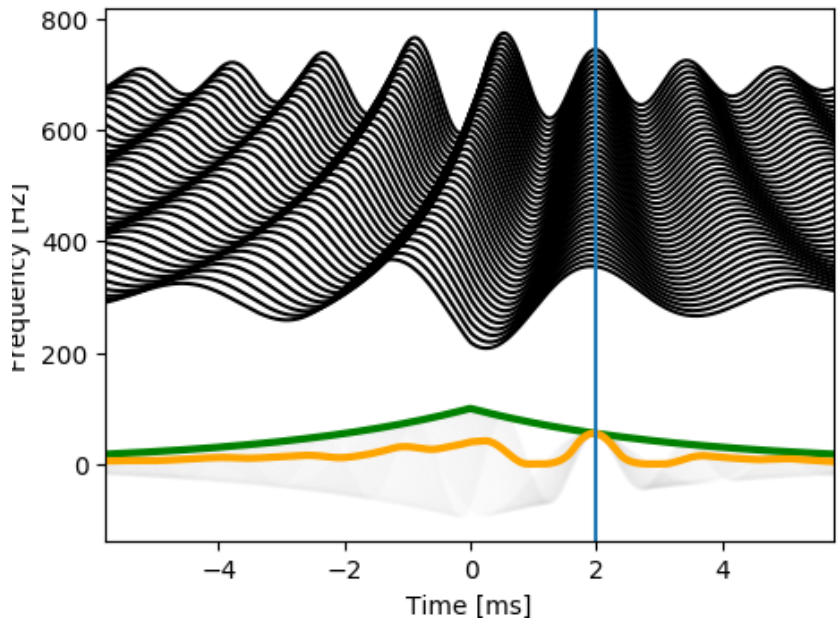
Analysis:

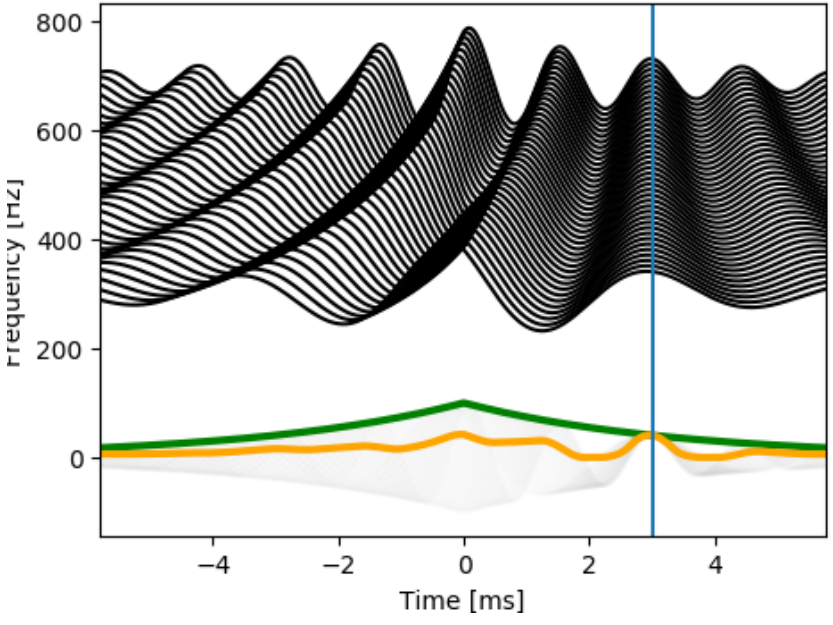
- low pass filter 60Hz, high pass filter 2Hz
- automatic removal of bad channels
- denoising source separation
- weighted average

