"Spikes alone do not behavior make: why neuroscience needs biomechanics"

Title borrowed from **Phil Holmes**, ED Tytell and AH Cohen

Gabriel Mindlin, covering P.H.

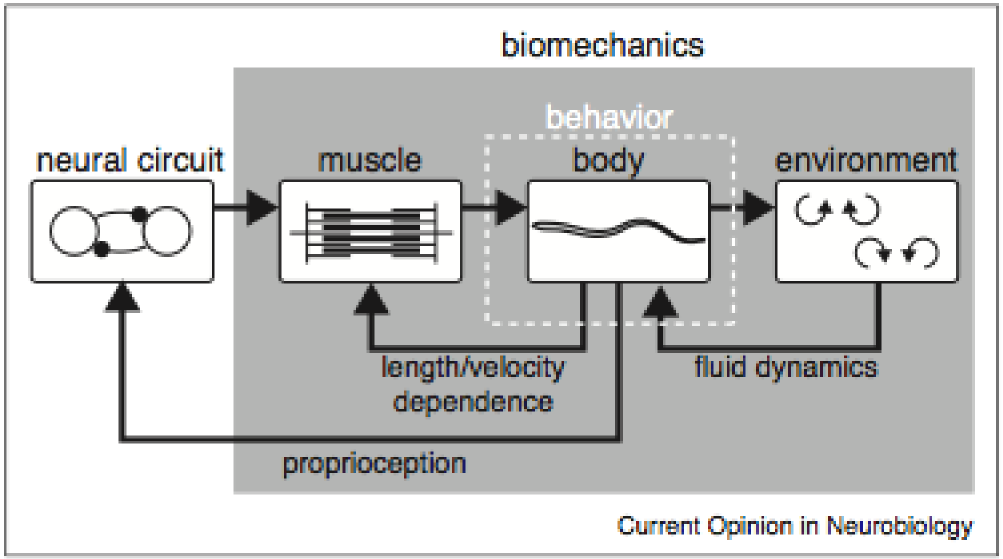
The idea of this micro course:

Behavior requires the interaction between a nervous system, a peripheral biomechanical device, and the environment.

Neural circuits do not function in isolation: they interact with the physical word, take sensory inputs and produce outputs via muscles, which interact with the physical world.

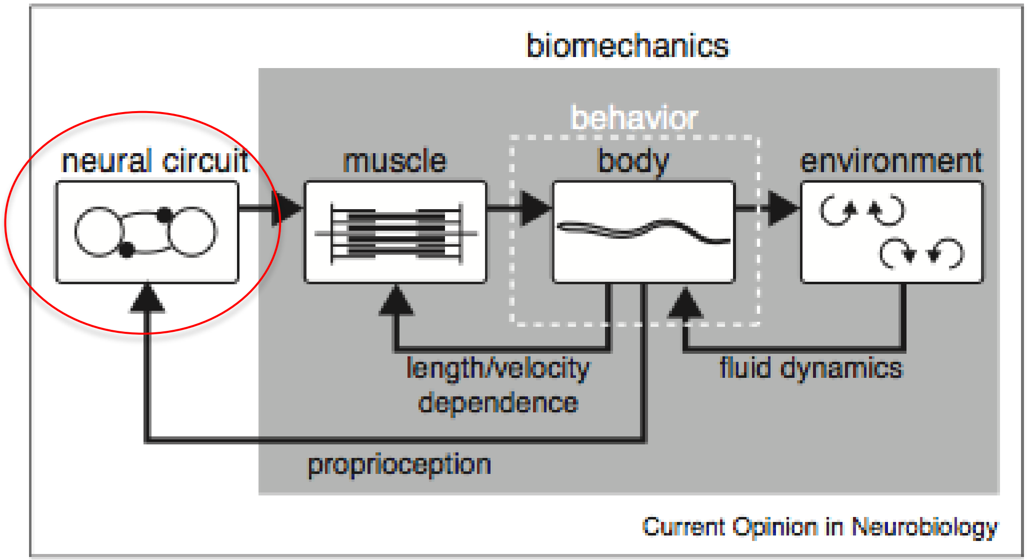
Therefore, the activity of neural circuits can only be understood by considering biomechanics of muscles, bodies and the exterior world.

Inspiring figure:

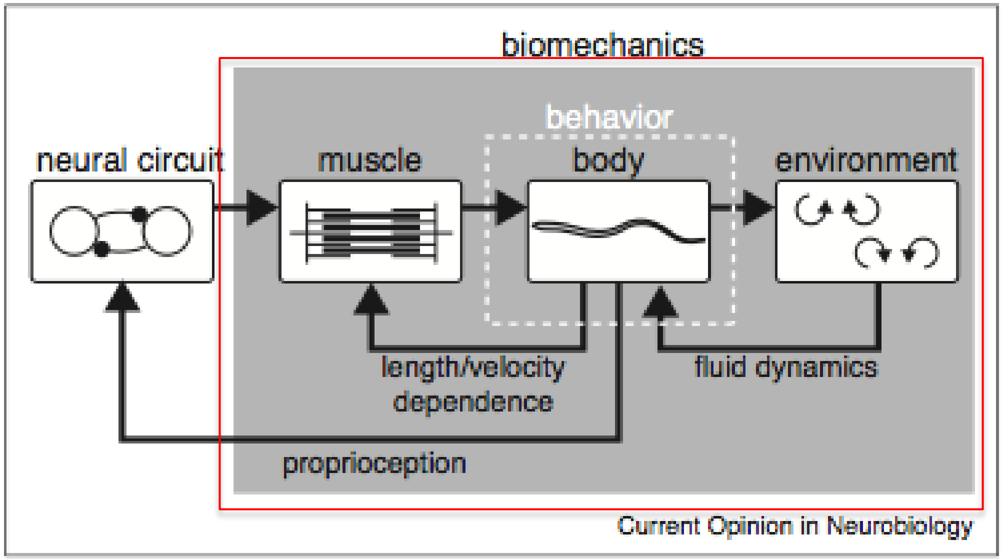


Inspiring figure:

Neuroscience focuses on this.

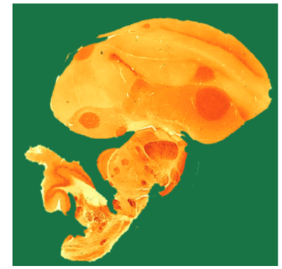


Inspiring figure:

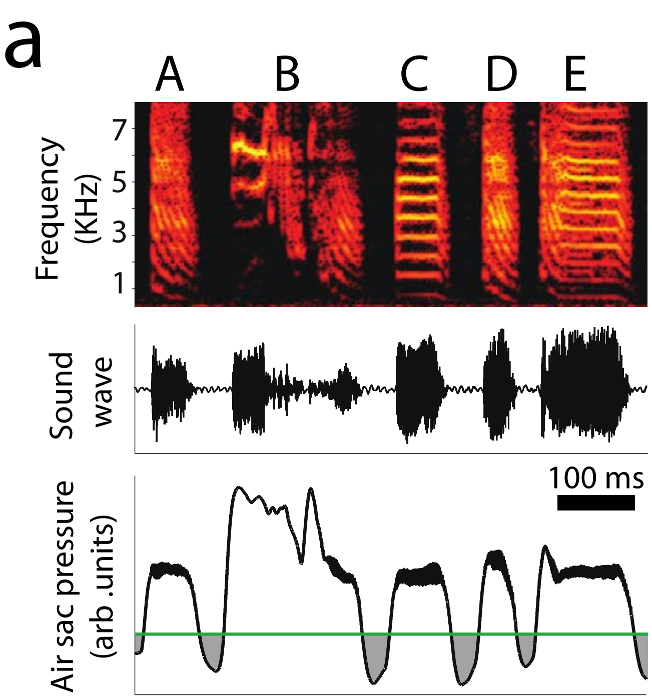


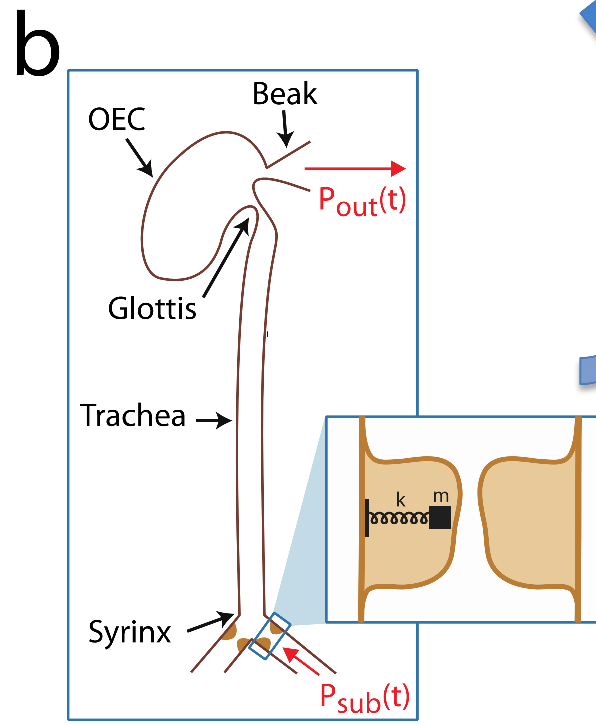
Today we discuss the importance of understanding this.

