Image: http://physics.ust.hk/dusw/

Tonal Detection in Noise: An Auditory Neuroscience Insight

Buddhika Karunarathne[1] and Richard H.Y. So[1,2]

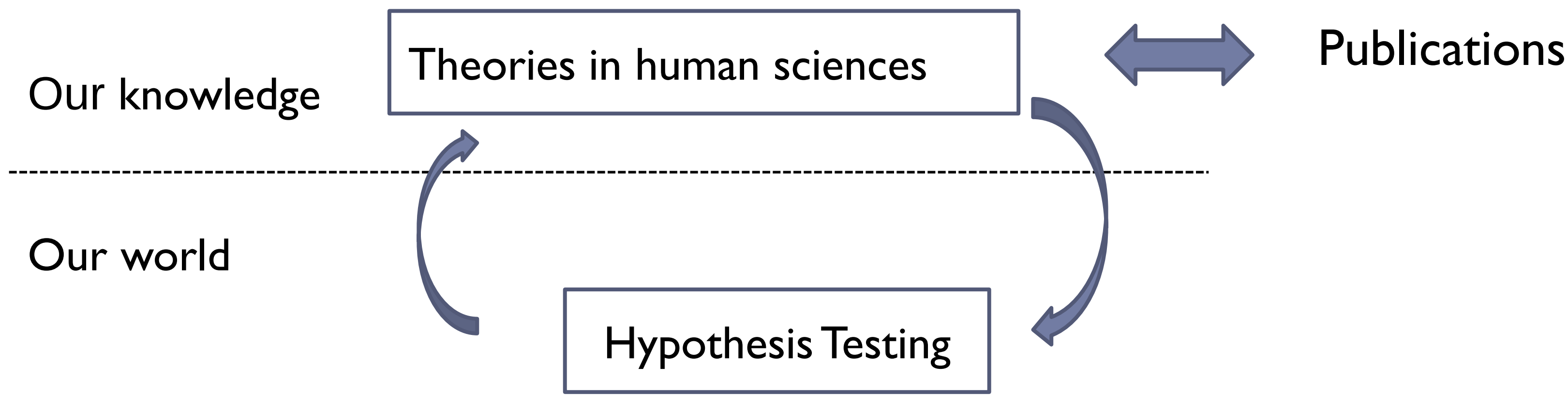
[1]Dept. of IELM, Hong Kong University of Science & Technology, [2]Division of Bio-Medical Engineering, Hong Kong University of Science & Technology

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

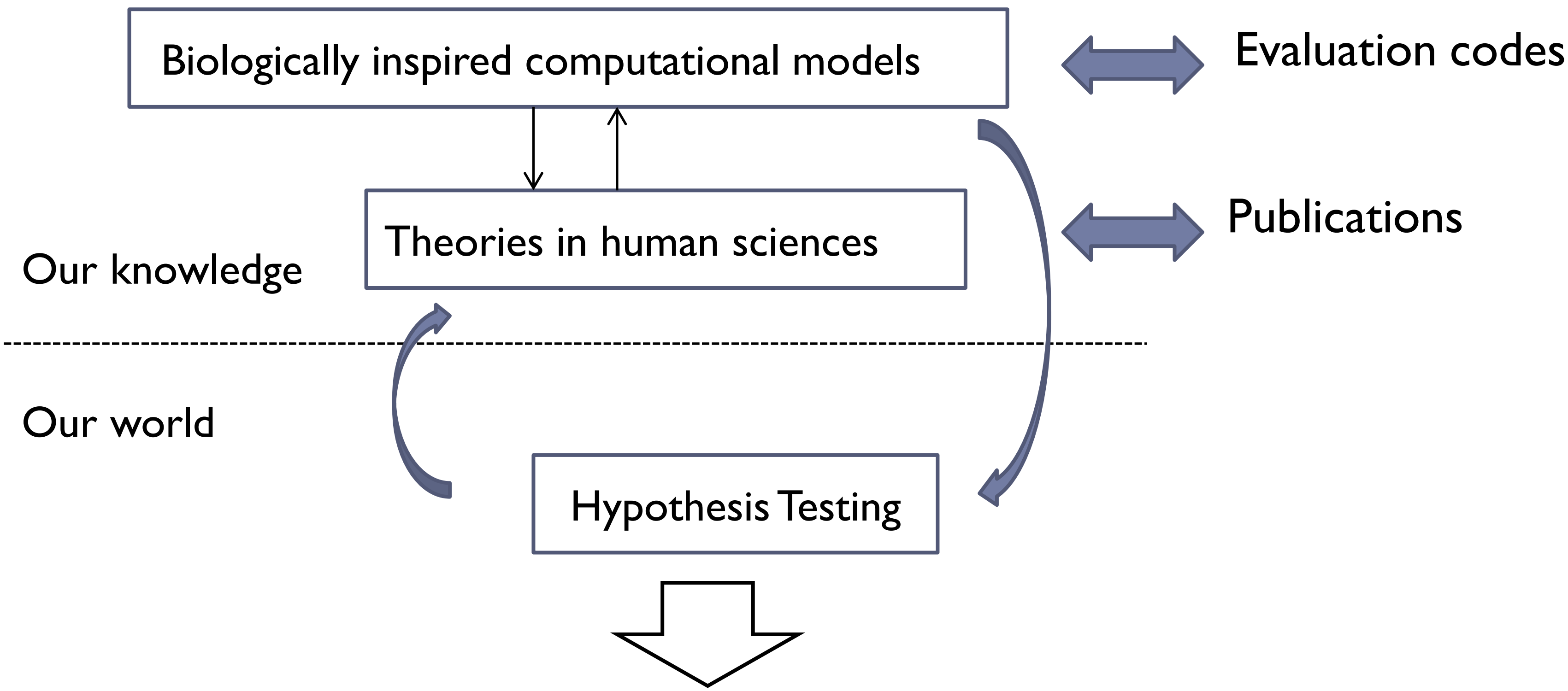
4/17/2015

Ergonomics & Neurosciences

Traditional ergonomics



Computational Ergonomics

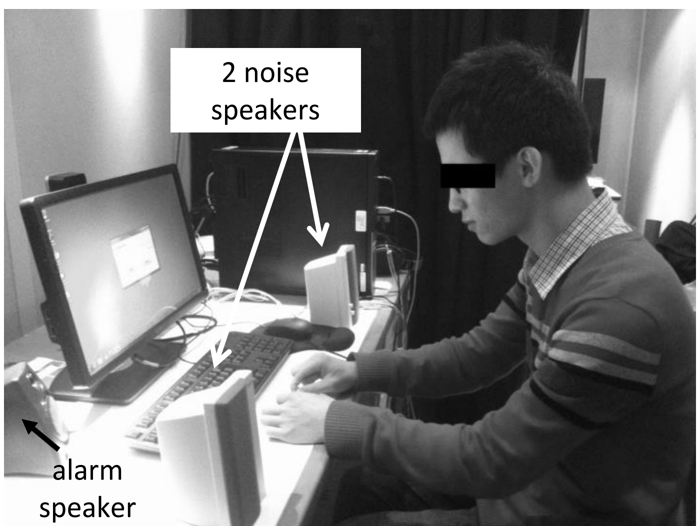


Predictions without the need of experiments

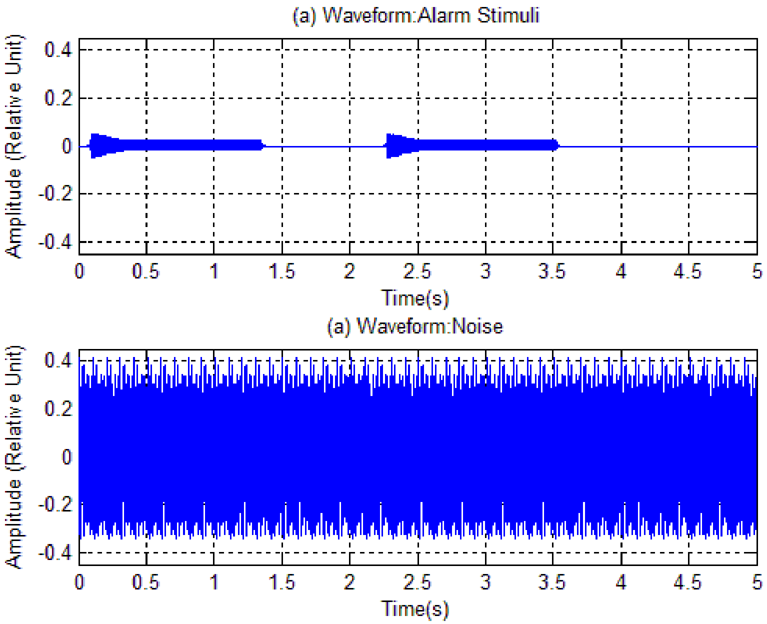
Industrial Problems

- Aging workers with degraded hearing can still detect alarm in the presence of 80dBA noise
- Alarms with Signal-to-Noise Ratio (SNR) of -18 dBA can be detected with 100% accuracy (0% false detection and 0% missing)