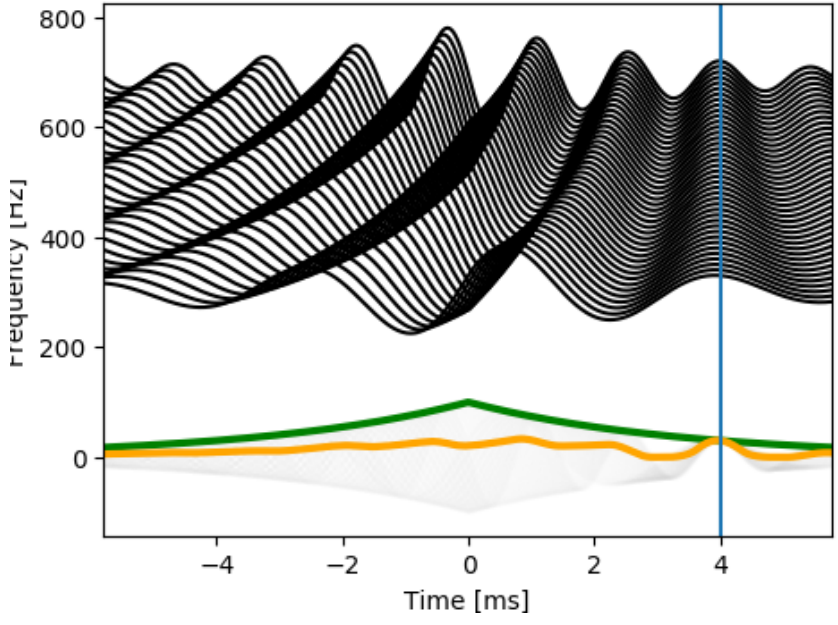
EXPERIMENT 1

STRAIGHTNESS WEIGHTING






800
600
400
200
0
Frequency [Hz]
−4
−2
0
2
4
Time [ms]

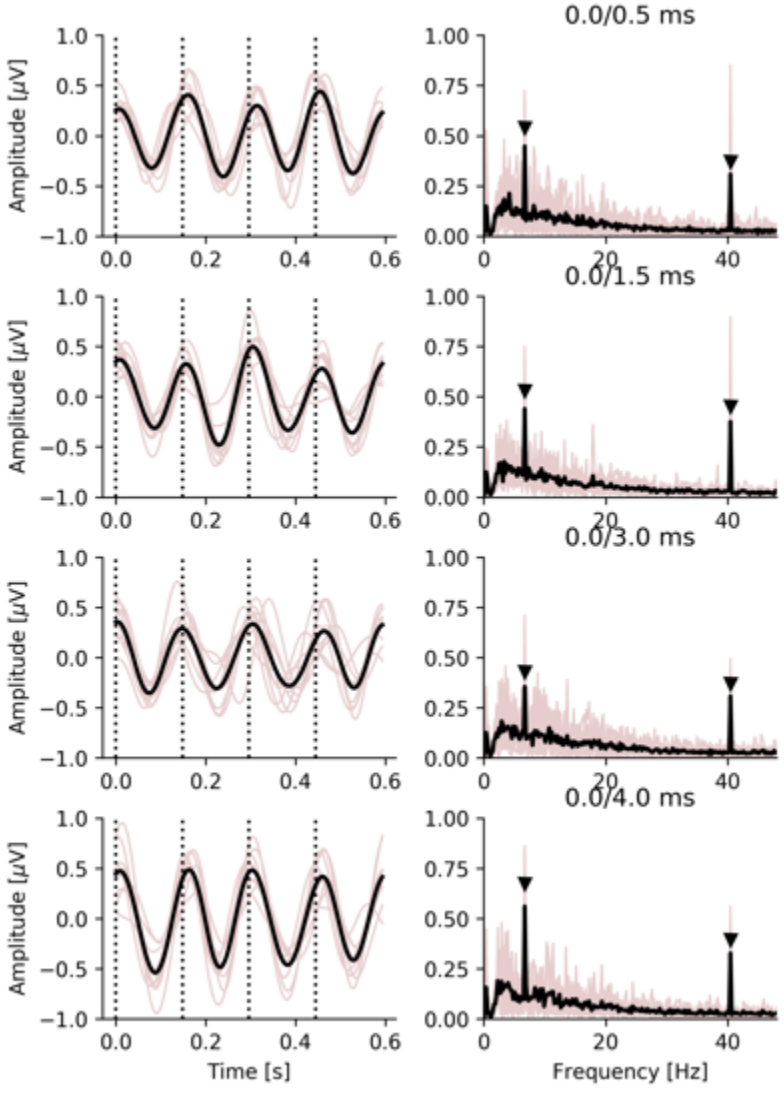

800
600
400
200
0
Frequency [Hz]
−4
−2
0
2
4
Time [ms]

