Illusory Percepts from Auditory Adaptation

… a link between Tinnitus and Zwicker tone

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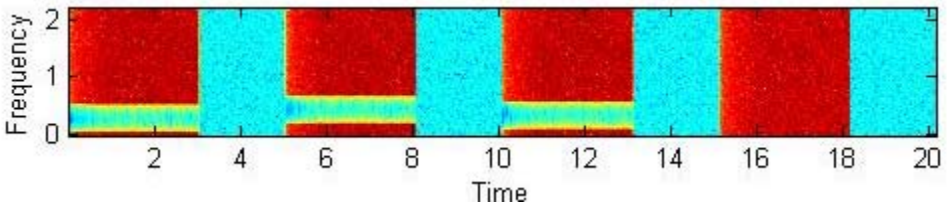
Tinnitus and Zwicker tone

Tinnitus:

- Associated with hearing loss
- Phantom “ringing” often at the frequency of loss.
- Not detected in the periphery and thought to involve central adaptation mechanisms.

Zwicker tone:

- Follows notched noise
- Short “ringing” percept at notched frequency
- Neural correlate unknown.

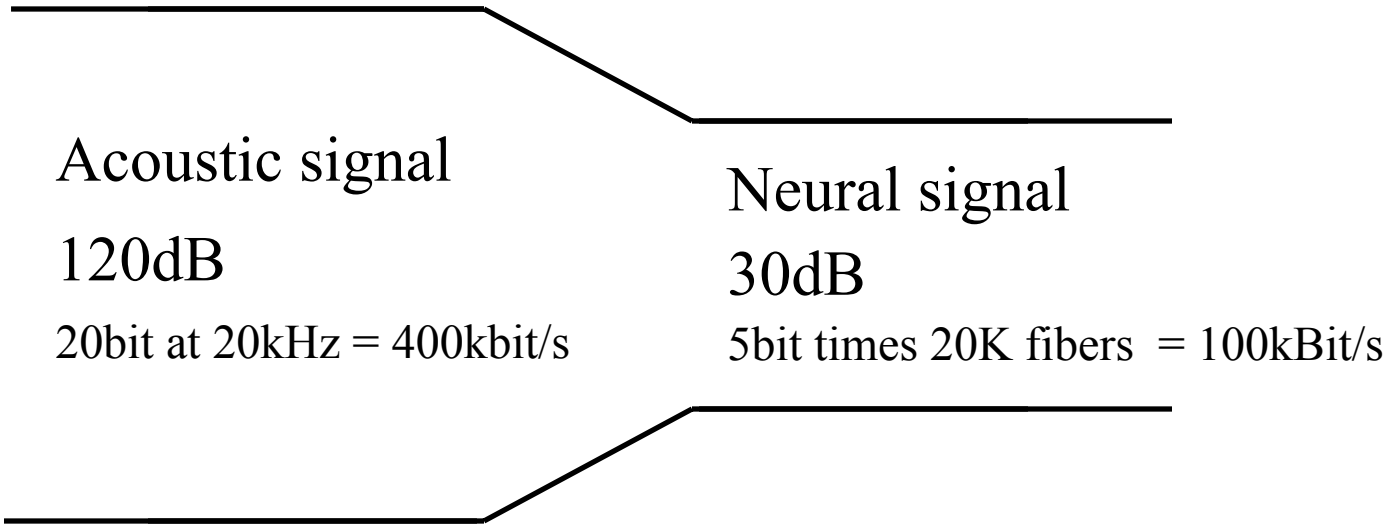


Tinnitus and Zwicker tone

Hypothesis:

Central adaptation increases gain due to reduced input in hearing-loss band (or notched band) thereby magnifying internal noise that is perceived as “ringing”.