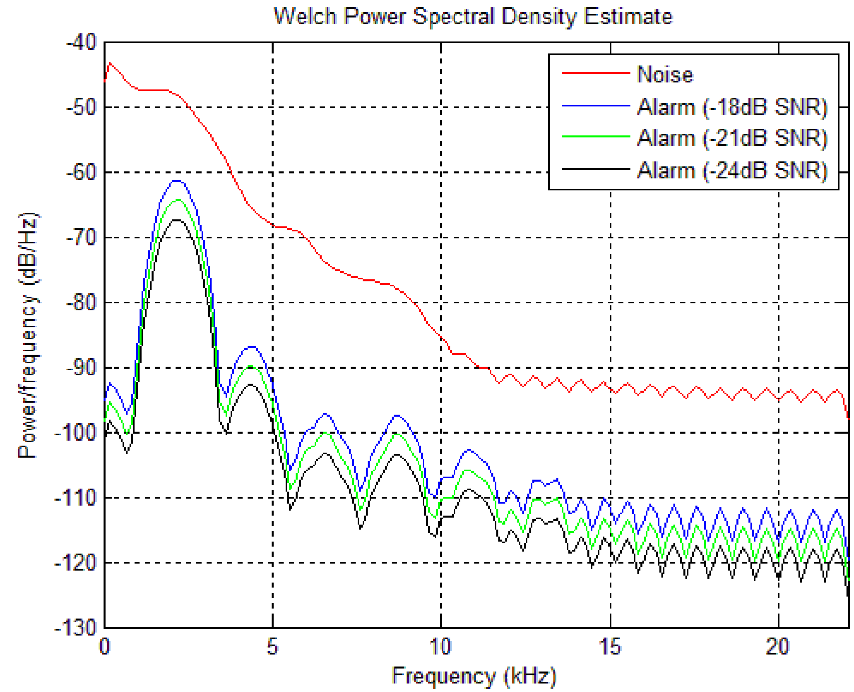
Seek to repeat it in the Lab



Experiment Conditions



Temporal Characteristics: Alarm & Noise

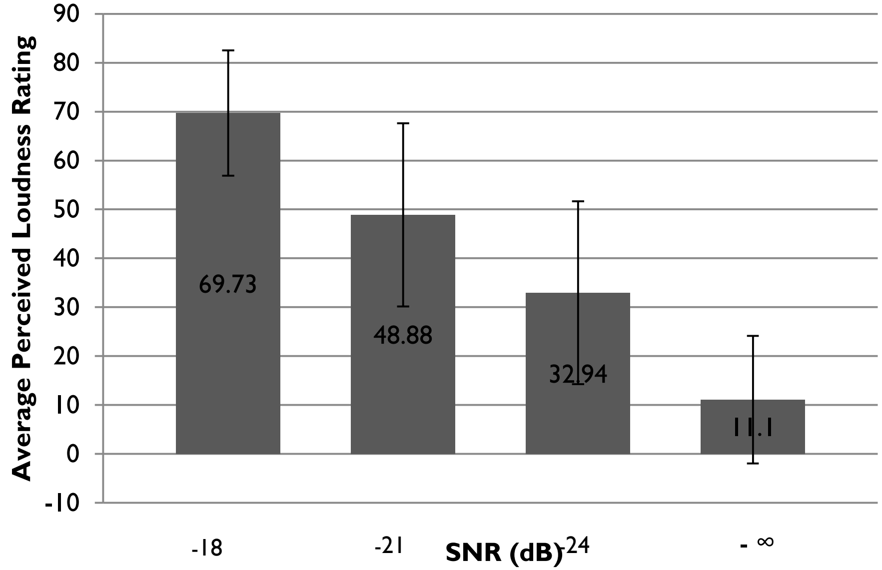


Spectral Characteristics – Welch PSD

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Lab Experiment 1

- 12 Human subjects with normal hearing
- Rated the perceived loudness of a train alarm in the presence of 80dBA noise
- Rating Scale: 0-100 (Usage of a hardware slider)
- Average Perceived Loudness Ratings for different SNR conditions are given in the graph



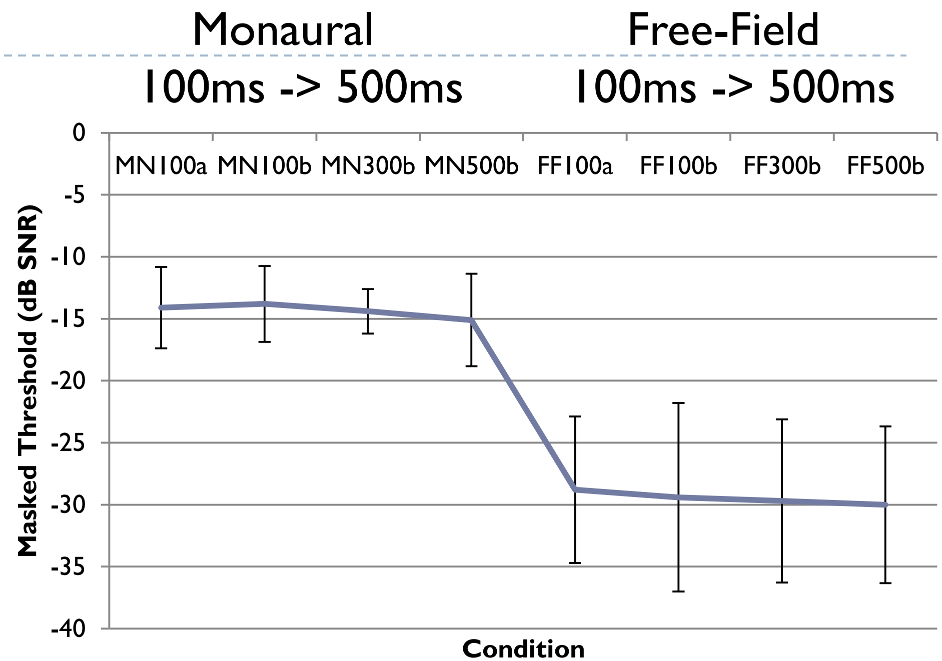
Main Finding:

Persons with normal hearing are able to hear an alarm in the presence of 80dBA pink noise even with a SNR level of -24dB

Publication: Karunarathne, B., So, R.H.Y. and Kam, A.C.S. (2014) Alarm vigilance in the presence of 80dBA pink noise with negative signal-to-noise ratios. Contemporary Ergonomics 2014 (Eds: Sarah Sharples & Steven Shorrock), Taylor & Francis, pp.443-449

