Cochlear Nonlinearity and Amplification in the Guinea Pig

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Abstract

As two key components of cochlear transduction and frequency tuning, the electrophysiological responses of the outer hair cells (OHCs) and mechanical displacements of the organ of Corti have previously been studied in the gerbil cochlea by us and others. To investigate the consistency of cochlear mechanics in the mammalian cochlea, we measured motion and voltage responses in the base of the guinea pig cochlea. We measured (1) the extracellular voltage generated by OHCs, termed local cochlear microphonic (LCM) and (2) displacements within the organ of Corti complex (OCC) to single and multi-tone stimuli. In guinea pig LCM and displacement measurements were conducted through a hole in the wall of the cochlea; in gerbil displacement was measured through the round window. In the best frequency (BF) region, we found similar LCM responses in guinea pig and gerbil: strong nonlinearity to both single and multi-tone stimuli. Below the BF region, we found that the mild nonlinearity in guinea pig LCM responses to single tones was less pronounced than in gerbil. Also, the strong sub-BF nonlinearity in LCM responses to multi-tones, that has been previously observed in gerbil, was less pronounced in guinea pig. Displacement measurements were performed using optical coherence tomography. In the BF region, we observed similar cochlear displacements in guinea pig and gerbil: a strong nonlinearity in the BF region both at the basilar membrane and within the OCC. The sub-BF nonlinearity in OCC displacements is less pronounced in guinea pig than gerbil. The differences that we observed in LCM and displacements responses in guinea pig versus gerbil could have a variety of reasons, for example anatomical differences, or the angle of measurements, which in gerbil were made through the RW, and would detect longitudinal as well as transverse motion. Further voltage and displacement experiments focusing on the OHC region are ongoing. Our findings so far suggest that the micro-mechanics of cochlear amplification are mostly similar in guinea pig and gerbil, with small differences.

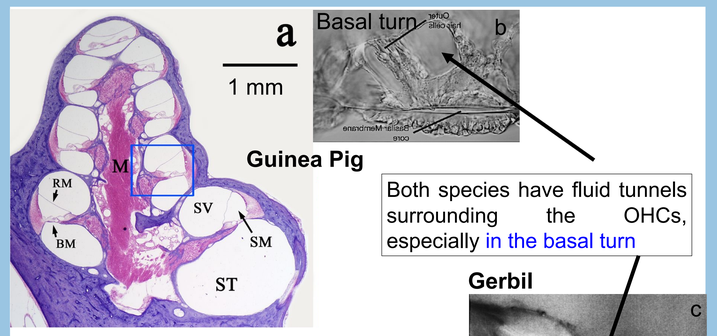


Figure 1: Anatomy. a. Iyer et al. *Scientific reports* 6 (2016). b. Warren et al, PNAS 113 (2016). c. Edge et al, Hearing Research 124 (1998).

Sound stimulus

I) Single tones between ~1 kHz – 40 kHz with frequency space of 500 Hz.
II) Multi-tone Zwuis complexes, 60 frequencies between ~5 kHz – 35 kHz:

Acknowledgments: This work was supported by R01 DC015362 and the Emil Capita Foundation.

References:

Fallah, E., Strimbu, C. E., & Olson, E. S. (2019). Nonlinearity and amplification in cochlear responses to single and multi-tone stimuli. *Hearing research*, *377*, 271-281.

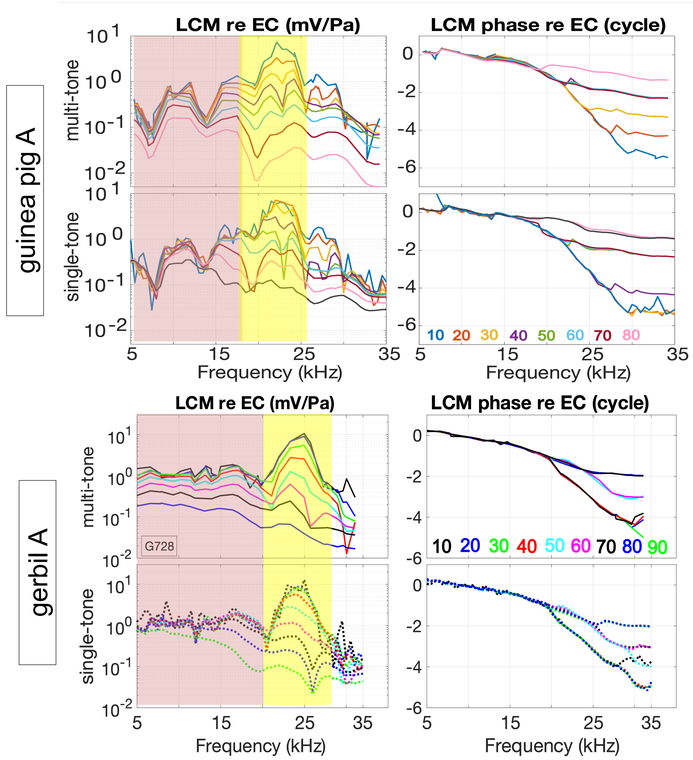
Cooper, N. P., Vavakou, A., & van der Heijden, M. (2018). *Nature communications*, *9*(1), 1-12

Van der Heijden, M. & Joris, P.X. (2003). J. Neuroscience, 23: 9194-9198.