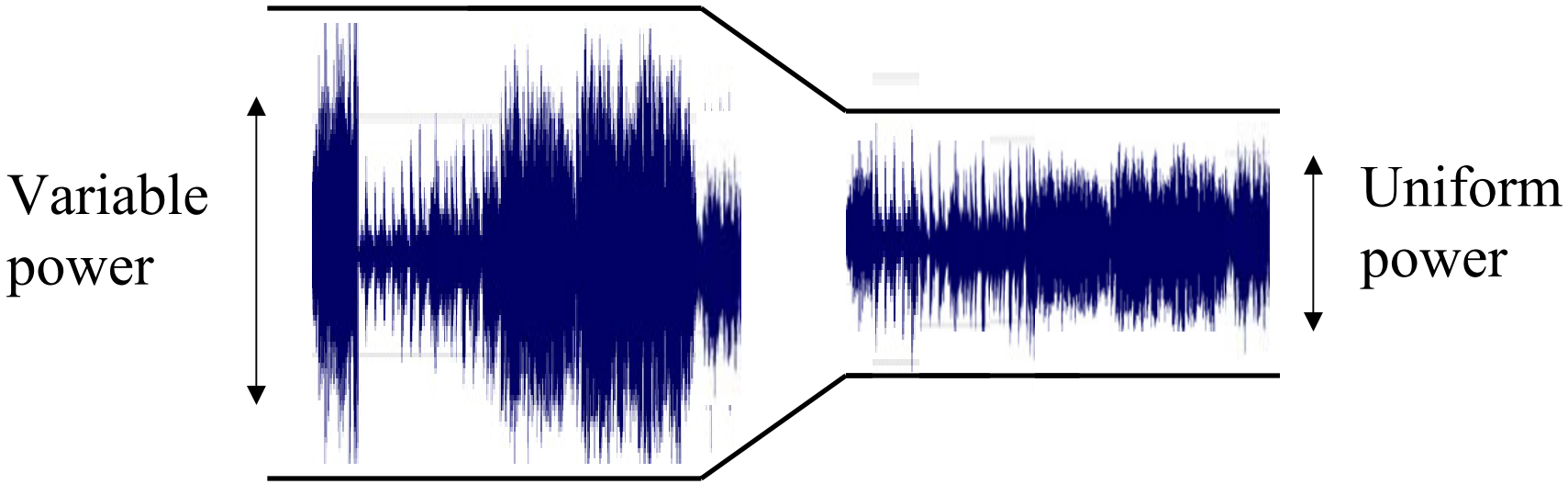
Information bottleneck



We postulate that an adaptation mechanism is required to optimally use the available information capacity.

Gain adaptation

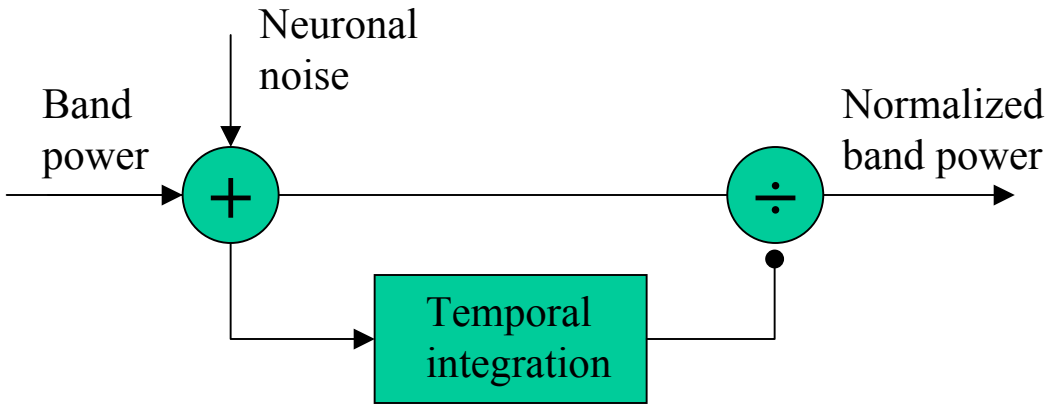
Simplest mechanism: Integrate power in some time window and normalize the signal to have unit power on that time scale.