An example: birdsong



brain

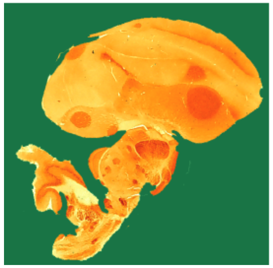




behavior

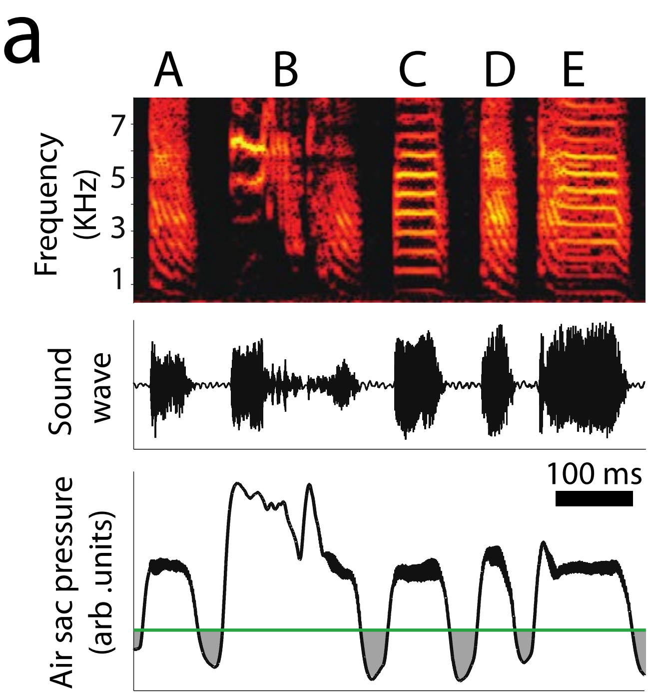
Nonlinear device

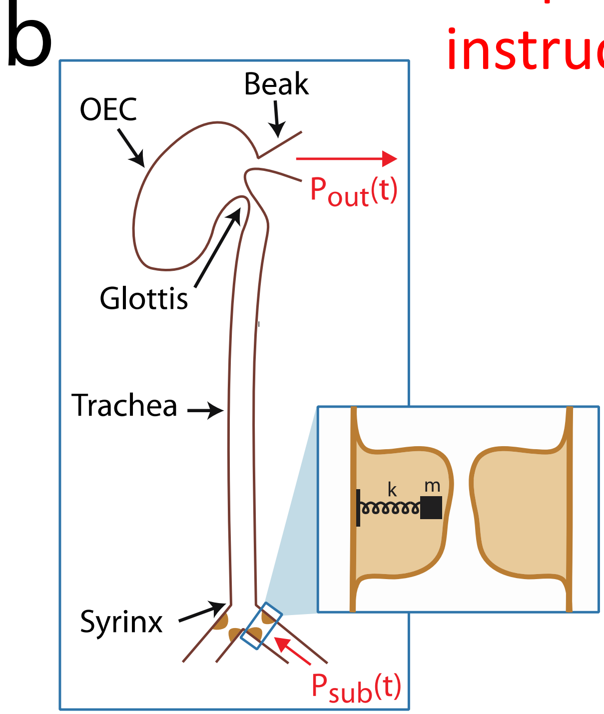
Interesting Role of biomechanics



Brain

Simple instructions





Behavior

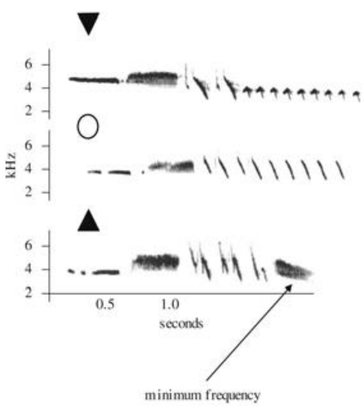
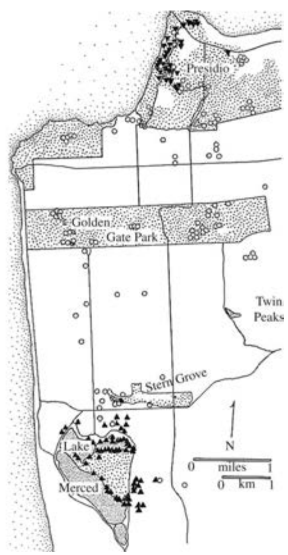
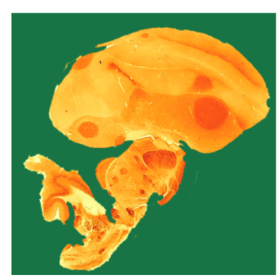
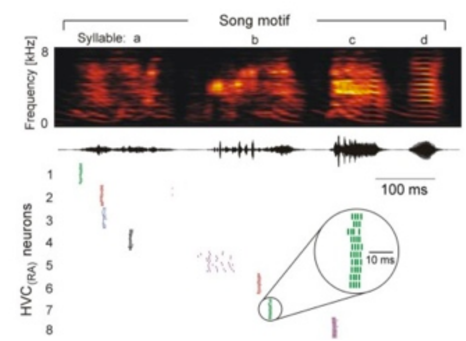
Complex sounds

Nonlinear device

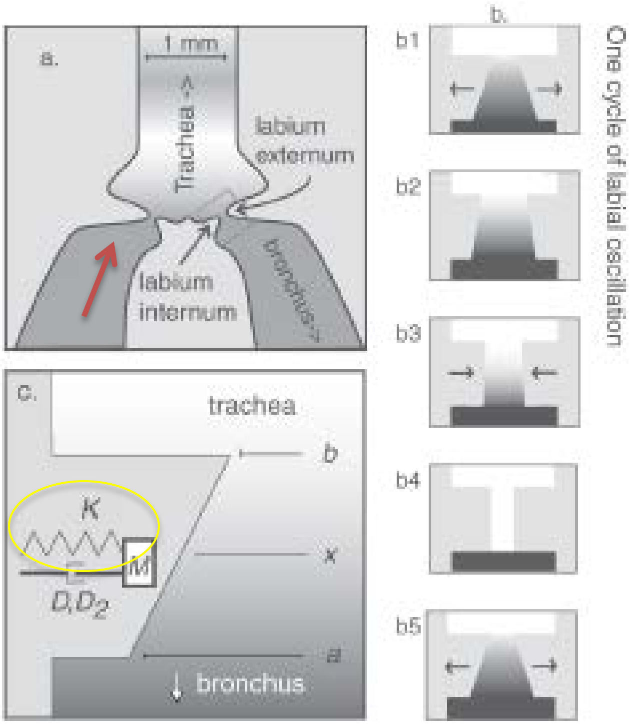
Why birdsong?

A great model for understanding learning:
40% of the known species require a tutor in
order to learn the “right” vocalizations of their species.

Landmarks in History

50’s	70’s	00’ s
 		
Dialects	Vocalizations reflected The operations of a definable Collection of neural structures	The ability to monitor Neural ability in awake Singing birds.

Our first steps in the field: the basic mechanics of labial motion

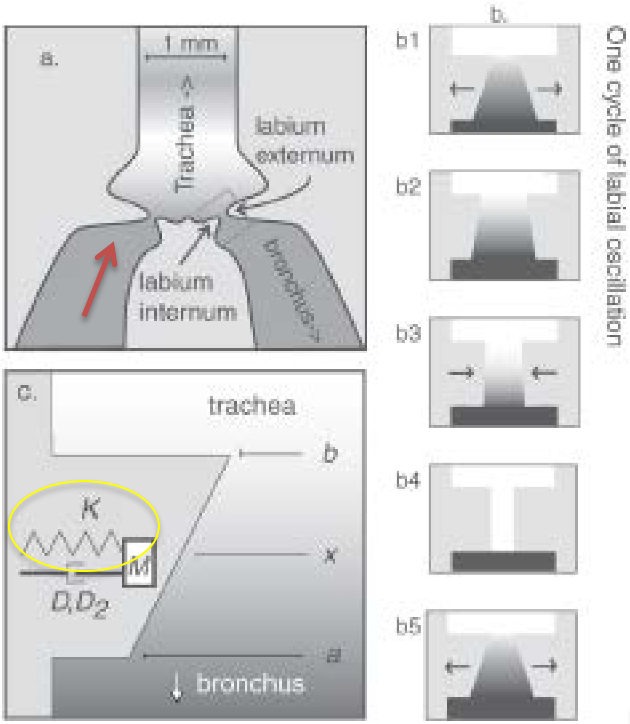


$$\frac{dx}{dt} = y,$$

$$\frac{dy}{dt} = (1/m)\left[-k(x)x - b(y)y - cx^2y + a_{lab}p_s\left(\frac{\Delta a + 2\tau\tau}{a_{01} + x + \tau y}\right)\right].$$

Two time dependent parameters
Control many features of the vocalizations:
air sac pressure and s.v. tension

Our first steps in the field: the basic mechanics of labial motion



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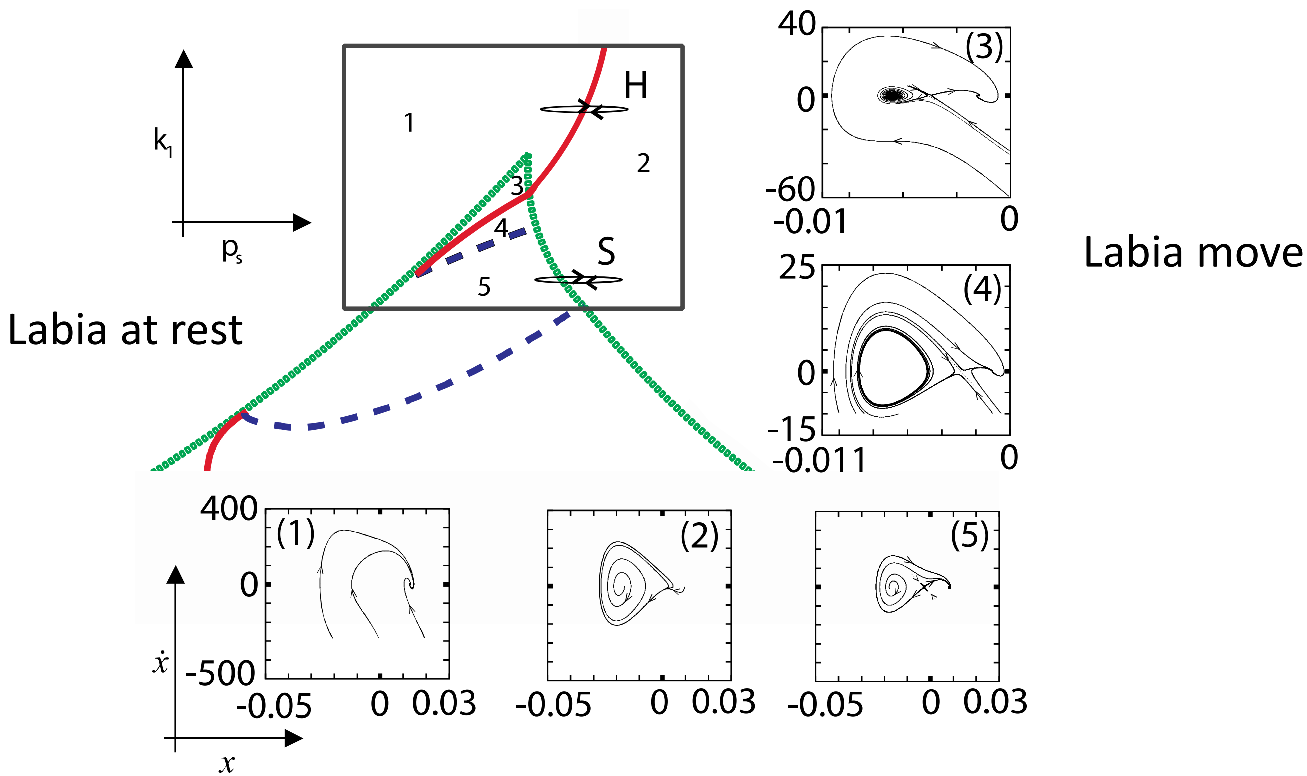
The time dependent parameters are **slow:**
The labial oscillations depend on the Interaction between the airflow and the labia

Which is the rationale behind that hypothesis?
Why complex sounds from such a simple model?



Regardless of the details of the model, many features of the sounds come In packages, determined by the underlying dynamics.