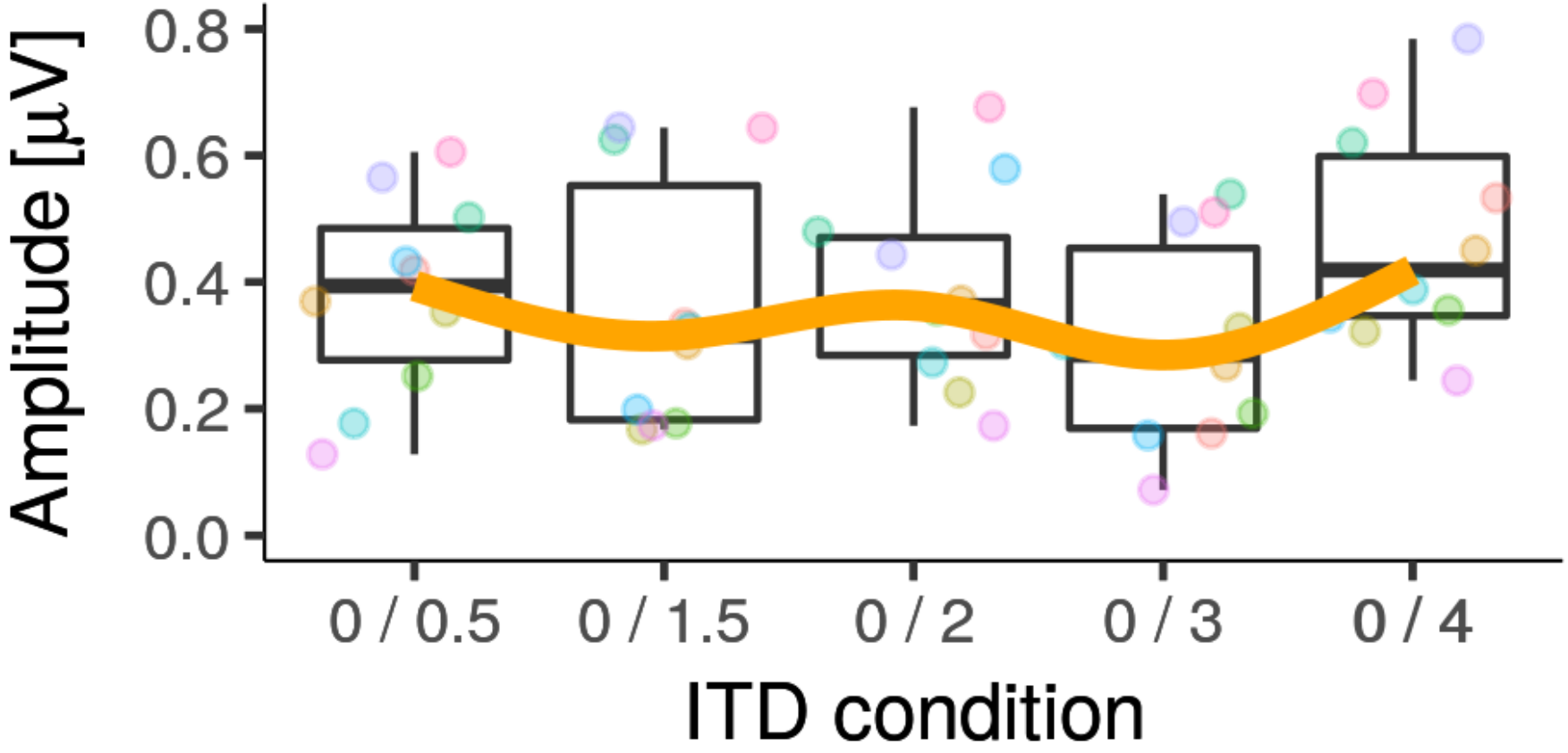
ITM-FRs obtained by switching between:

- 0 / 0.5 ms
- 0 / 1.5 ms
- 0 / 2.0 ms
- 0 / 3.0 ms
- 0 / 4.0 ms

RESULTS

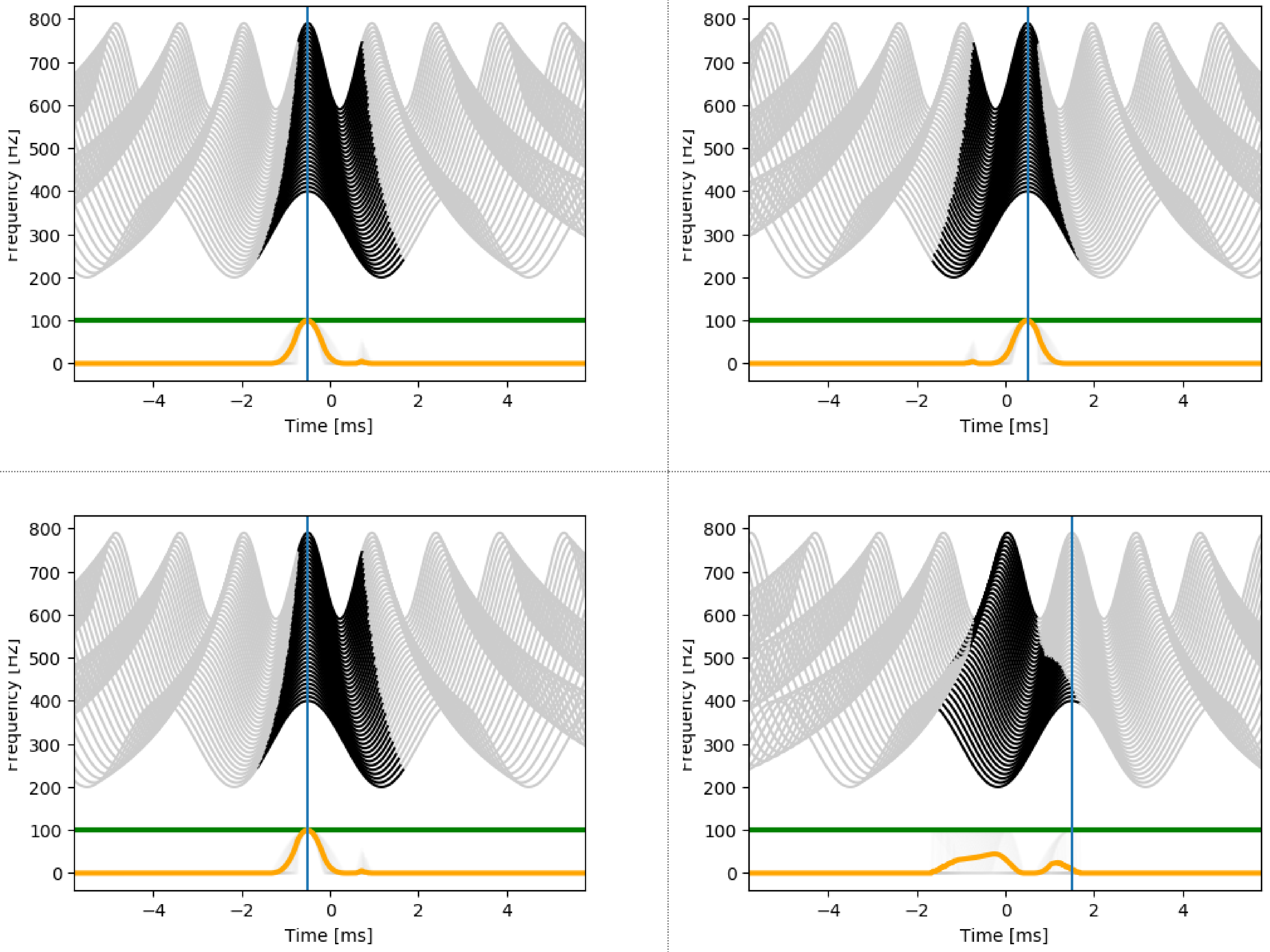
EXAMPLE RESPONSES



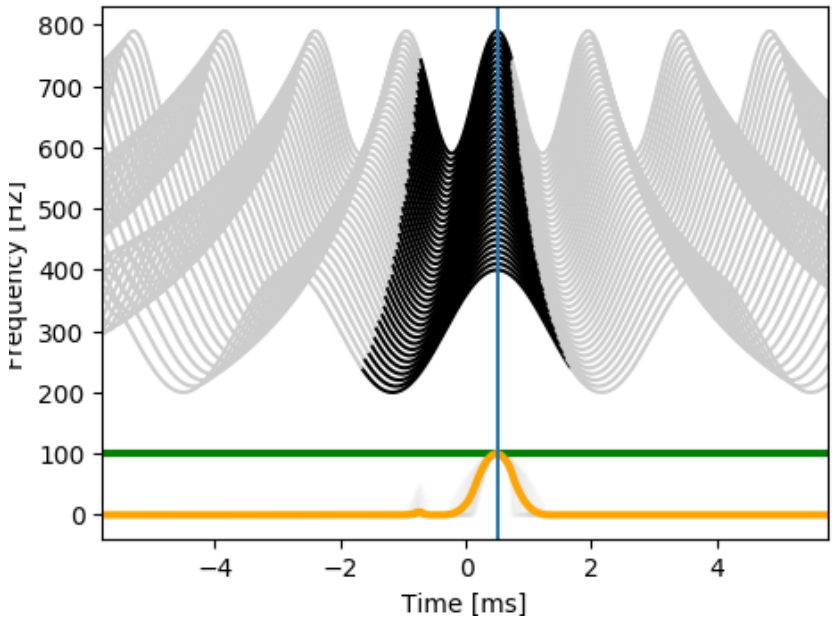


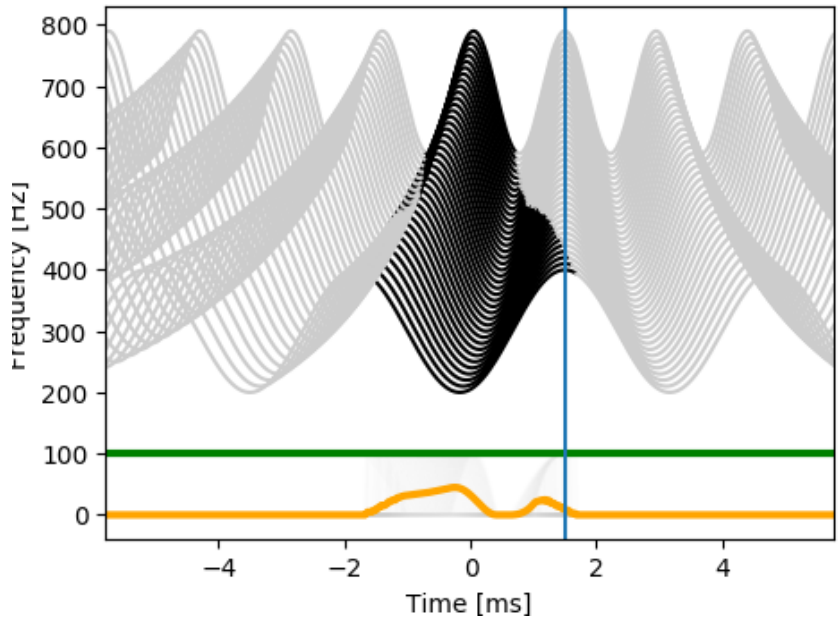
- ANOVA indicated that factor ITD condition was