Lab Experiment 2

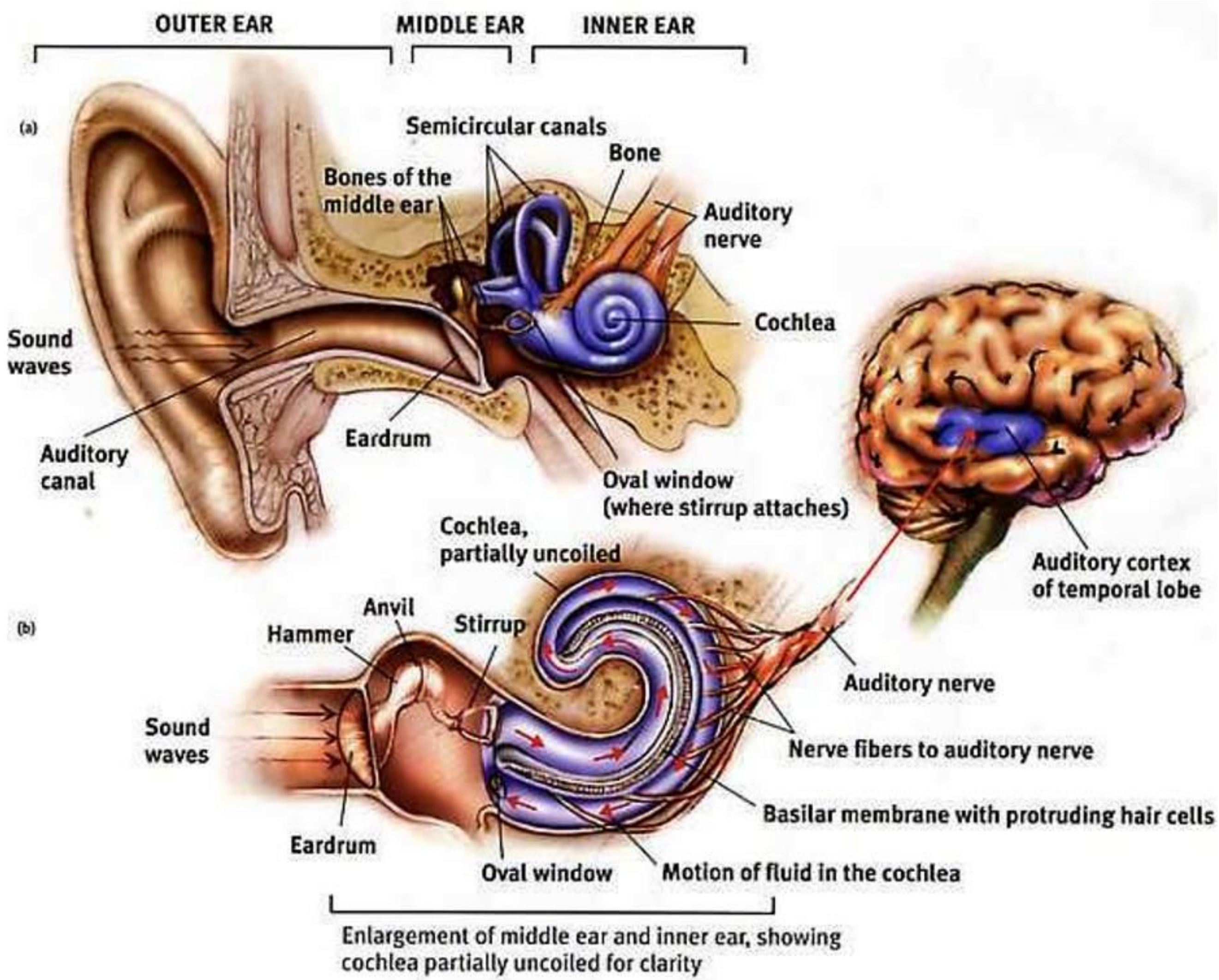
- 16 Human subjects with normal hearing
- Used Adaptive 2 Interval Forced Choice (2IFC) method for threshold estimation
- Varying duration of the alarm signal
- Noise level at 80dBA
- Initially 2 spatial information: Free-Field and Monaural



Main Finding:
Significantly different masked thresholds for Free-Field (-30dB SNR) and Monaural (-15dB SNR) reported.

Publication: Karunarathne, B., So, R.H.Y. and Kam, A.C.S. (2014) Effects of presentation method and duration on alarm detection threshold in the presence of loud pink noise. J. Acoust. Soc. Am., Vol. 135, No. 4, Pt. 2, April 2014, 2189

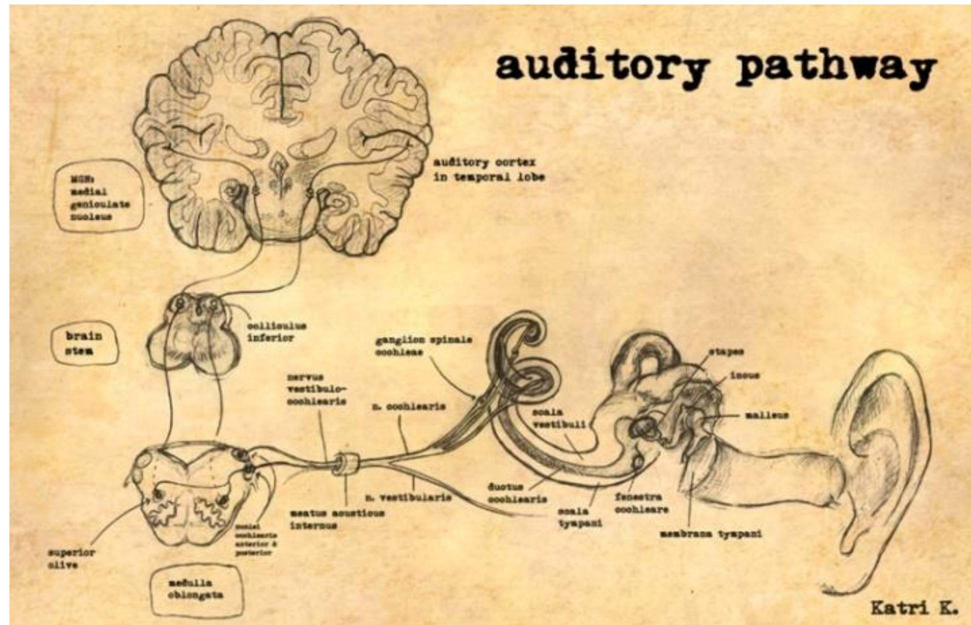
How and Why detection at very low SNR possible?

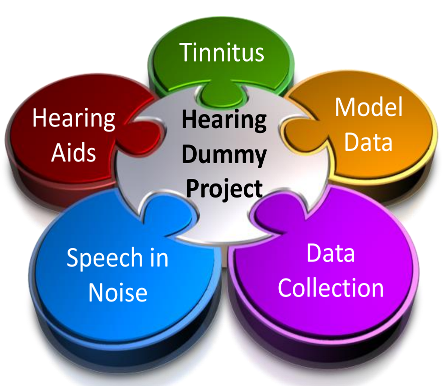


Source: http://www.murrayhearing.com/

Auditory Neuroscience Modeling?

We turn to our collaborator, Ray Meddis, to see whether findings are indeed consistent with the current knowledge of our neurosciences.

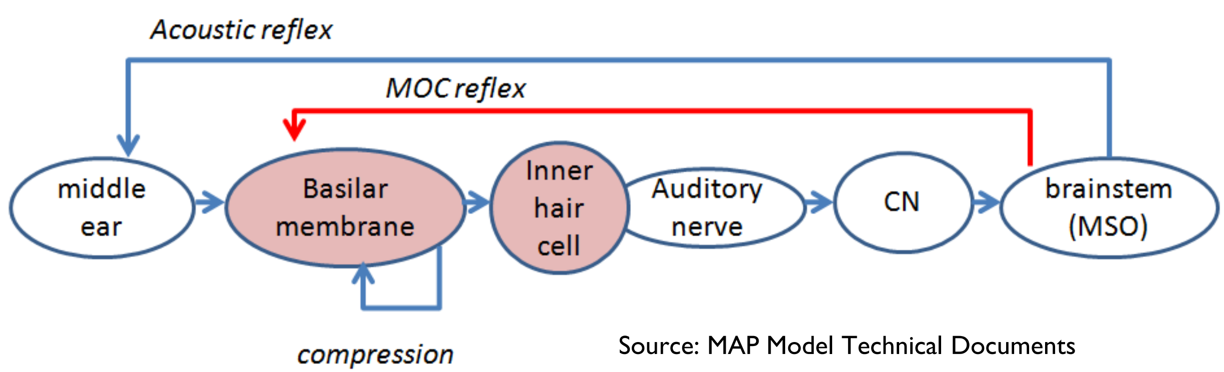




Matlab Auditory Periphery (MAP) Model

- Existing Matlab Auditory Periphery model (MAP)simulates and predicts the transmission of sounds from the pinna to the middle ear, the cochlea and the auditory nerves (Meddis, 2006a,b)

Would this model be able to explain our results on detection of auditory signals in the presence of loud noise?