An ICTP initciative

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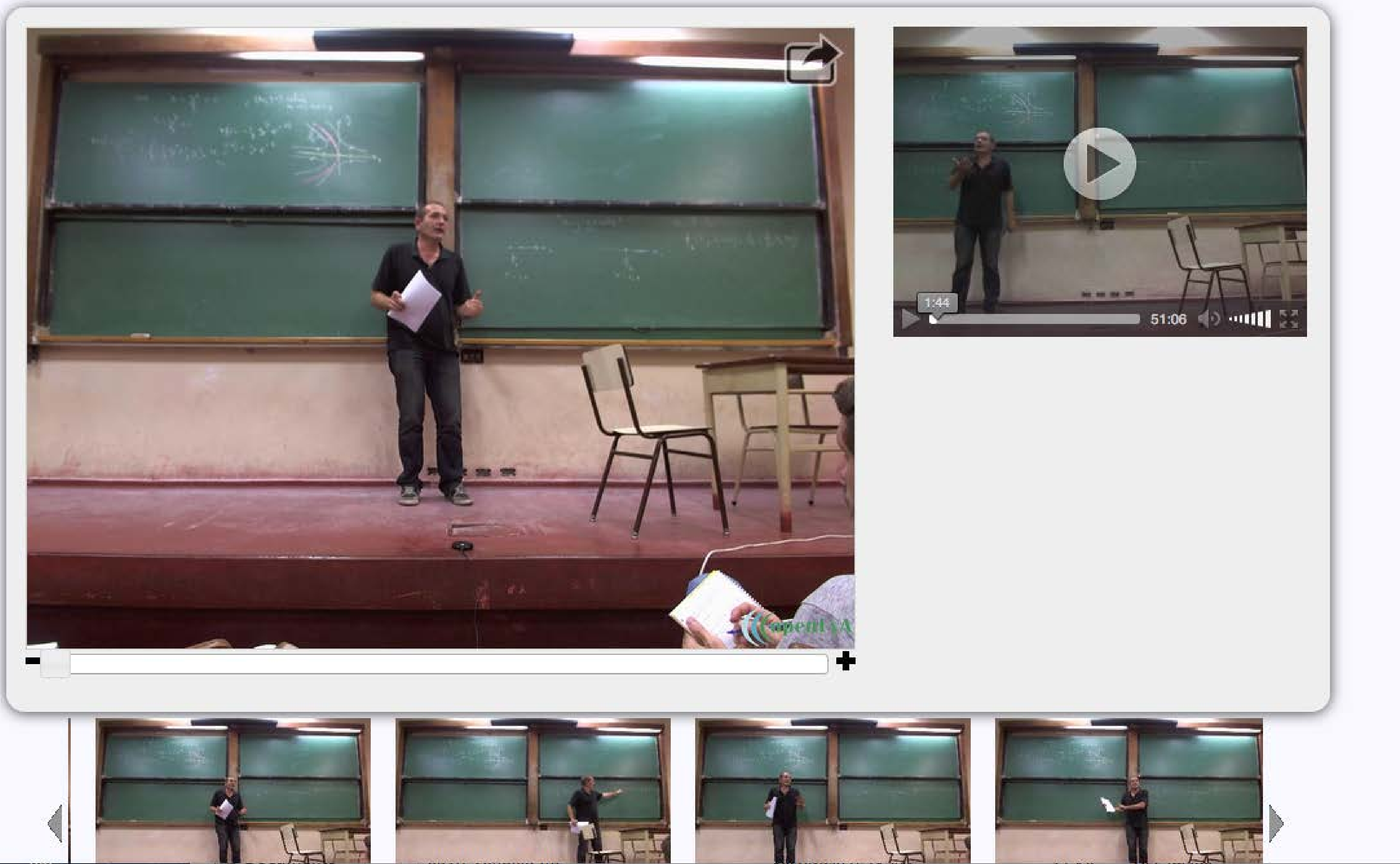
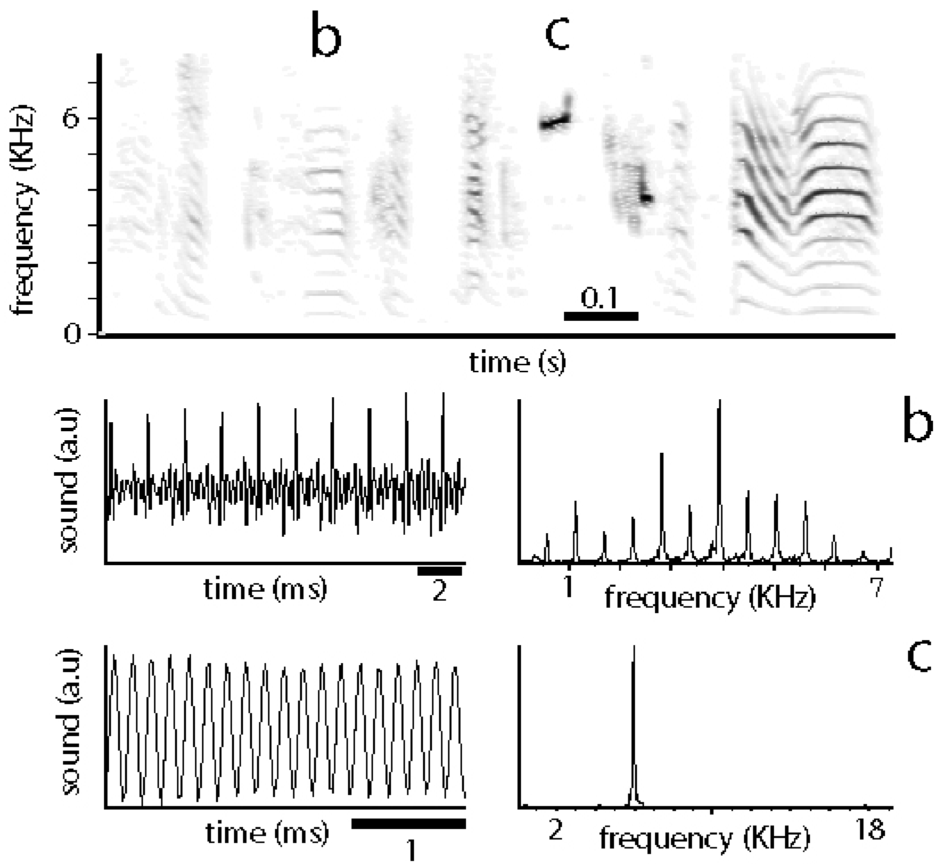
How the page works



Example of a “complex feature”



Zebra finch song

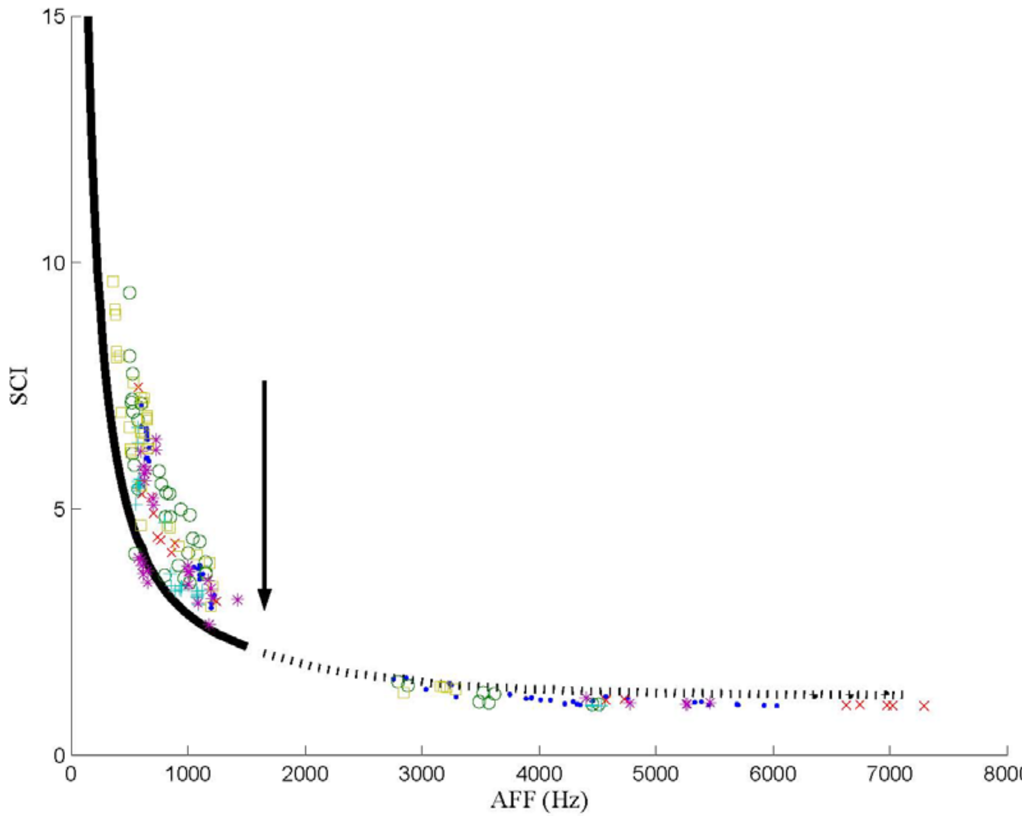
Spectrally rich notes

Almost tonal notes

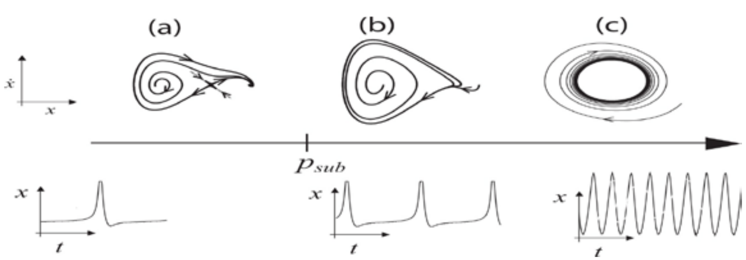
How to quantify this

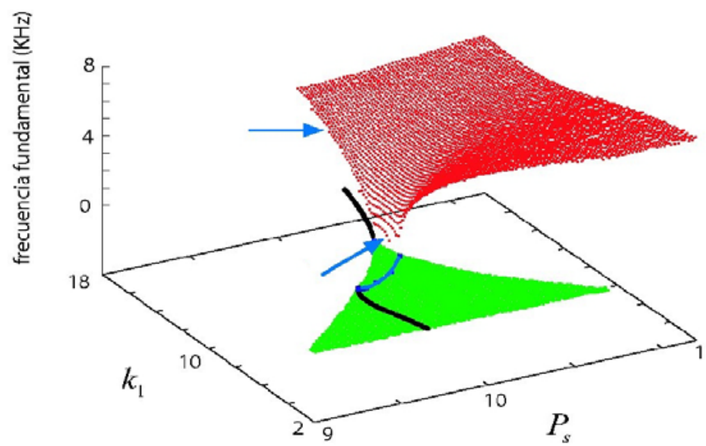
The spectral Index Content (SCI) is defined to Reflect how the energy is distributed in the spectrum compared to the energy in the Fundamental frequency component