Minimal gain adaptation model

Model assumptions:

- Operates separately in each frequency band
- Internal additive noise
- Power integrated in time
- Divisive normalization (or subtractive in the log domain)

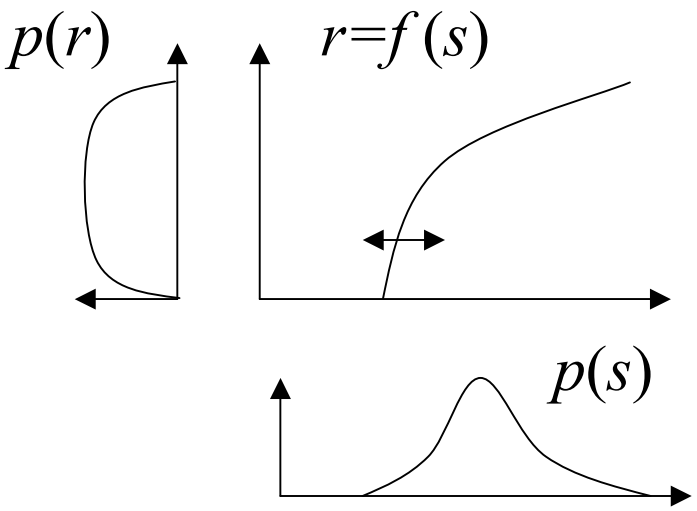


Gain adaptation - channel capacity

Available information capacity better exploited by

1. Maximizing bit rate of an amplitude limited channel.
2. Reducing redundancy of co-modulated frequency bands.
3. Lateral inhibition can then easily remove correlation.

1.



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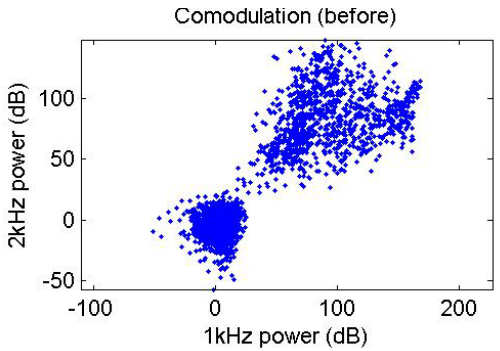