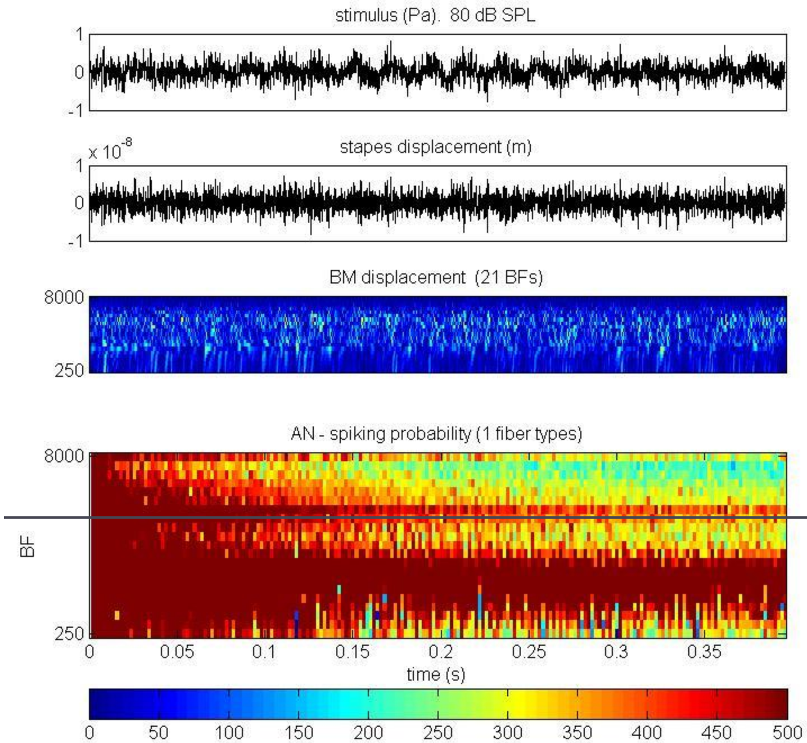


Source: MAP Model Technical Documents

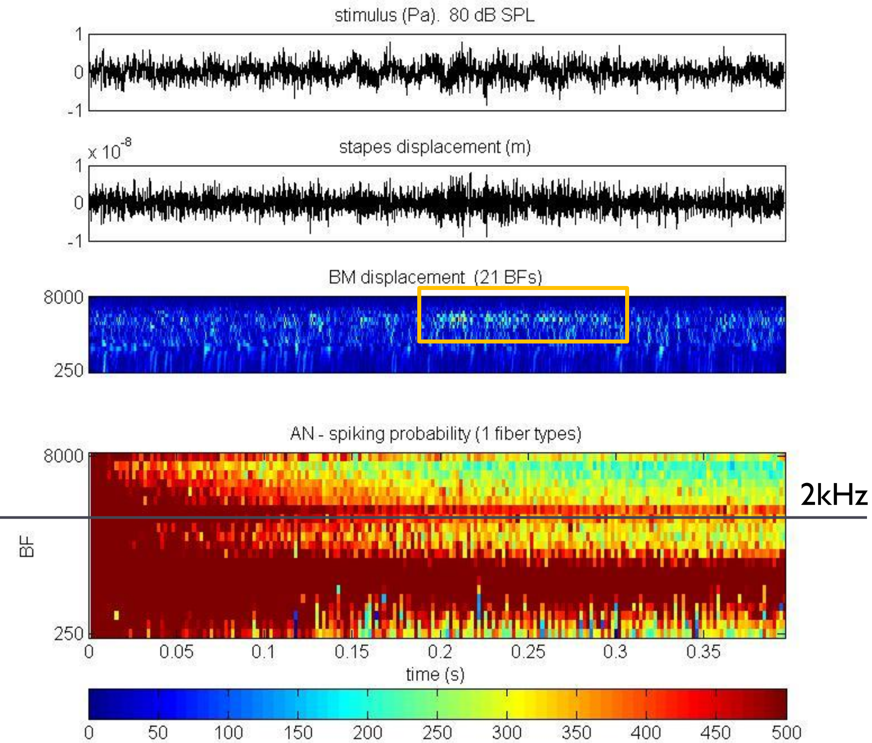
Stages of the auditory pathway modelled. Each shape represents a separate stage of signal processing in the auditory periphery.

Simulations

Noise Only vs Combined Stimuli(-15dB SNR)



Noise Only

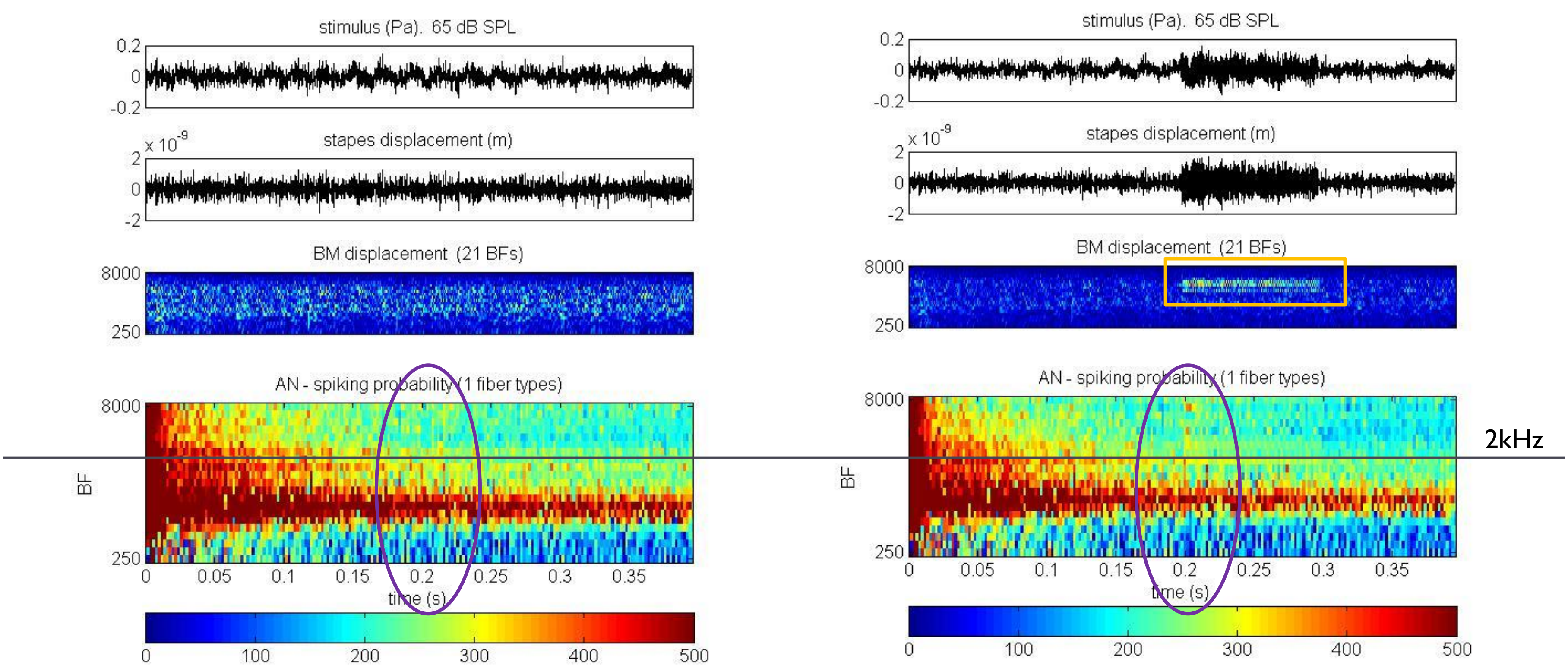


Noise + Alarm

Are there visible changes in the BM displacements? AN firing patterns?