$$SCI = \left(\sum_i \omega_i \varepsilon_i / E\right) \Big/ AFF$$

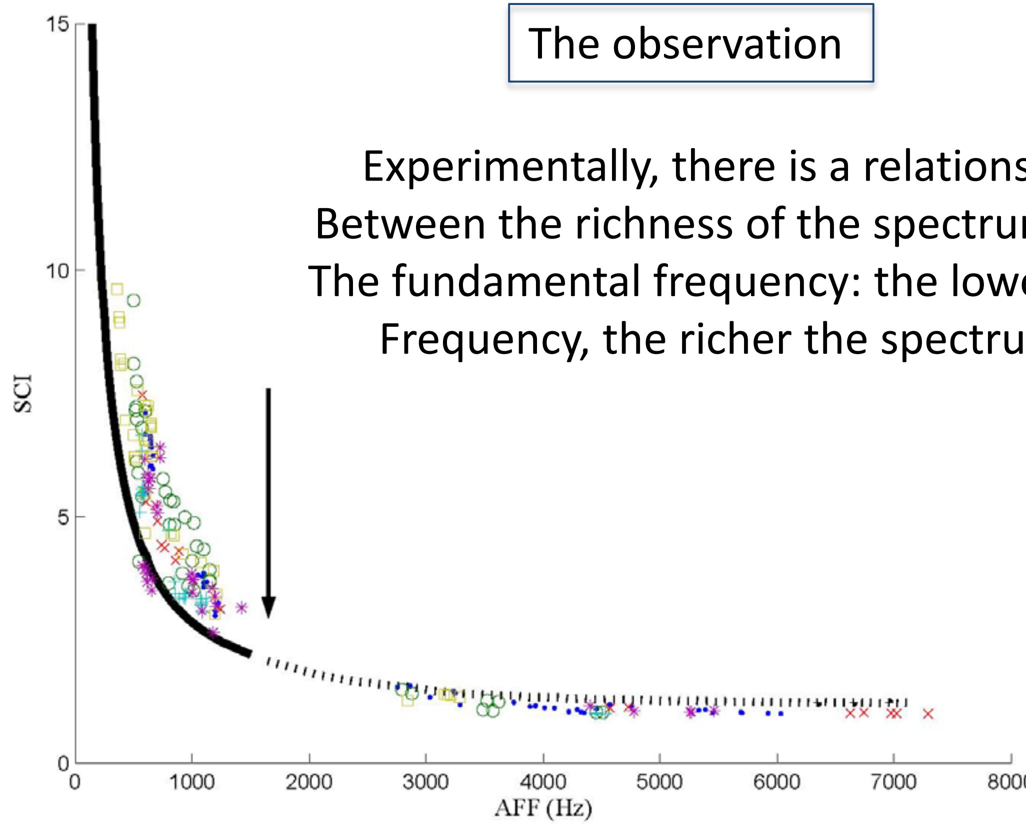


Signature of a snilc?



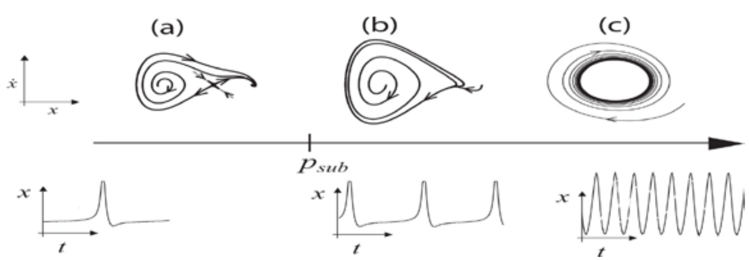


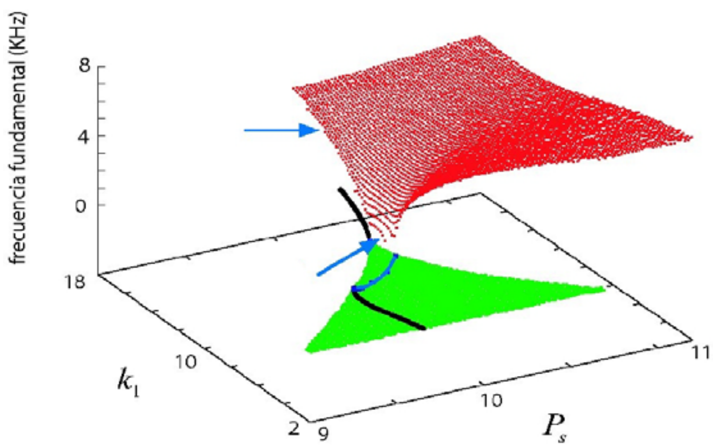
The observation

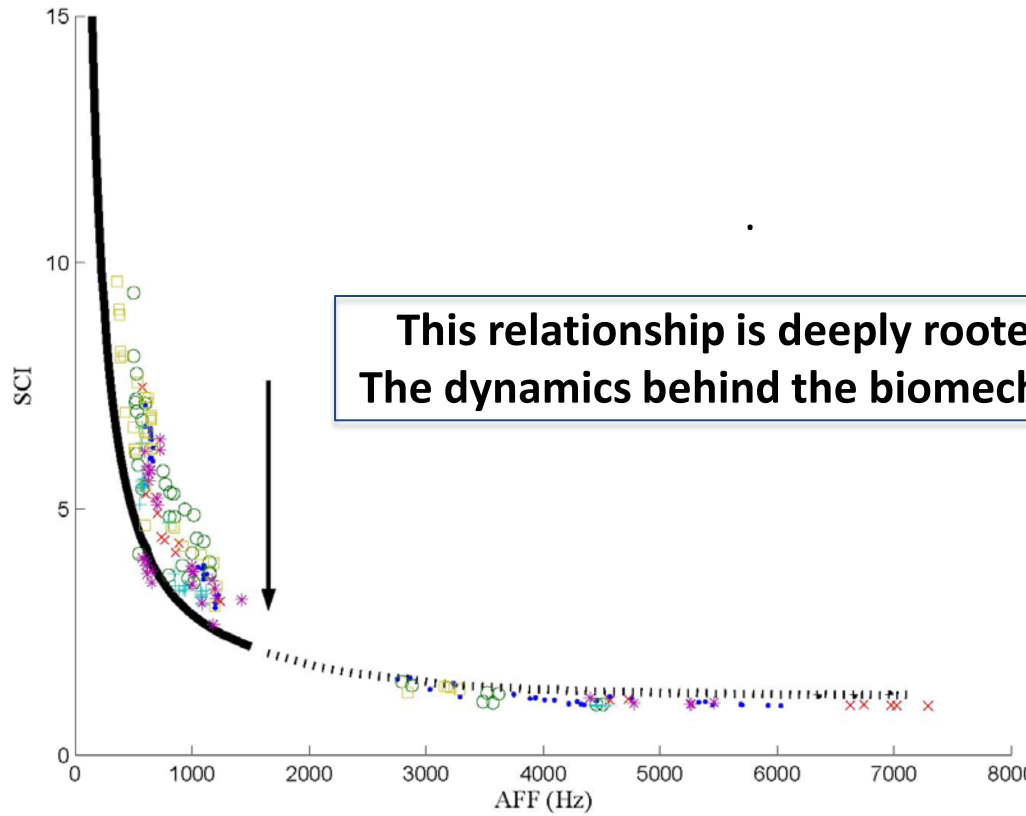


Experimentally, there is a relationship
Between the richness of the spectrum and
The fundamental frequency: the lower the
Frequency, the richer the spectrum.

Signature of a snilc?

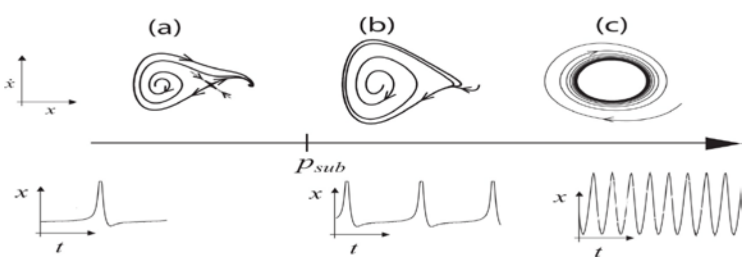


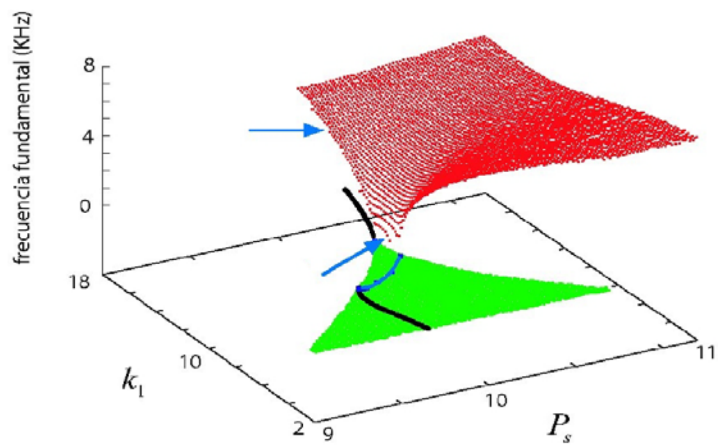




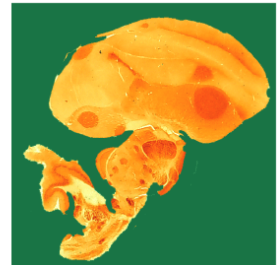
This relationship is deeply rooted in The dynamics behind the biomechanics