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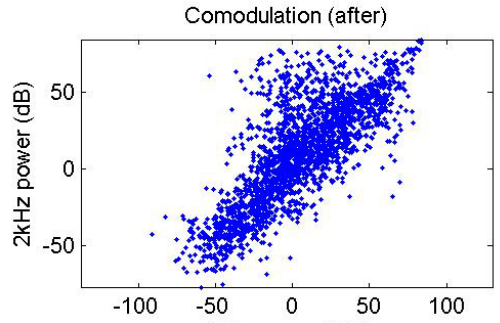
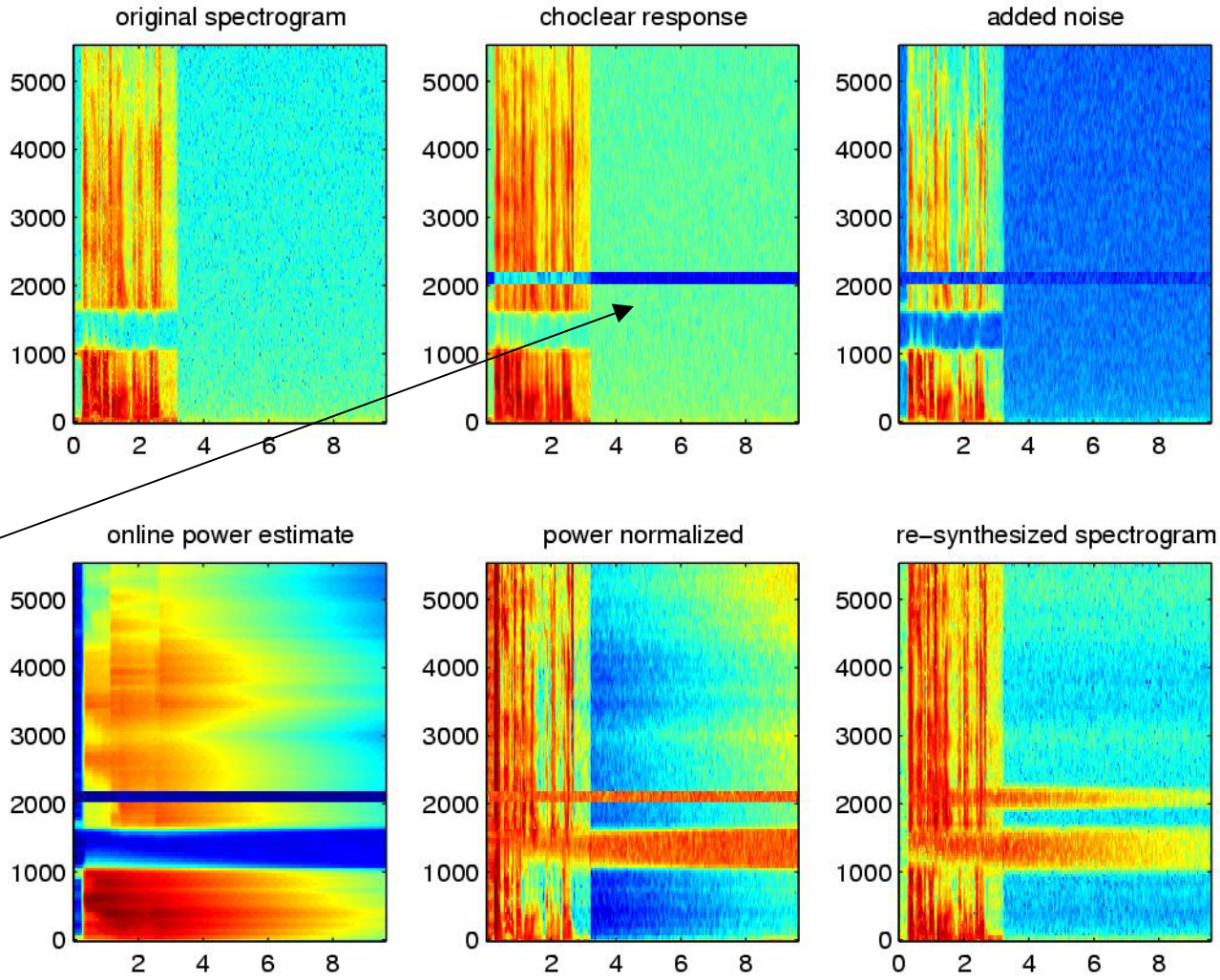