significant (F(4, 35.04) = 7.5, p = 0.0001)

EXPERIMENT 2 ADAPTING BINAURAL DETECTORS



800
700
600
500
400
300
200
100
0
Frequency [Hz]
−4
−2
0
2
4
Time [ms]

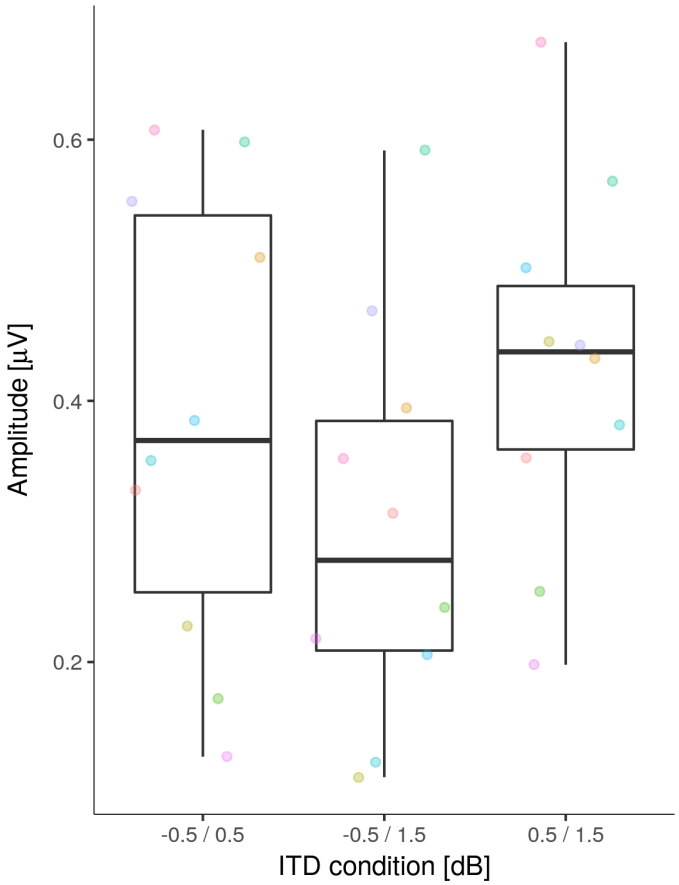

800
700
600
500
400
300
200
100
0
Frequency [Hz]
−4
−2
0
2
4
Time [ms]