Signature of a snilc

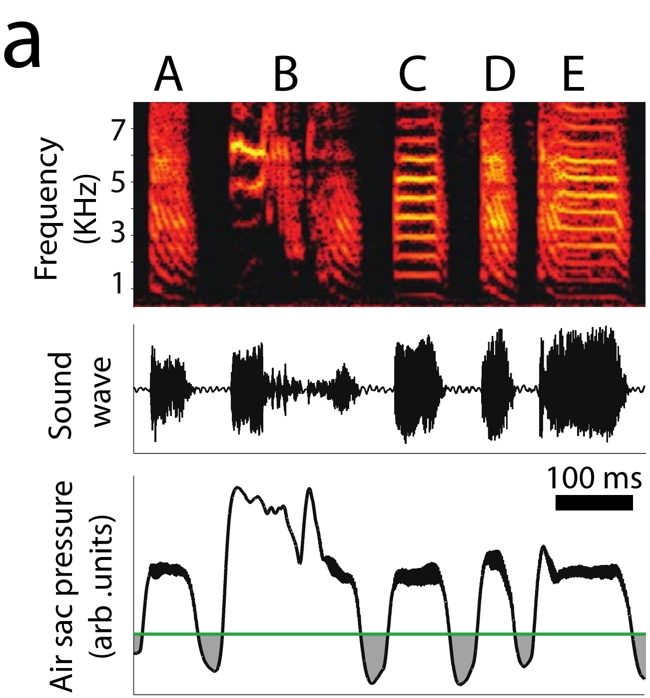


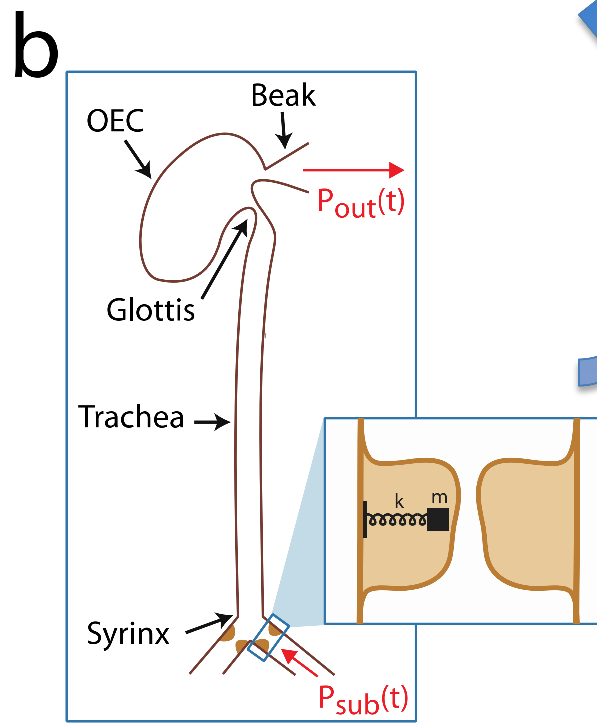


So far, the dynamics
Of the labia



brain

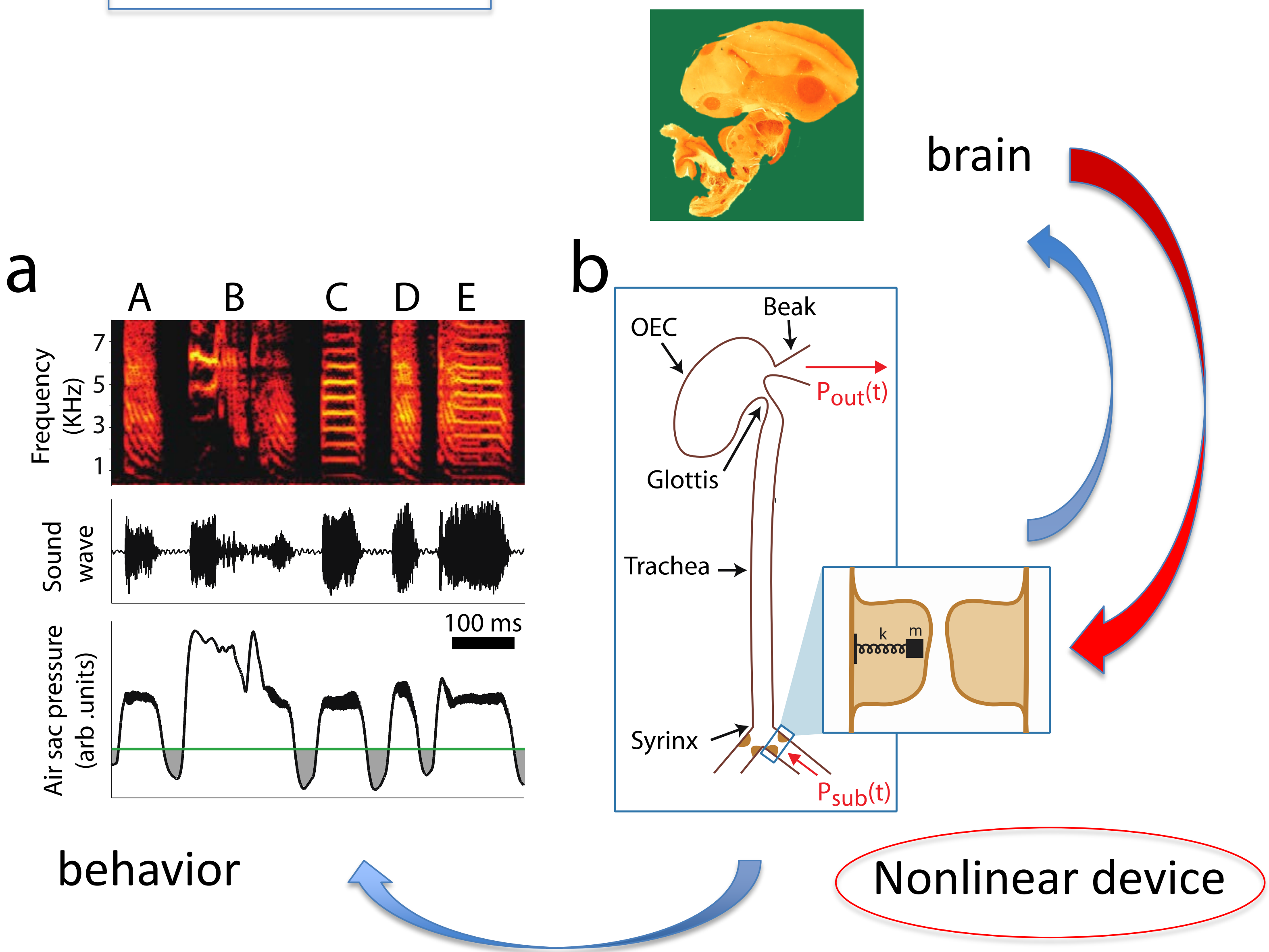




behavior

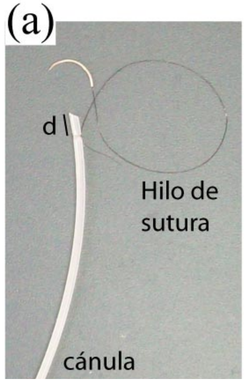
Nonlinear device

Now, the instructions

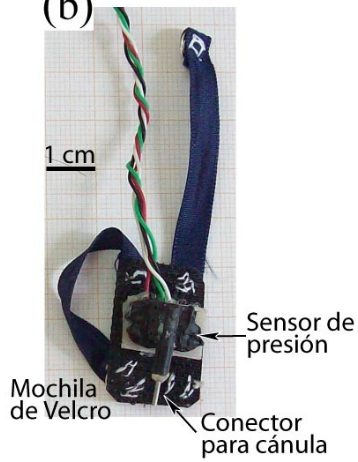


In our model, the (time dependent) parameters were
the air sac pressure and syringeal tension. We can measure them

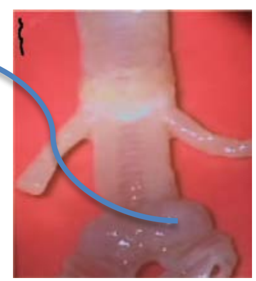
(a)



(b)

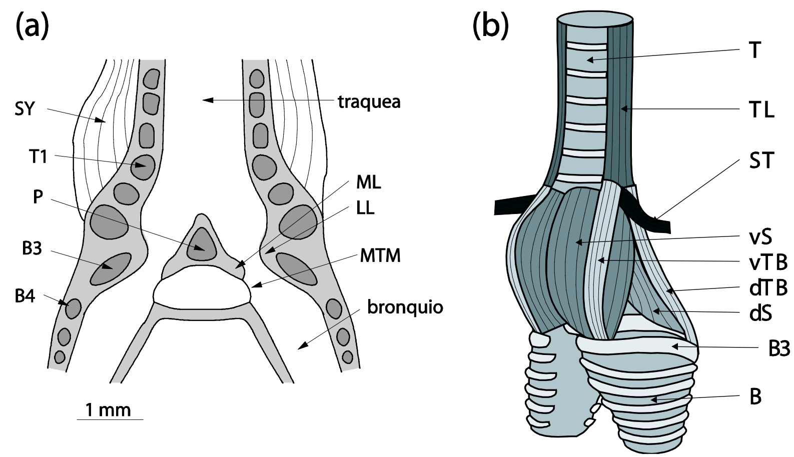


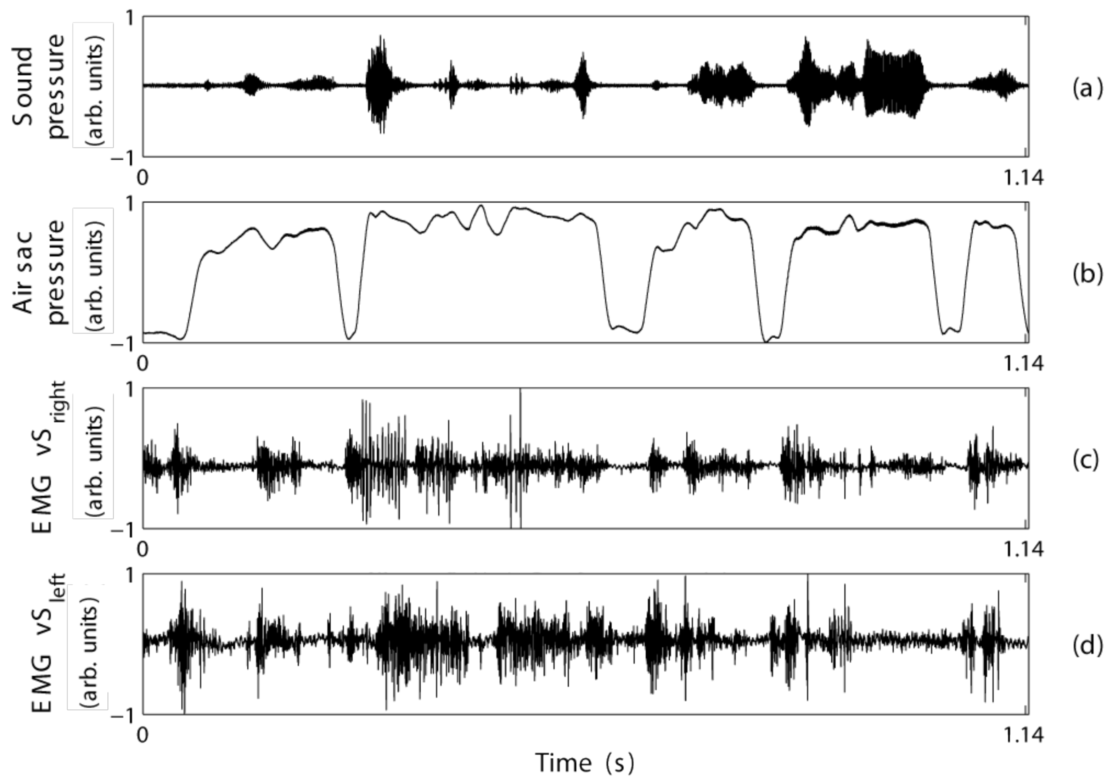
Tension
(activity of vS muscle)