Simulations

Noise Only vs Noise + Alarm (0dB SNR) at 65dBA



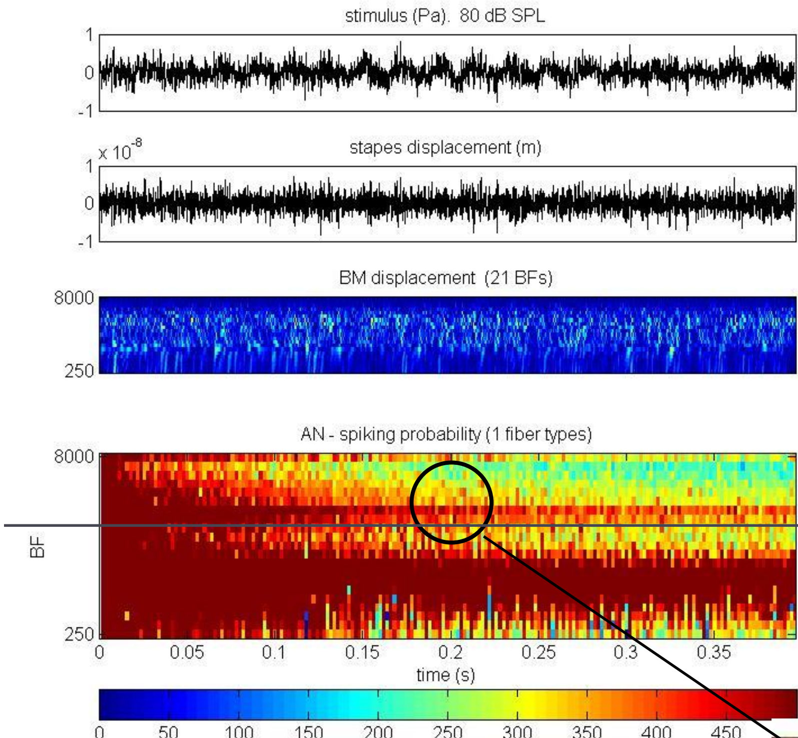
Noise Only

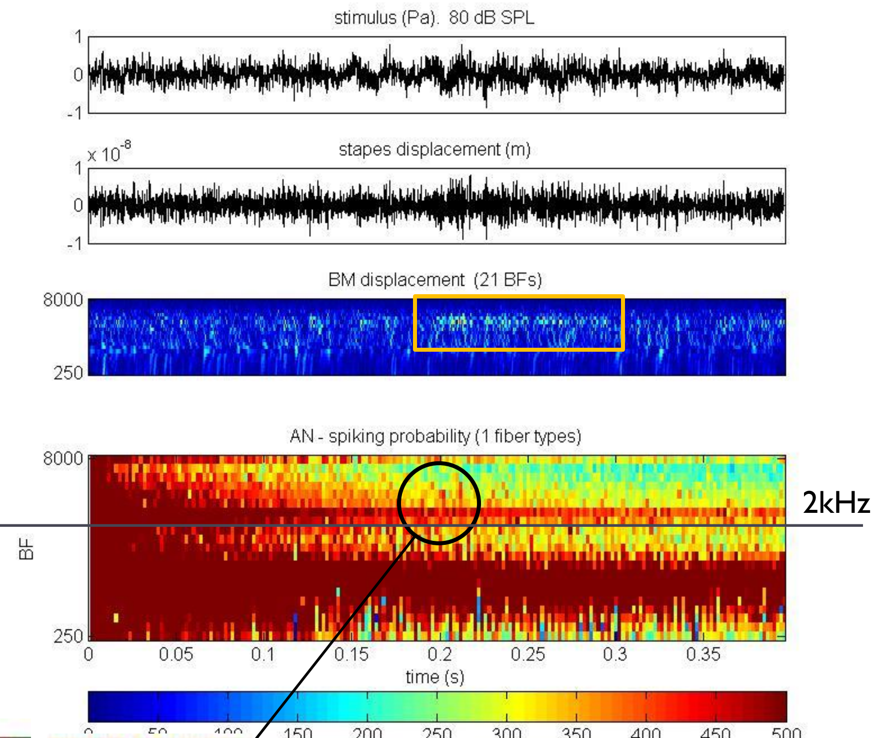
Noise + Alarm

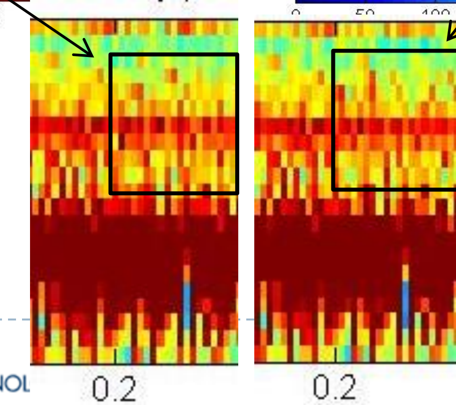
Visible changes in the AN firing patterns are also observed!