Results

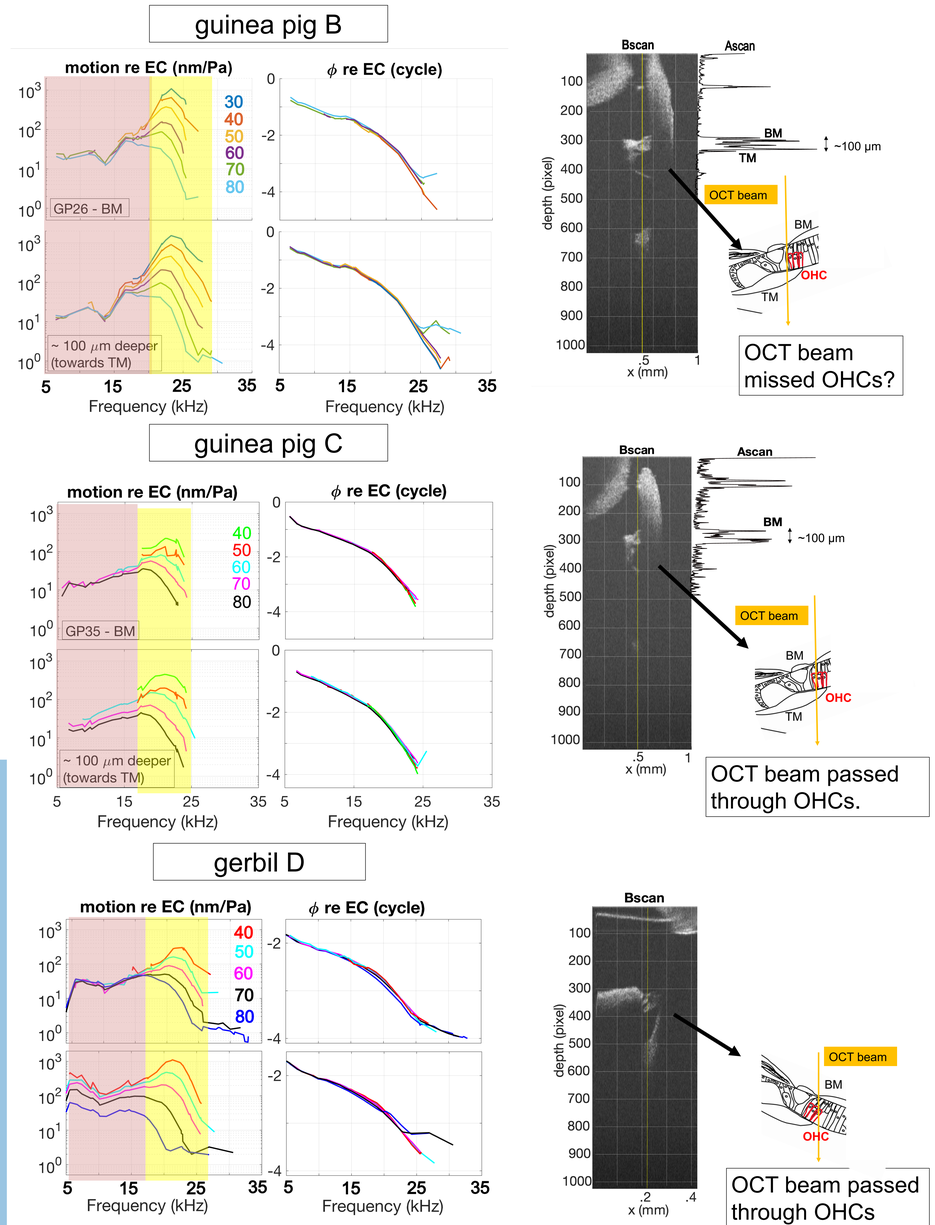
Local Cochlear Microphonic (LCM)

- In the best frequency (BF) region, we found similar LCM responses in guinea pig and gerbil: strong nonlinearity to both single and multi-tone stimuli.
- Below the BF region, we found that the mild nonlinearity in guinea pig LCM responses to single tones was less pronounced than in gerbil.
- Also, the strong sub-BF nonlinearity in LCM responses to multi-tones, that has been previously observed and published by us in gerbil, was less pronounced in guinea pig.



Displacements in the organ of Corti complex

- In the BF region, we observed similar cochlear displacements in guinea pig and gerbil: a strong nonlinearity in the BF region both at the basilar membrane and within the OCC.
- Sub-BF nonlinearity: Depending on the lateral location and the angle of OCT measurement we observed this nonlinearity rarely, usually sub-BF nonlinearity was not observed. Thus, the sub-BF nonlinearity in OCC displacements seems to be limited to a relatively narrow OHC region.



Methods

Local Cochlear Microphonic (LCM)

The Local Cochlear Microphonic (LCM) responses were measured by a tungsten microelectrode (resistance ~ 1 MΩ) through a small hole (diameter ~ 100 μm) in the first turn of the cochlea in 10 guinea pigs. The electrode was advanced ~ 1mm to a position close to the BM.

Displacements in the organ of Corti complex

Displacements of the basilar membrane (X_{BM}) and a location in the OHC region (X_{OHC}) were simultaneously measured in 15 guinea pigs using optical coherence tomography (OCT), in some animals through the same hole made for LCM measurements (slightly enlarged).