With Franz Goller, 2003-present

Most of our time, we are measuring these Instructions sent to the syrinx…





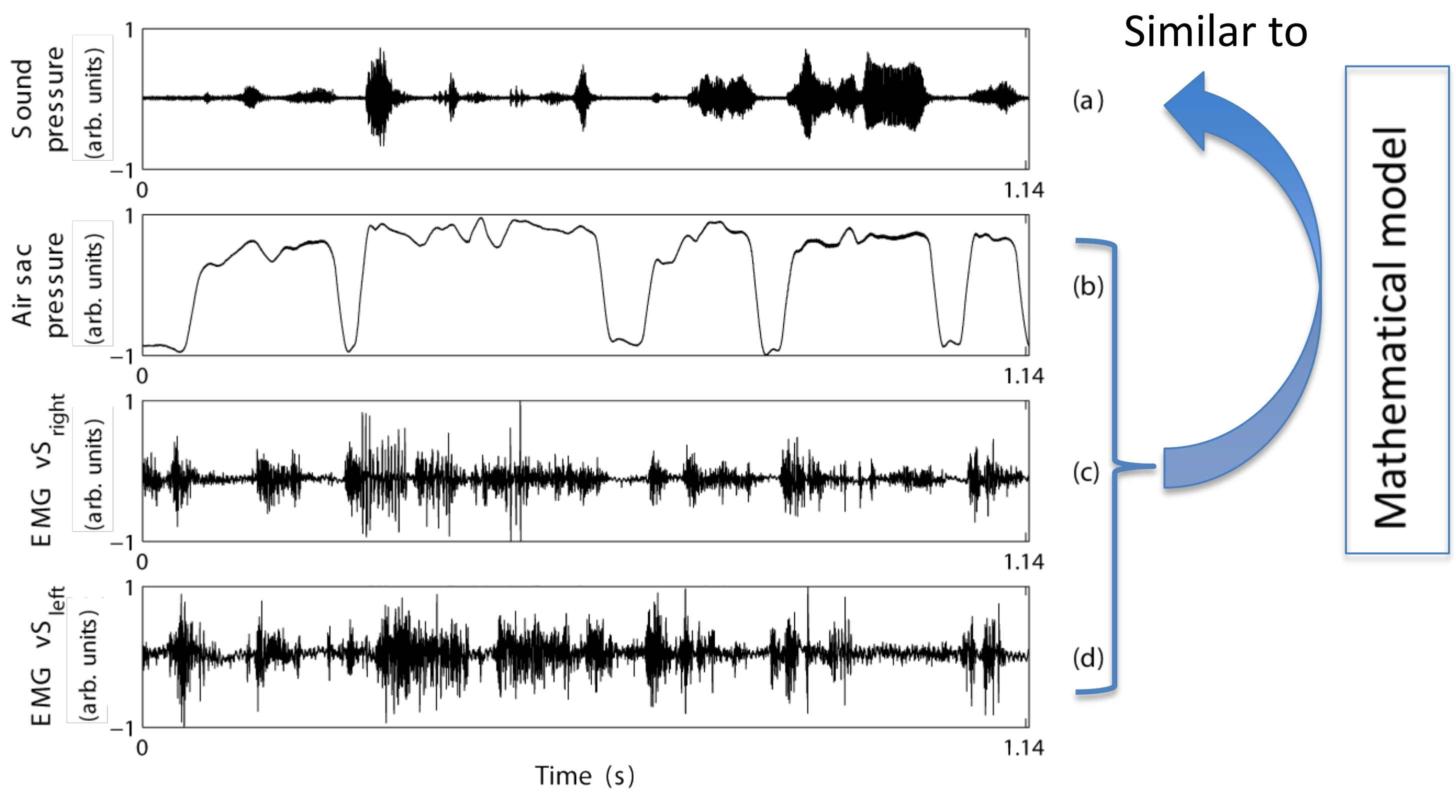
sound

pressure

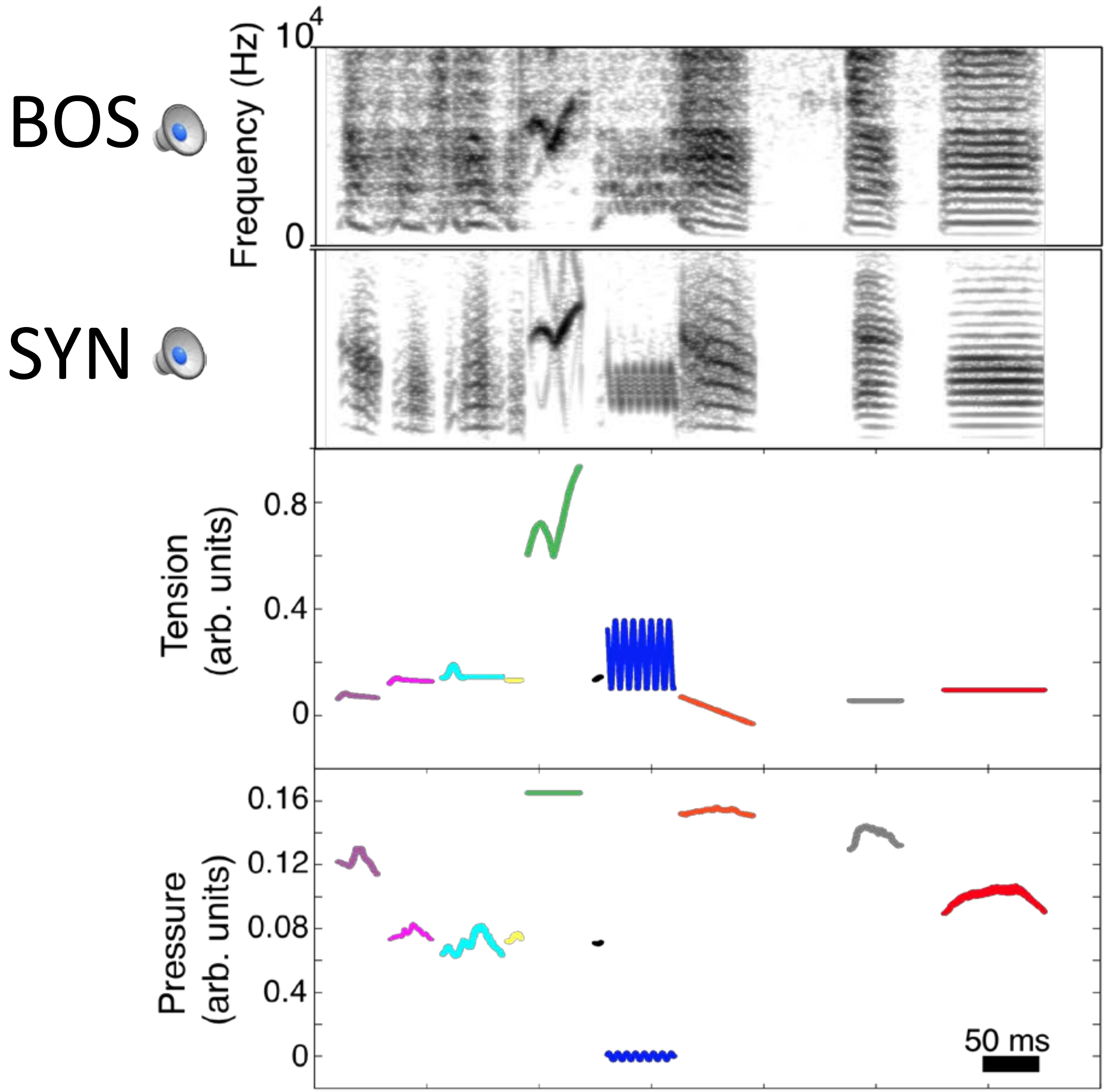
Tension (right)

Tension (left)

Actually, the first test to the model was to
Integrate it with these instructions as time dependent
parameters, comparing the synthesized sounds with the song

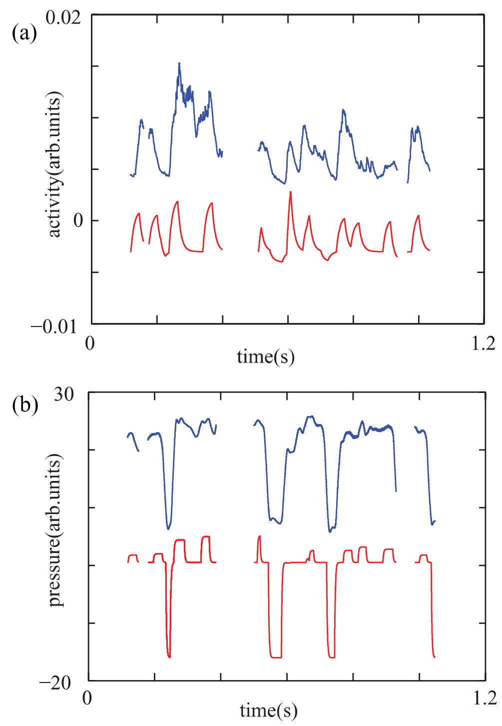


Strategies to test the model



To get a synthetic song, we fit α (pressure) and β (tension) in the normal form model so that BOS and SYN share spectral Features (Fundamental, Spectral content)

Reconstructed Instructions, Compared with the measured ones…



Or we can ask the bird!