Simulations

Noise Only vs Combined Stimuli(-15dB SNR) – 400ms





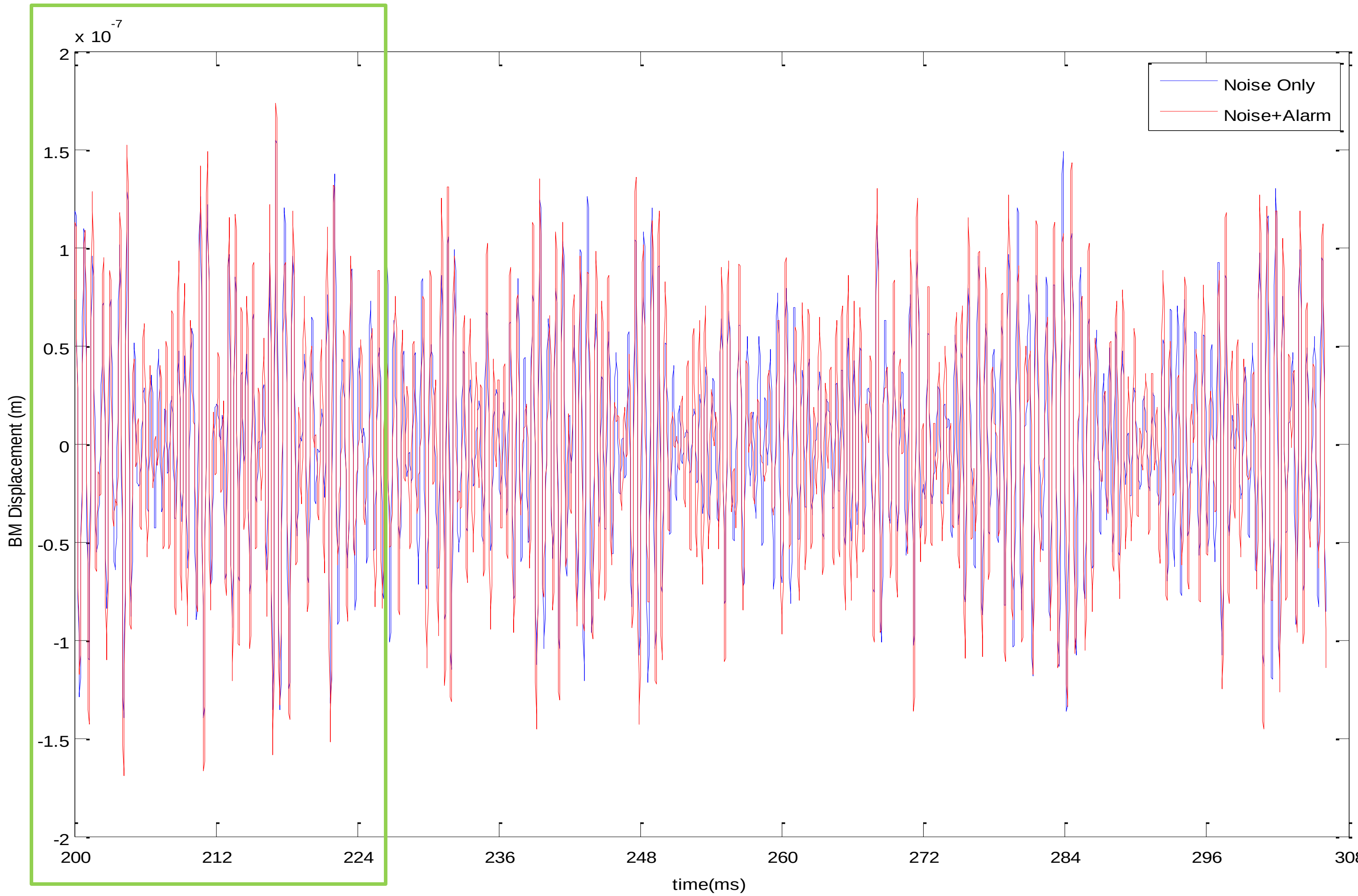


Noise Only

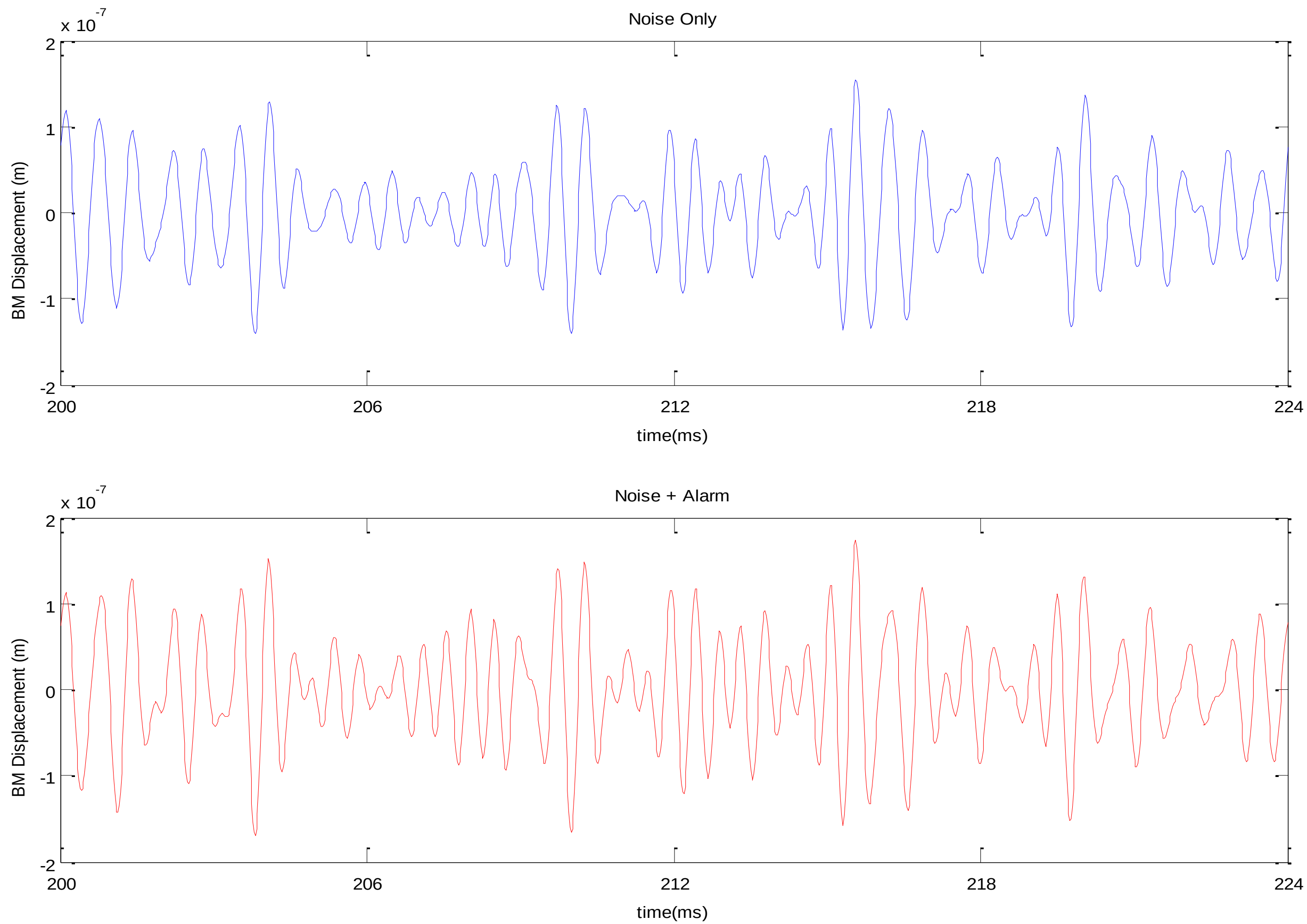
Noise + Alarm

Now , let's take a second and careful look at the firing pattern. At 200ms (0.2s), the alarm started.

Time Series Data (BM Displacement)



Time Series Data (BM Displacement)



香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

2000Hz BF

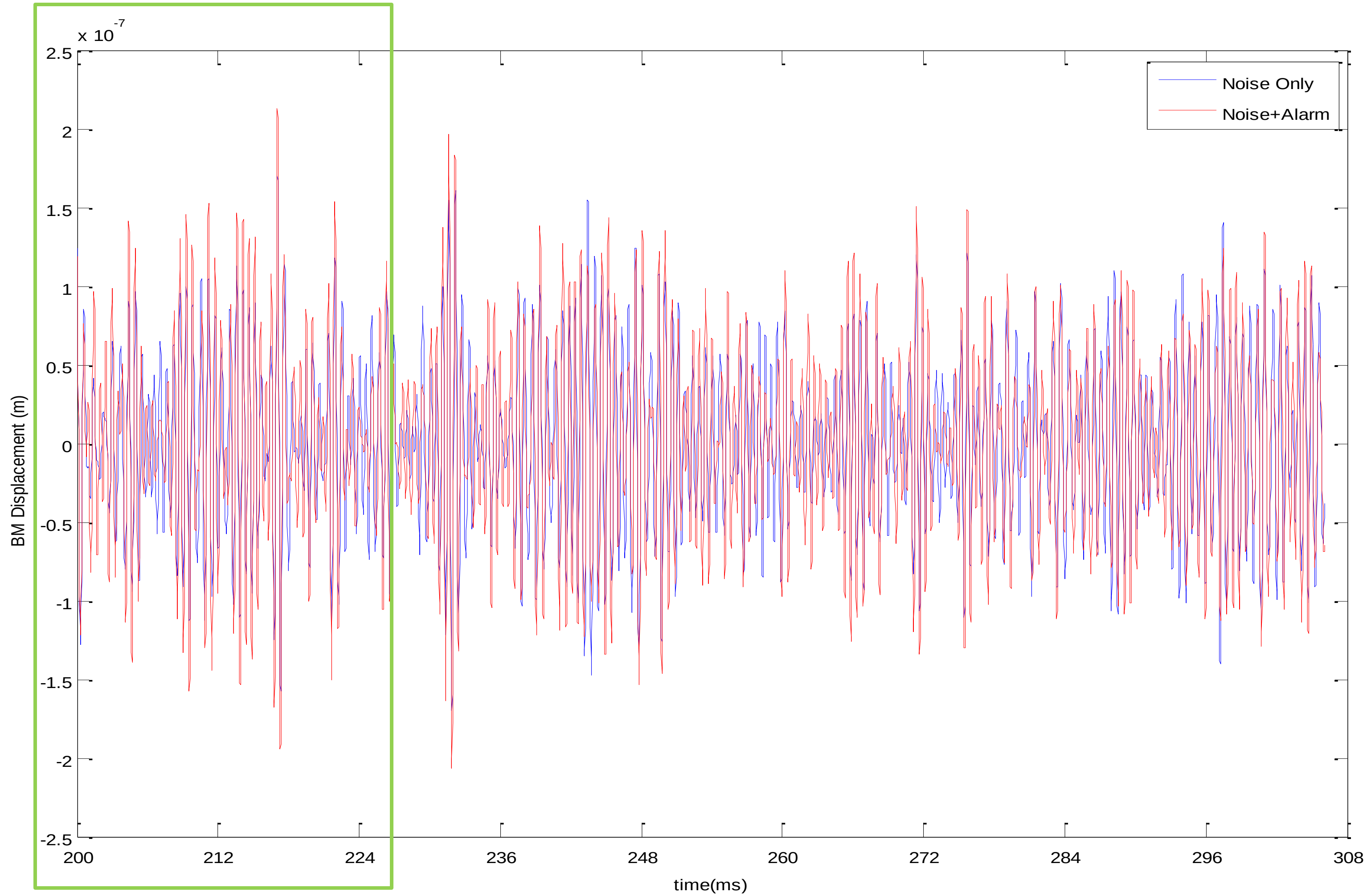
Observable Differences

- Increase of Amplitude at the BM
  - Due to the amplification provided by the outer hair cells

https://auditoryneuroscience.com/ear/dancing_hair_cell

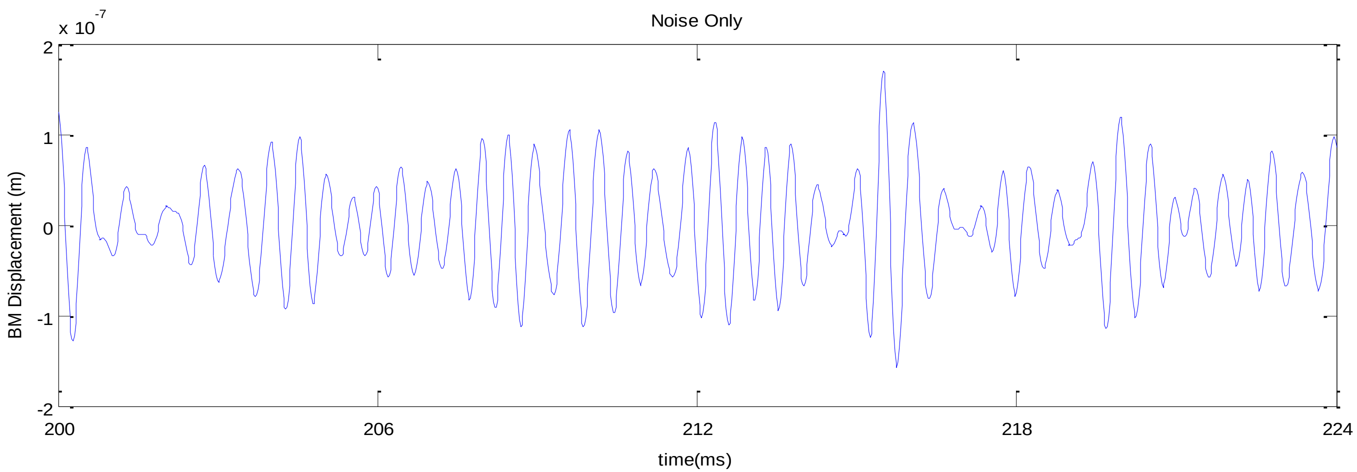
- Frequency separation at the BM
  - Additional frequency components are introduced