Phantom percepts result for reduced input power



Notched input

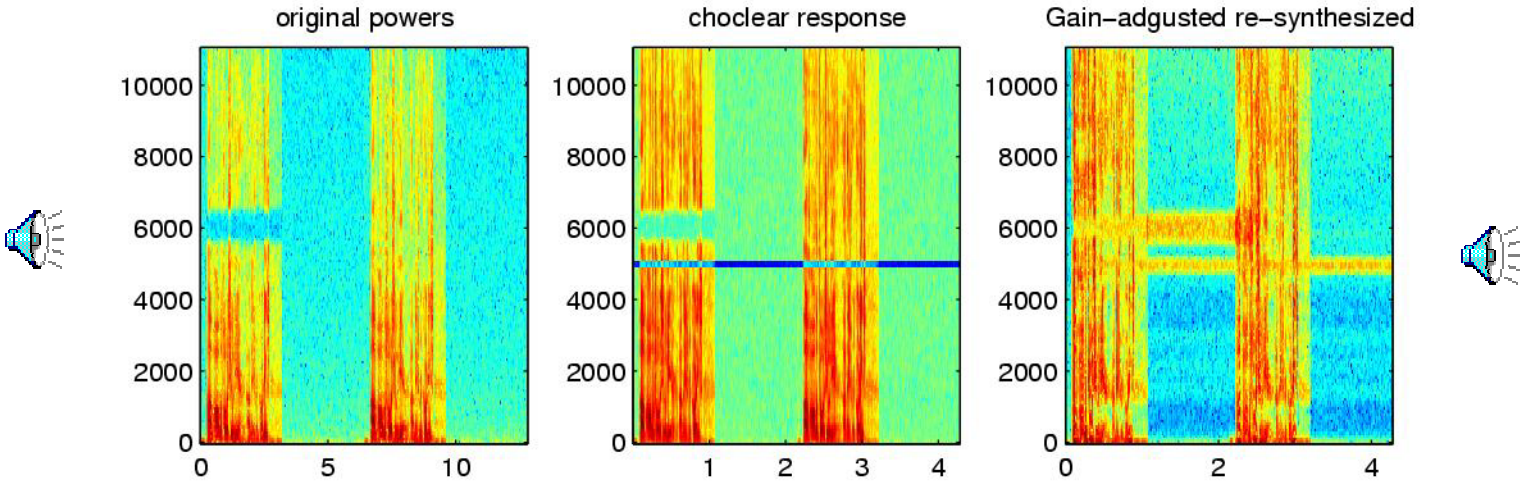
Peripheral hearing loss

"Tinnitus"

"Zwicker tone"

Phantom percepts result for reduced input power

We reconstructed signal to gives a sense of the "perception" after gain adaptation.

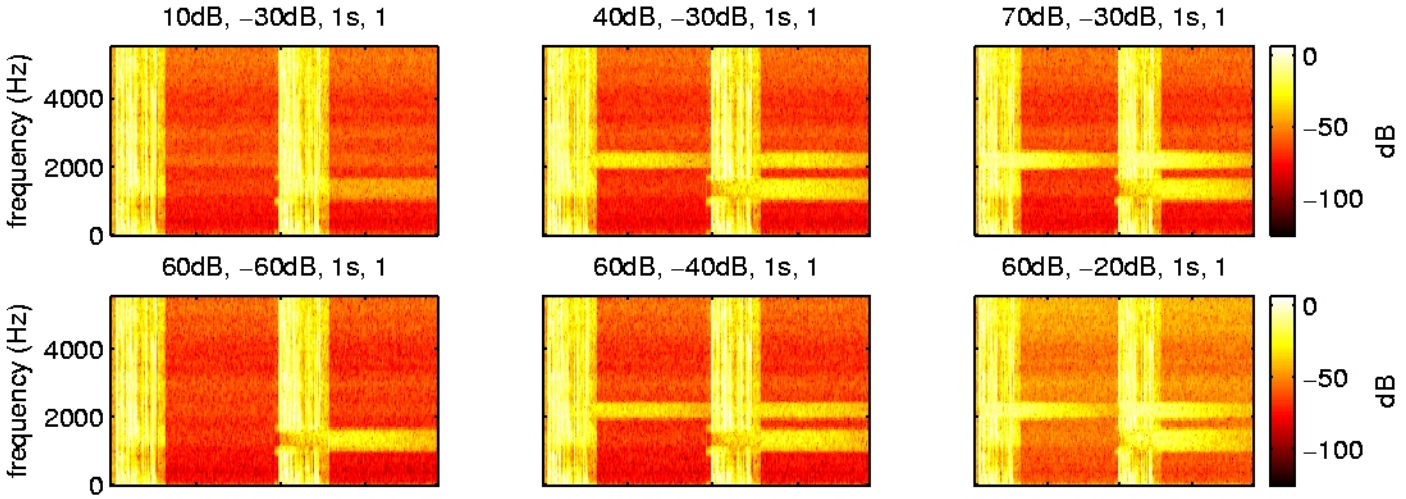


Assumption during reconstruction: Total power of the signal is encoded in separate channel. (Optimal encoding)

Postdiction consistent with data

Theory explains various key features of Tinnitus (ZT):

- Percept frequencies match the hearing loss frequencies (noise band gap).
- When including lateral inhibition the predominant percept is at the lower edge of the hearing loss (band gap).
- Sharp edges produce stronger percept.