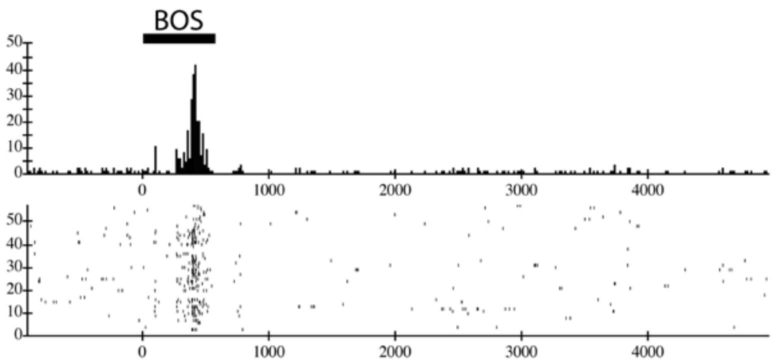
In the course by Vijay, he discussed how to get the receptive
Field of neurons: let us see how that would work in this system

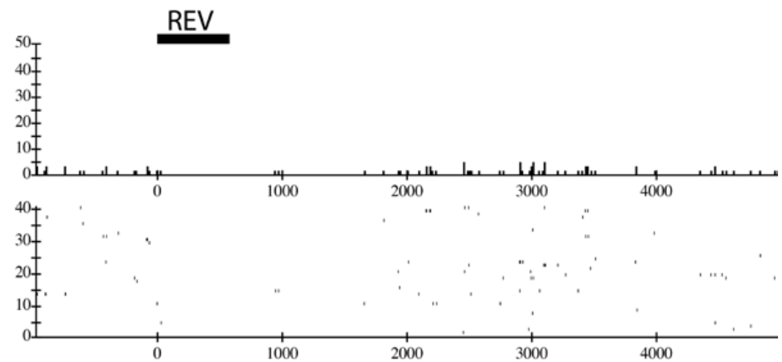
From Dan’s Lab

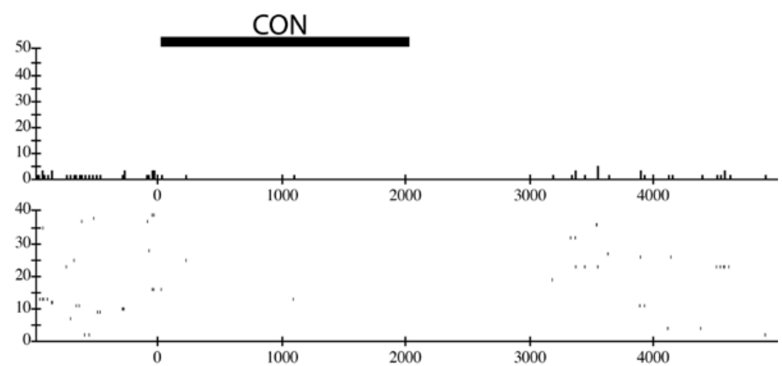
From Dan’s Lab

Testing the model

Neurons in HVC respond selectively to the bird's own song (BOS)

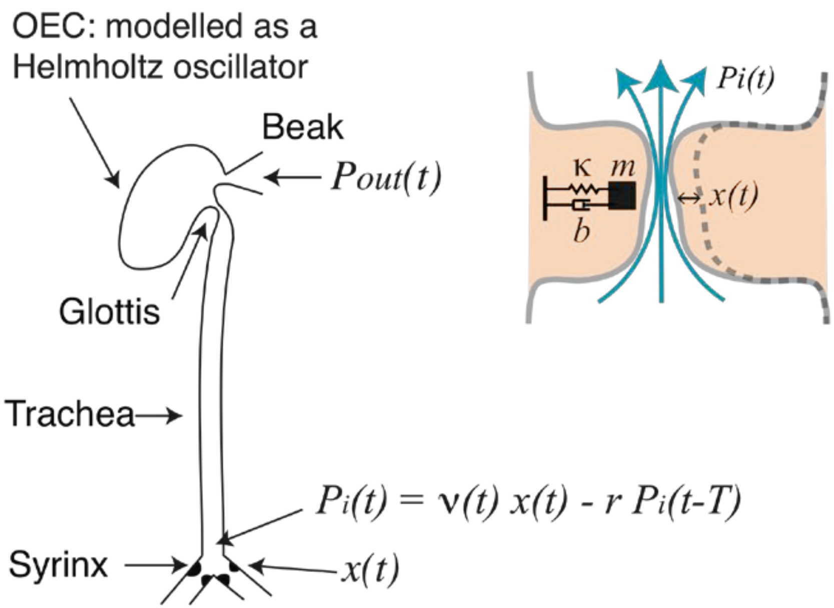


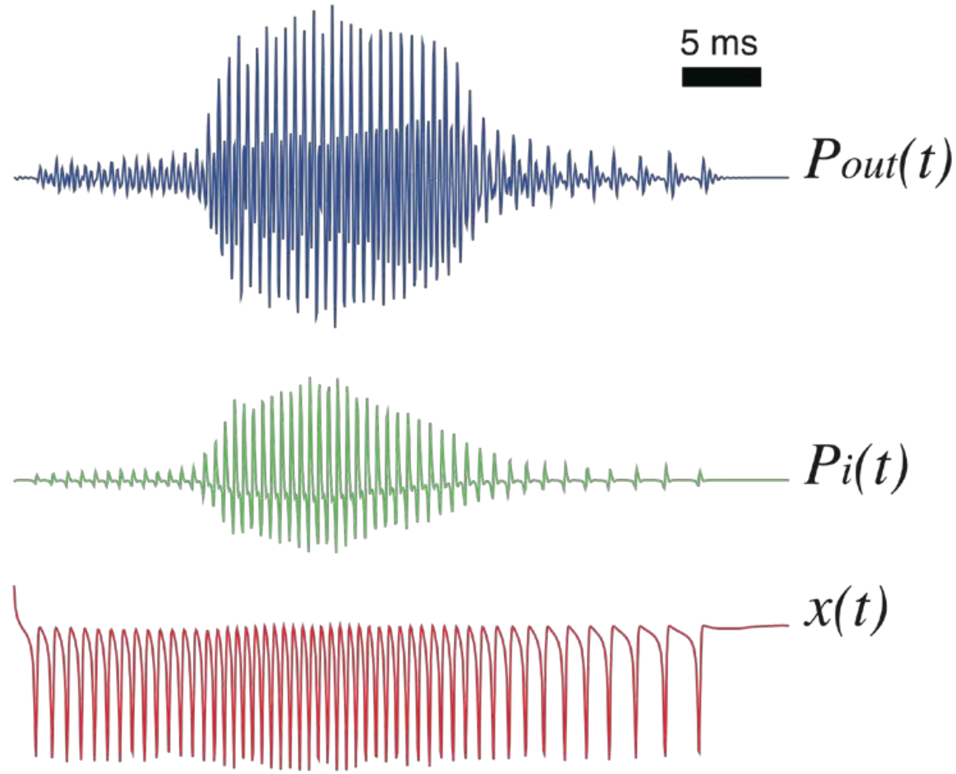




Data by Ana Amador

A more detailed modeling





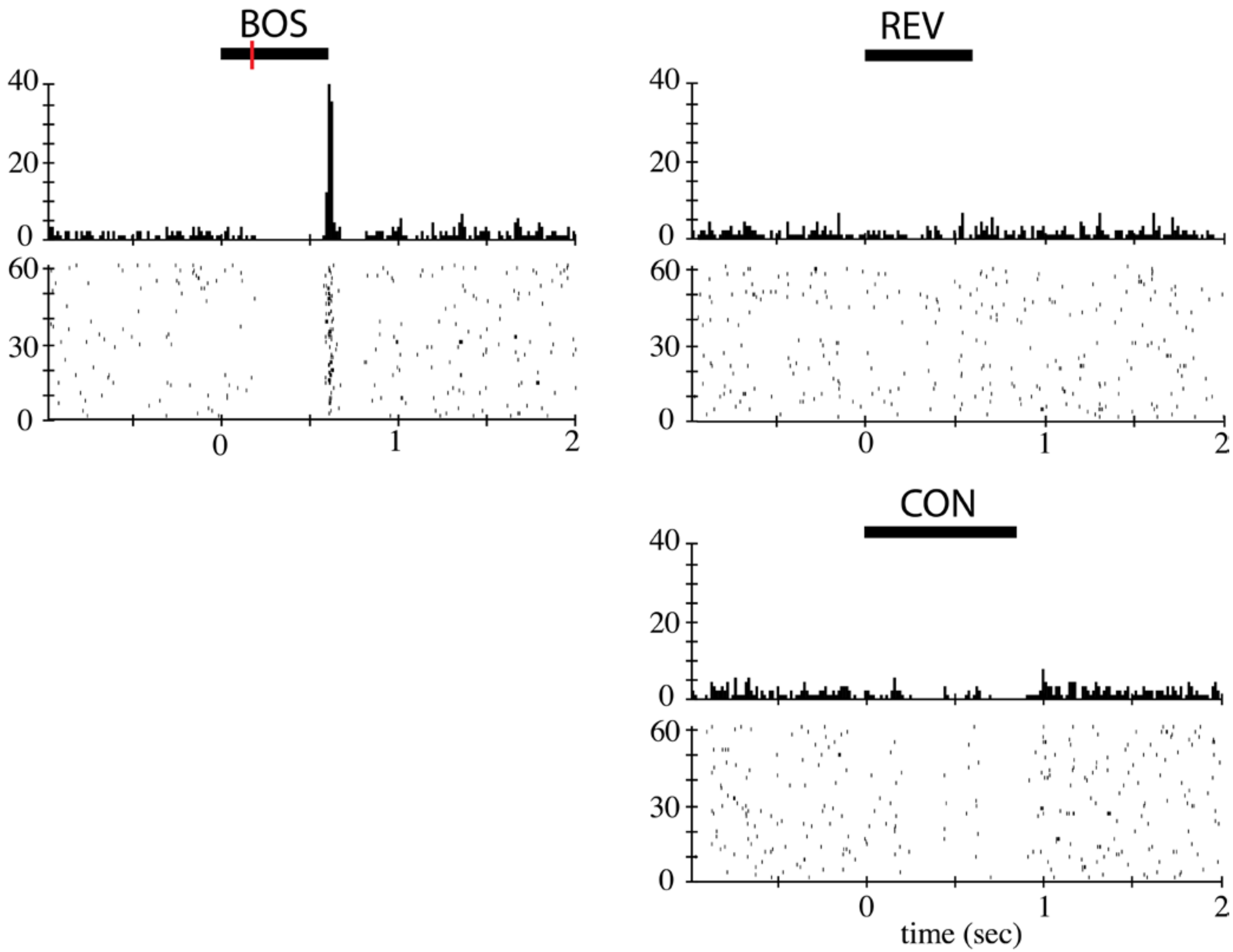
$$\frac{dx}{dt} = y$$

$$\frac{dy}{dt} = -\alpha(t)\gamma^2 - \beta(t)\gamma^2 x - \gamma^2 x^3 - \gamma x^2 y + \gamma^2 x^2 - \gamma x y$$

