A Comprehensive Predictive Model for low and high frequency Cochlear Mechanics

Cochlear preformance: Able to detect 20 micropascals Pa
and withstand 20 pascales while static
changes of 10's of PA are easily handled
discriminate frequencies 0.2% Center bandwidth

why we need mathematical models
- Cochlea is small inaccesable and animal experiments are slow and difficult and in vivo (alive) mechanics experiments in humans impossible

Physiologically vanurable to damage

with the introduction of OTC its easier to see (??)

Cochlear frequency analysis

airborne pressure → stapes vibration → traveling wave on basilar membrane

Kinimatic Model on outer ~~[illegible]~~ dark narrow hair cells

waves go from ___ mps to ___ mps

Moving on to mathematical model

Mechanical-electric-acoustic model of the cochlea

Fluid

- inviscid except from viscosity of OoC (fluid) in TM RL shearing

Motion

BM (mode shape)

TM shear motion

TM bending motion

Fluid-structure coupling

Somatic motility and mechano electrical (MET) channels

4 electrical degree of freedom

Ramamoorthy et al 2007

Organ of Corti micromechanics

Checking model on biophysical structures using methods of mechanics

OHC model: OHC somatic motility

Electrical domain

estimates SV, SM, ST

? media tympani

Today talk about a quasistatic model

Macroscopic scale: Coupling electrical propagation to OCH motion

Micromechanics of OOC

Actually get rid of

Result is a matrix you can solve

Model result

Impact of RC filtering on somatic motility

Ramamoorthy, DeO 2007

The efficacy of B motility and somatic motility

Maoiel 2011

TMS ability to add stability for higher gains (Meaud 2010)

Effects of genetic manipulations on linear and non linear cochlear mechanics

Predictions for lower frequencies were more challenging

difficulty in achieving accurate transition

to low frequency response has lead to speculations on the source

· Applied data on gain were conflicting

Motivation and Background

Basilar mechanics is different from apical mechanics

OCT Data: He et al 2018

Recio-Spinoso and Oghalai 2017

Auditory Nerve fibers are tuned differently from base to apex

Temchin et al 2008

In addition there is base frequency scaling

Liu and Neely 2008

Exponential scaling holds at the base but not at the apex

Some previous work

Sheraz 2010

Differences seen in psychophysical experiments empirically divides cochlea into basal and apical sections

Reichenbach and Hudspeth 2010

Electromechanical properties of the Apex

Motallebzadeh 2018

- Mouse high frequency cochlea
- No lowpass characteristics
- No TM

there is still a gap for a physiologically based computer model

Tonotopic organization in the cochlea

look at photo

Hypothesis inclusion of apical viscosity and outer height changes along with cytoarchitectural changes will give rise to realistic tuning

maybe — Fluid when compressed will stretch horizontally

Developmental asymptotic ... idk?

Fernandez 1952

Tapered box model

Building of chochlear based fiber — condensed membrane coupled to fluid

3-d fluid discretization of Navier Stokes

(Taylor-hood elements

(Cheng, white and Grosh

CNAME 2008)

(Chang, li, grosh JCP 2013)

Spectrum

Later lifelong developmental asymptotic method fMCRL, 3Lilhd at Sleep

Results: base

Low Spl
High Spl
de Boer and Nuttall (2000)
Adds to this experiment,
Just change how sensitive
the animal is to
change gain

Model calculations of
BM gain and
phase matched experiments at base

Model recreates tuning at the apex

RL gain
RL Phase

Recio-Spinoso 2018

Active vs passive w/ live v dead animal
Net motion of the two are out of the
phase

Hensen Cell measurement in gerbil
Poor low frequencies

Predictions

Warren et al 2016

1) cytoarchitecture leads to preferential amplification of RL motion over BM motion at apex

2) Neural tuning

Sasmal and grosh (2018

model recognizes transitions in neural FTC from base to apex

Rhode et al (2012)

Freeman and Weiss (1990)

What happens if we change temporal and viscosity at the apex

Dallos (1970)

Cheatham and Dallos (2001)

what damped ARF viscosity and natural RL gains

Greenwood 1990 Greenwood map

Artificially changing the fluid viscosity

Significant alteration of
apical response

look at picture

Relative motion of RL and BM

He et al 2018

RL gain RL phase

BM gain BM phase

Model predicts broadband RL gain
and relative phase of RL and BM

Conclusions — look at picture

Future work
nonlinear time domain calculations
developing a higher fidelity model - substructure
fluid and neural stimulation
different modes of excitation of
sensory hair bundles are likely powered
at low frequencies for model and tuning curves