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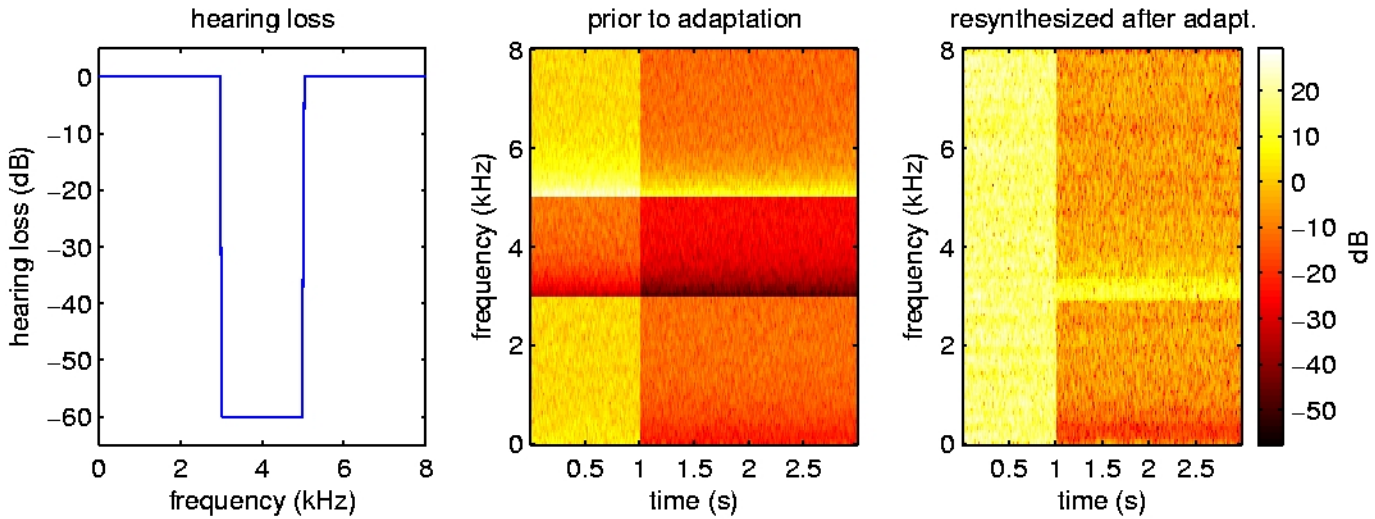