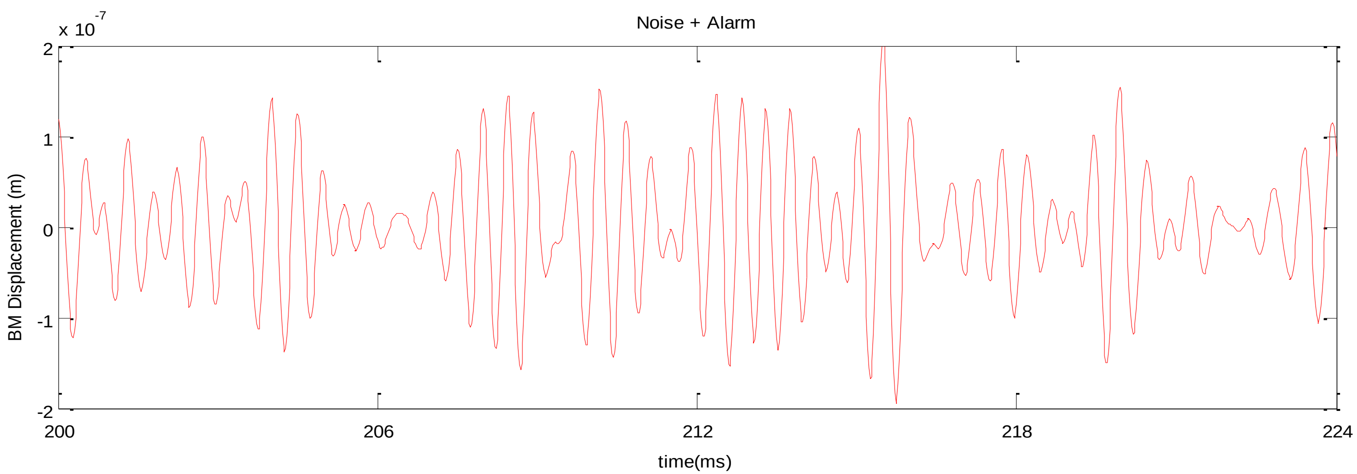
Time Series Data (BM Displacement)



2378Hz BF

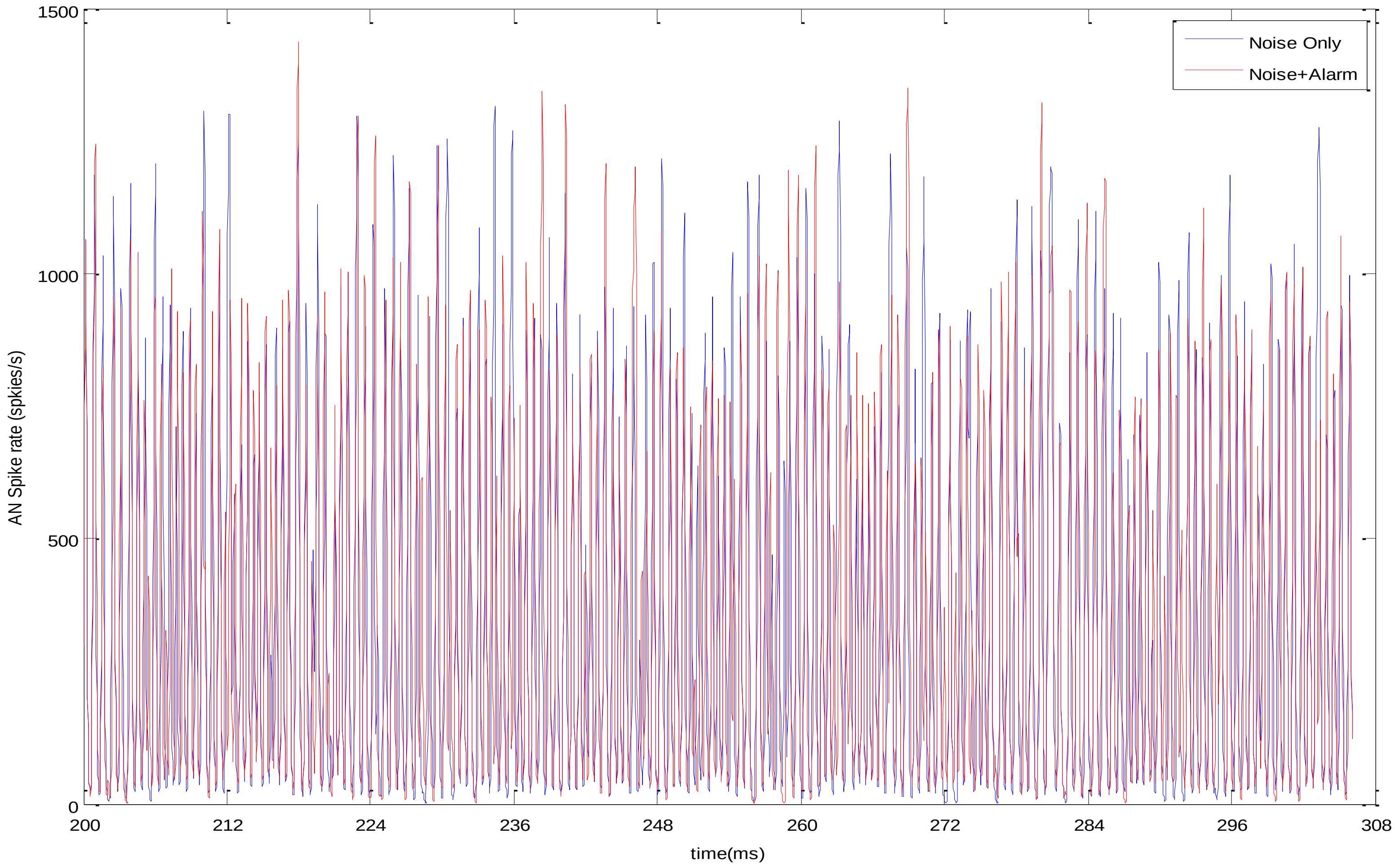
Time Series Data (BM Displacement)





2378Hz BF

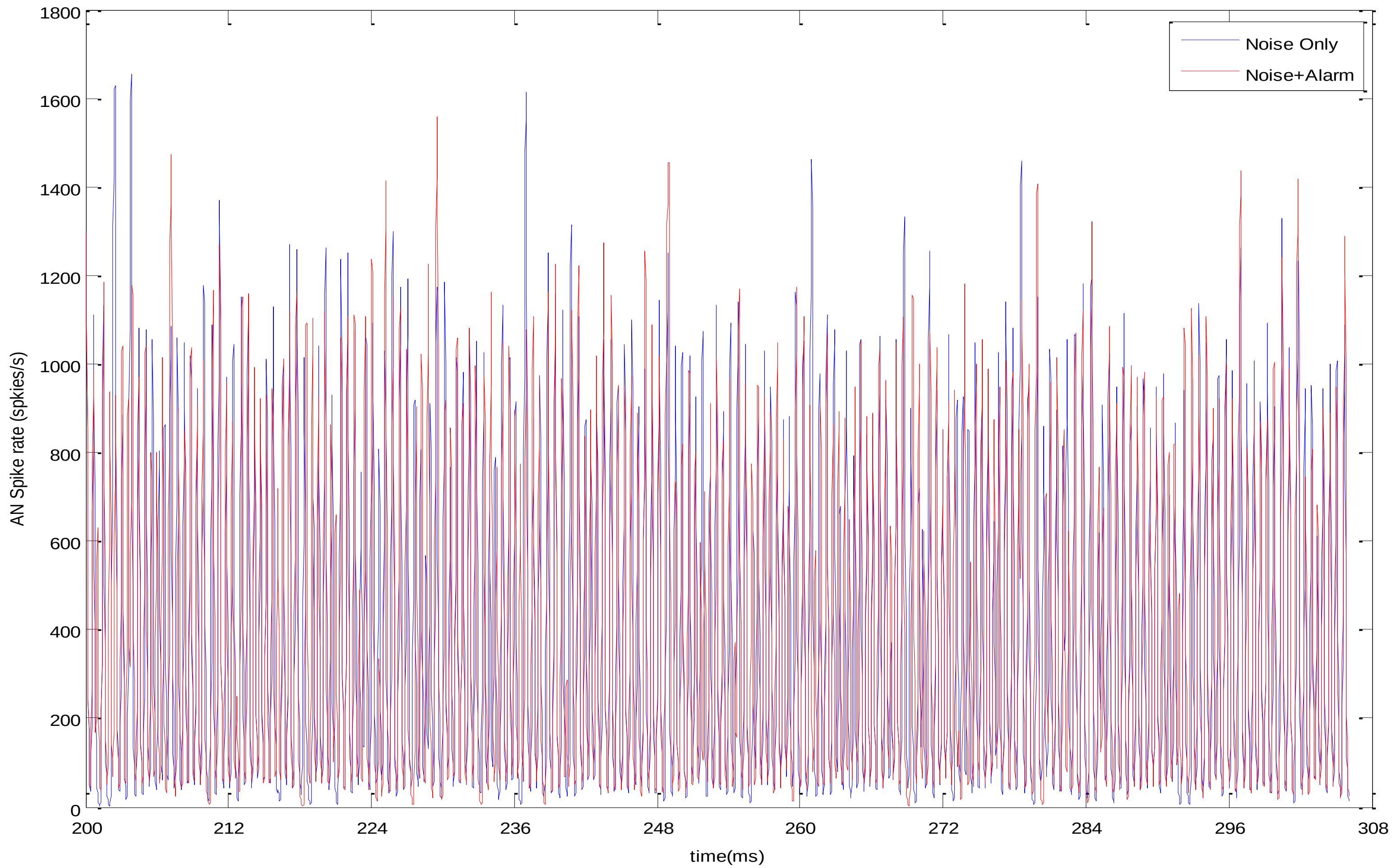
Time Series Data (AN Firing Rate)