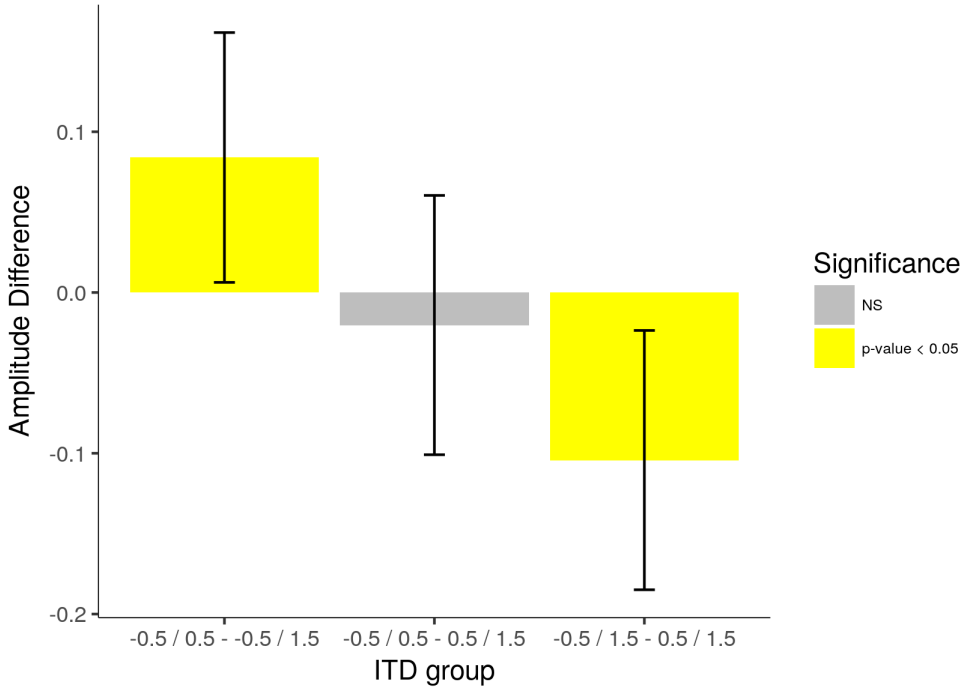

800
700
600
500
400
300
200
100
0
Frequency [Hz]
−4
−2
0
2
4
Time [ms]

ITM-FRs obtained by switching between:

- -0.5 / 0.5 ms
- -0.5 / 1.5 ms
- 0.5 / 1.5 ms

RESULTS


0.6
0.4
0.2
Amplitude [µV]
-0.5 / 0.5
-0.5 / 1.5
0.5 / 1.5
ITD condition [dB]

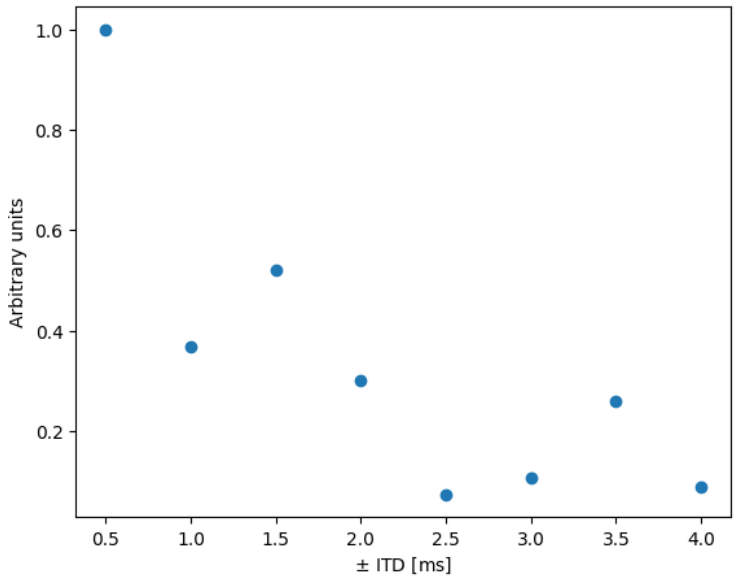

0.1
0.0
-0.1
-0.2
Amplitude Difference
-0.5 / 0.5 - -0.5 / 1.5
-0.5 / 0.5 - 0.5 / 1.5
-0.5 / 1.5 - 0.5 / 1.5
ITD group
Significance
NS
p-value < 0.05