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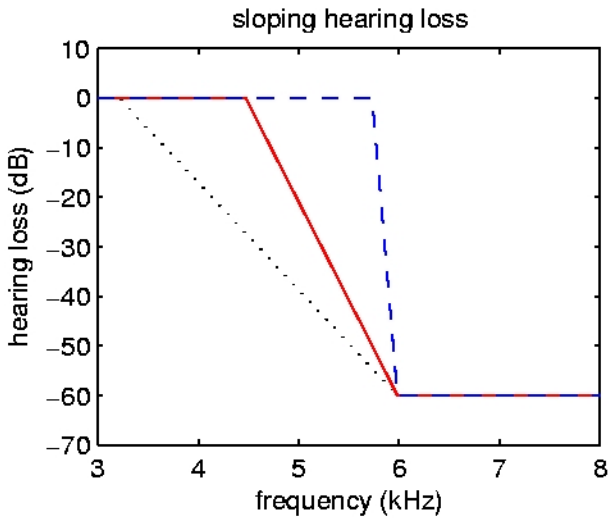
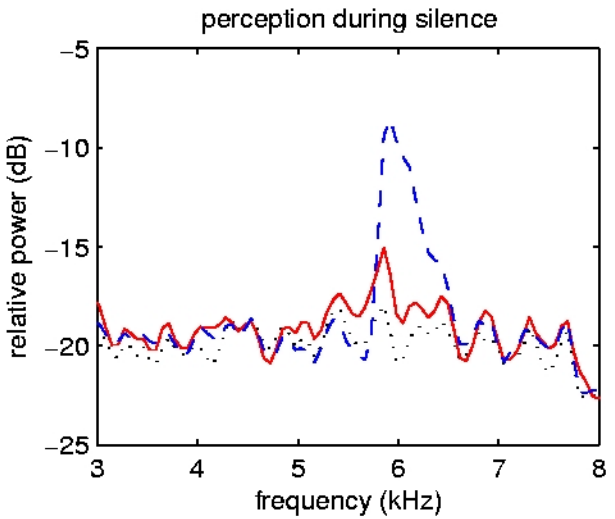
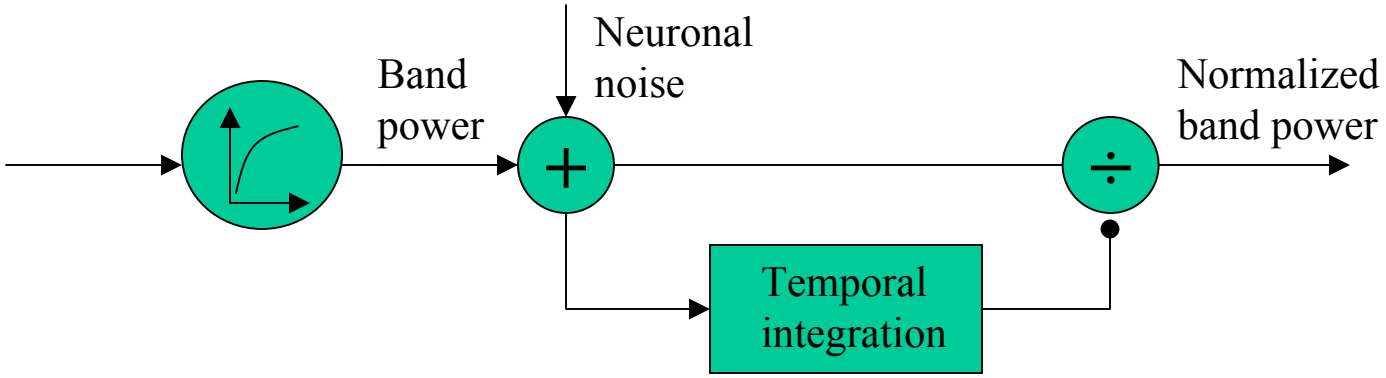
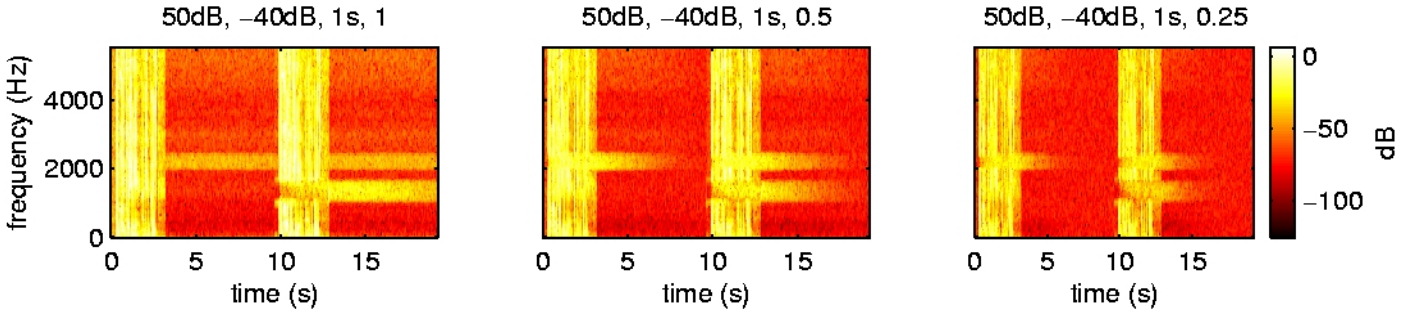




Prediction?