香 港 科 技 大 學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

2000Hz BF

Time Series Data (AN Firing Rate)



2378Hz BF

Implications and more..

- Simulations have shown small but repeatable differences in the AN firing patterns related to the experiment stimuli

- MAP model has been used to predict the benefits of medial olivo-cochlear system (MOCS) efferent feedback for speech perception in the presence of noise
  - Brown et al., 2010
  - Clark et al., 2012

- Auditory efferent feedback may help inhibit perception of continuous noise and increase the probability of transient noise (Liberman and Guinan, 1998; Dolan and Nuttall, 1988)
- Efferent feedback could improve speech perception in noise (Giraud *et al.,* 1997; Kumar and Vanaja, 2004)

How would MOCS efferent feedback affect the detection tasks in our experiments?

香 港 科 技 大 學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Related Work

Study	Target Stimuli	SNR	MOC-Threshold Relationship
Micheyl et al., 1995	Tone	Negative	Negative
Micheyl & Collet, 1996	Tone	Negative	Positive
Wagner et al., 2008	Speech	Negative	None
Bhagat & Carter, 2010	Tone	Negative	Positive
Garinis et al., 2011	Tone	Negative	Negative

Mixed results suggest a gap in understanding of the role of MOCS efferent feedback and tonal/speech detection!

Usage of OAEs

- Oto-Acoustic Emissions (OAEs) are sounds made by our inner ear as it works to extract the information from sounds to pass on to the brain

Contralateral Noise

OAE Strength

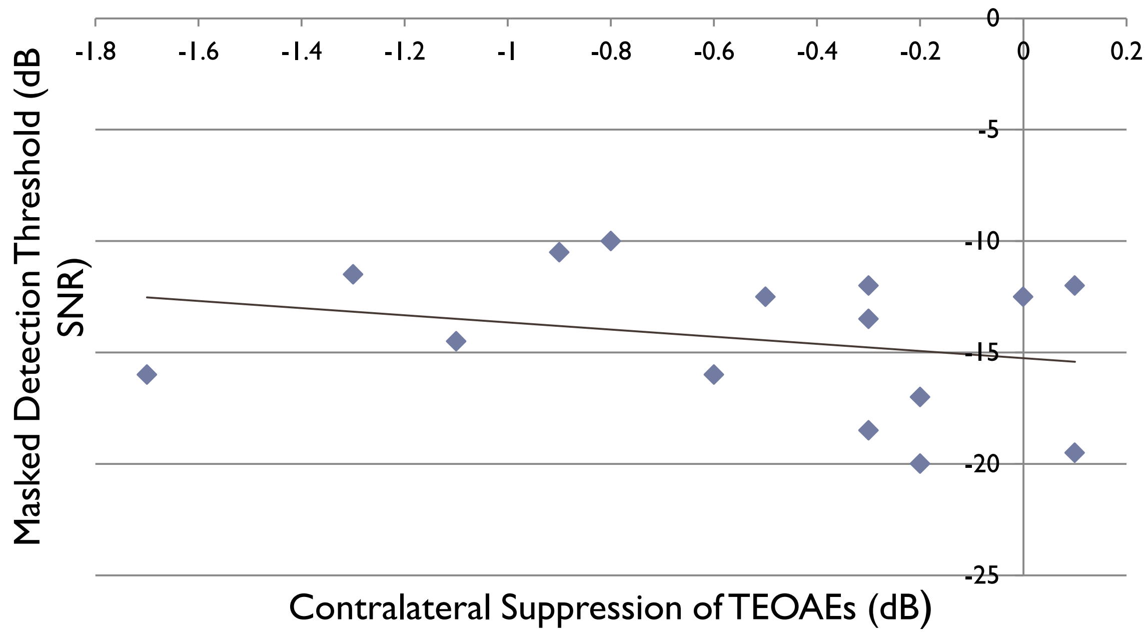
Contralateral Suppression of OAEs

MOC Efferent Feedback Strength

Example usage: Micheyl *etal.*, 1995

Images: http://www.otodynamics.com/

Lab Experiment 3 - Results



Pearson's r = - 0.526, p = 0.044, n=15

Relationship between contralateral suppression of TEOAEs and masked detection thresholds

- A significant ($p<0.05$) negative correlation was observed between contralateral suppression of TEOAEs and masked detection thresholds

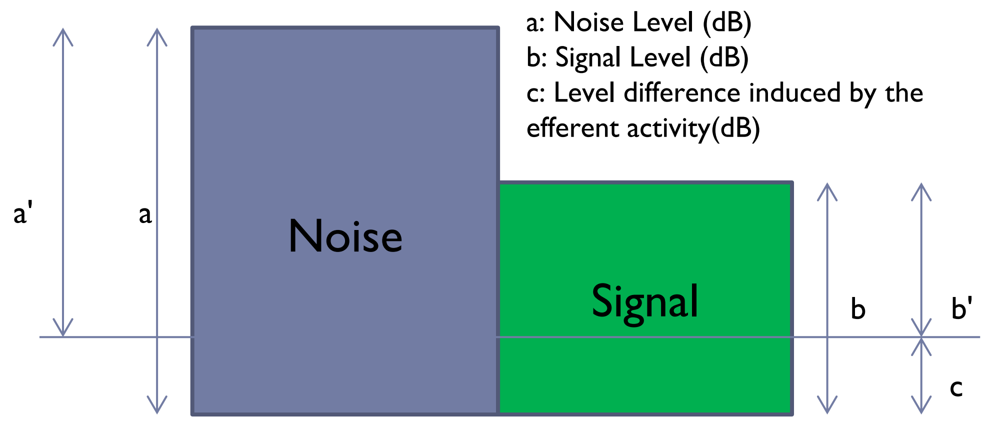
Stronger the MOC effect, higher the thresholds (worse detection performance)!

Discussion

MOC Efferent Feedback Strength

Significant
Negative
Correlation

Masked Detection Threshold



$$a' = a - c$$

$$b' = b - c$$

$$When\ a > b$$

$$\frac{a}{b} < \frac{a\prime}{b\prime}$$

$$Thus,$$

$$\frac{b}{a} > \frac{b\prime}{a\prime}$$

Therefore when the original SNR is negative (less than 1 when represented as a fraction), the efferent system feedback results in a further reduction of the SNR. As a result, the signal becomes more difficult to hear.

When the signal level is significantly lower than the background noise, the MOCS feedback has an adverse effect on the detection performance.

Conclusions

- Listeners with normal hearing are able to detect alarm signals in very low SNR conditions (-15dB SNR Monaural, -30dB SNR Free-Field)
- Biologically inspired auditory neuroscience models can be used to simulate these conditions and may be used as a prediction system for alarm/tonal detection
- Through the neuroscience model we were able to connect to other relevant research - effects of MOC
- Stronger the MOCS efferent feedback, worse the detection performance in negative SNR conditions

Future Work

- Investigate the individual differences
- Investigate the huge significant effect between Monaural and Free-Field
- MAP Model: Monaural → Binaural (Neuroscience aspect of spatial hearing)

Acknowledgement

- Hong Kong Research Grants Council for partially supporting this study.

Thank You!

Q & A