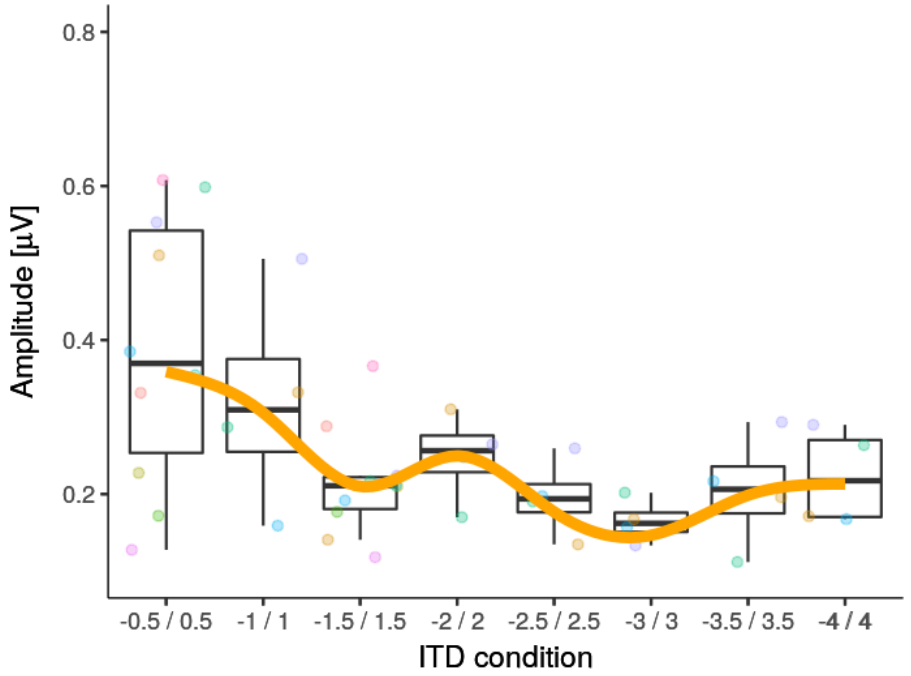
EXPERIMENT 3 COHERENCE CHANGES

ITM-FR obtained by switching between

- -0.5 / 0.5 ms
- -1.0 / 1.0 ms
- -1.5 / 1.5 ms
- -2.0 / 2.0 ms
- -2.5 / 2.5 ms
- -3.0 / 3.0 ms
- -3.5 / 3.5 ms
- -4.0 / 4.0 ms

RESULTS


1.0
0.8
0.6
0.4
0.2
Arbitrary units
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
± ITD [ms]


0.8
0.6
0.4
0.2
Amplitude [µV]
-0.5 / 0.5
-1 / 1
-1.5 / 1.5
-2 / 2
-2.5 / 2.5
-3 / 3
-3.5 / 3.5
-4 / 4
ITD condition

CONCLUSIONS

- Experiment 1 suggests that ITM-FRs do not decrease with ITD size when switching from zero.
- Experiment 2 shows that ITM-FR adaptation pattern is in line with the π-limit model.
- ITM-FRs obtained with symmetric ITDs show a decaying damping-like pattern peaking at multiple periods of the center frequency.

REFERENCES

Kriegstein, Katharina von, Timothy D. Griffiths, Sarah K. Thompson, and David McAlpine. 2008. “Responses to Interaural Time Delay in Human Cortex.” *J. Neurophysiol.* 100 (5): 2712–8. doi:10.1152/jn.90210.2008.

Thompson, Sarah K., Katharina von Kriegstein, Adenike Deane-Pratt, Torsten Marquardt, Ralf Deichmann, Timothy D. Griffiths, and David McAlpine. 2006. “Representation of Interaural Time Delay in the Human Auditory Midbrain.” *Nat Neurosci* 9 (9): 1096–8. doi:10.1038/nn1755.