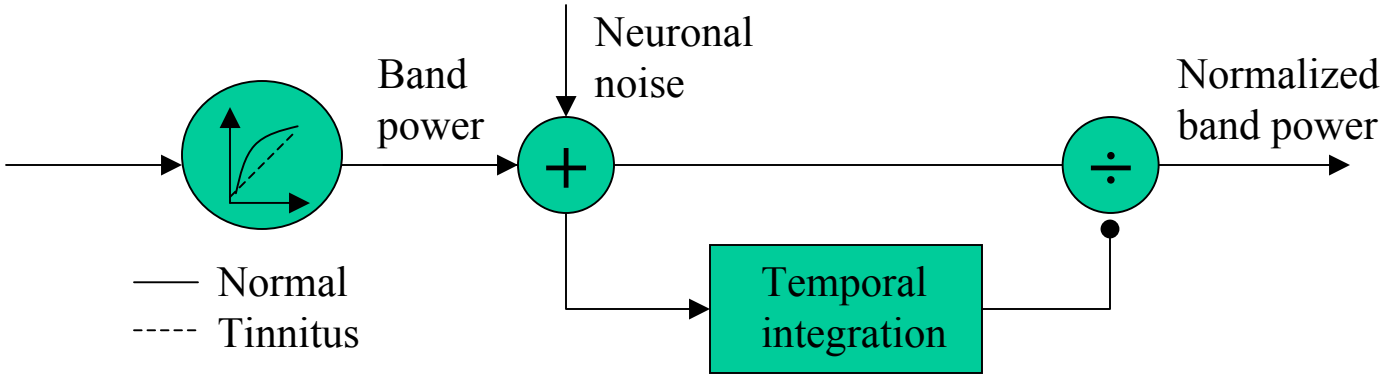
Outer-hair cells in normal cochlea produced non-linear compression. When including compression the model phantom percept is weaker.





Prediction: Tinnitus → Zwicker

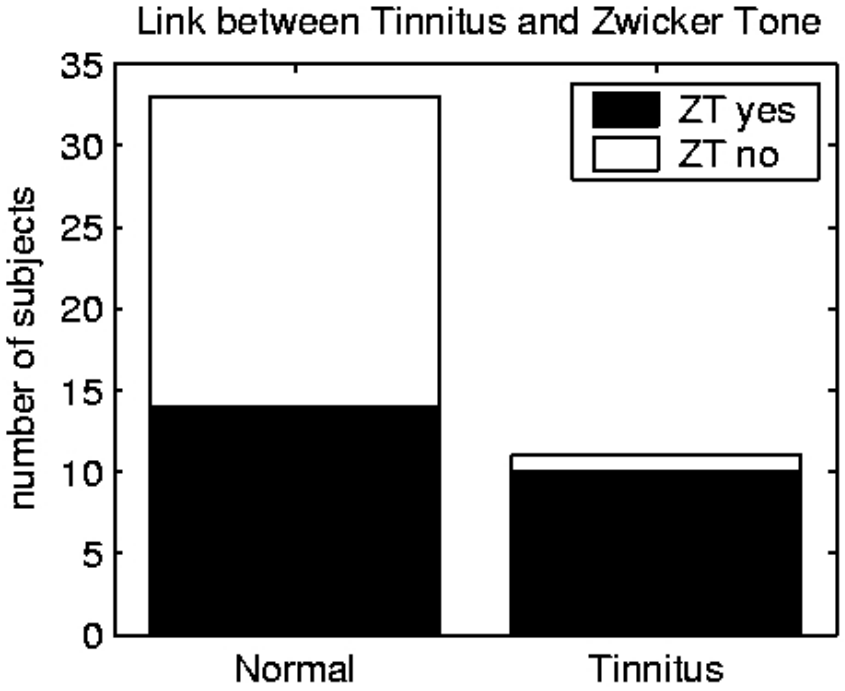
Tinnitus is often associated with reduced peripheral compression.



Prediction: Tinnitus subjects are more likely to hear the Zwicker phantom percept.

Prediction: Tinnitus → Zwicker

We tested this prediction by asking 44 volunteer subjects (11 tinnitus and 33 normal) to listen to notched noise and asked if they heard the the Zwicker tone.



Ratios differ
$p<0.01$

First empirical link between the two phenomena.

Conclusion

Limited information bandwidth may necessitate gain adaptation which will adjust dynamic range and can reduces redundancy.

When input is reduced this adaptation magnifies internal noise to “fill the channel”, which is then perceived as phantom sound.

Generic gain-adaptation model explains some common features of both phantom percepts.

The model **predicted** that reduced compression which is often found in tinnitus should lead to stronger Zwicker percept.

Psychophysics **confirmed** that tinnitus subjects are significantly more likely to hear the Zwicker phantom percepts.