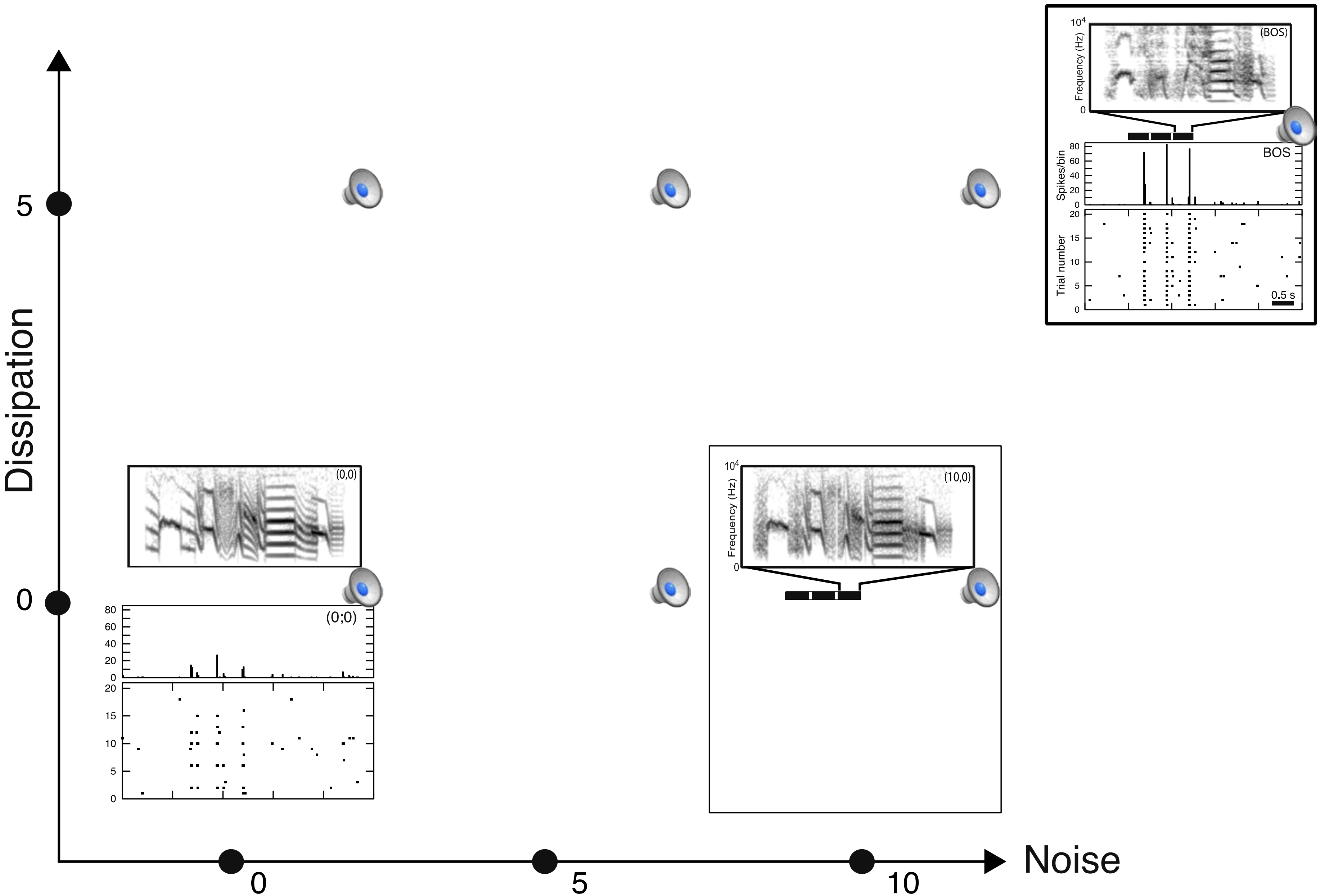
✓ More detailed modeling of the vocal tract (not just 3 tubes). Oropharingeal cavity as a resonator

✓ Intrinsic noise in the activity of the syringeal muscles

A more detailed modeling



A strategy for studying a hierarchy of importance for the elements in the model

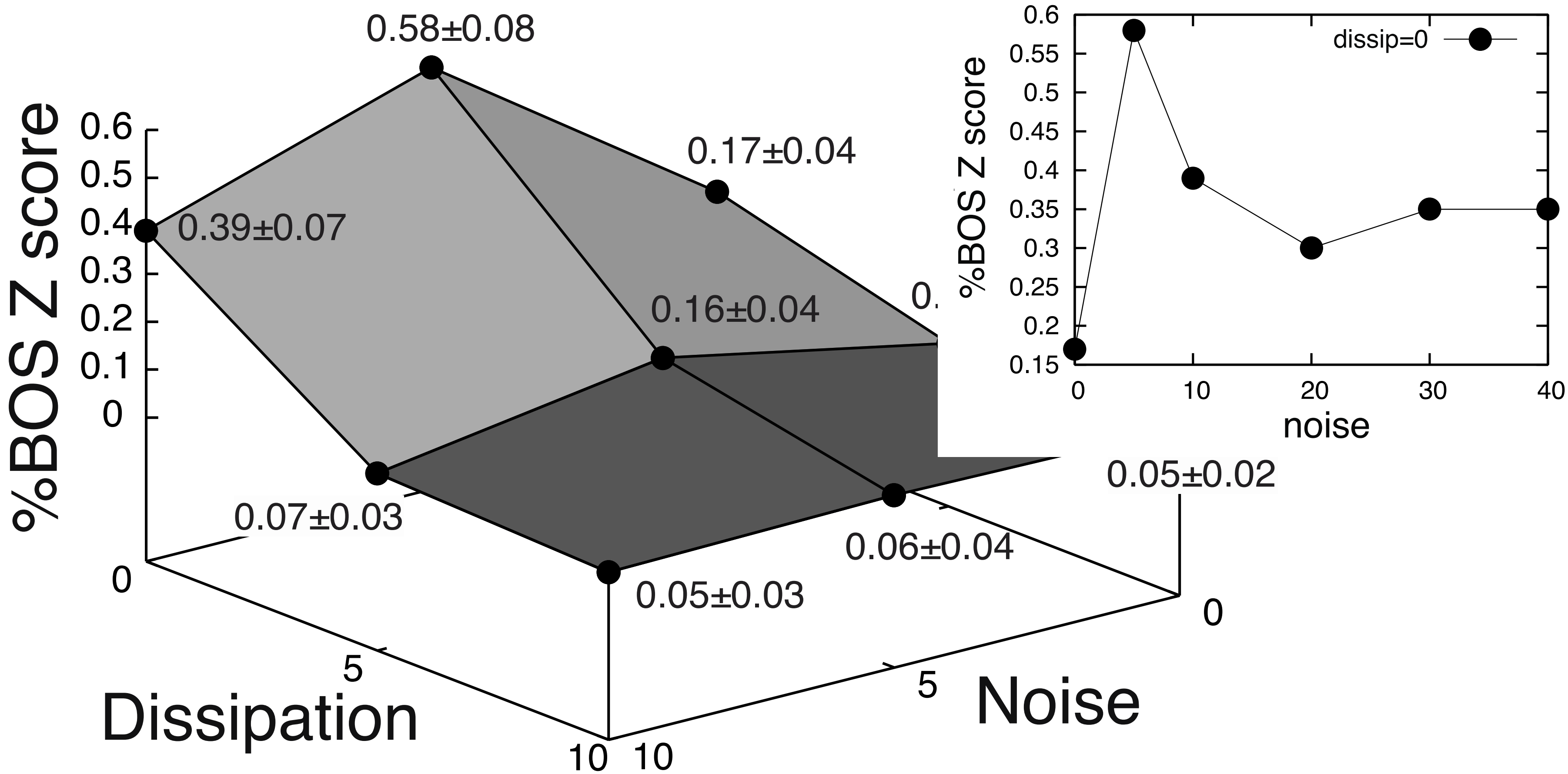


Tuning surface

Grouped data: 5 birds

The resonant cavity is very relevant (can be controlled by the birds while singing)

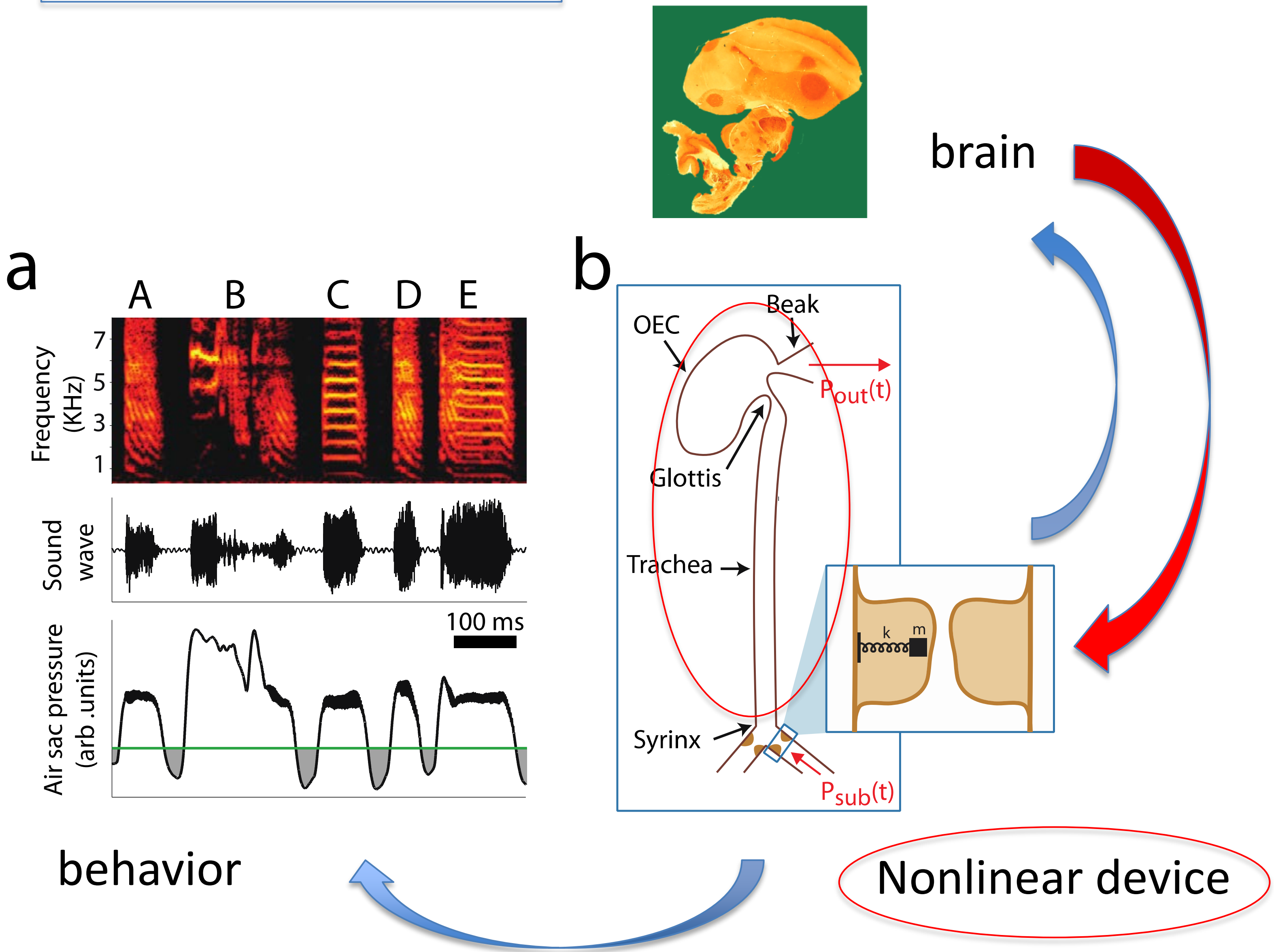
The noise has a particular value that maximize the responses



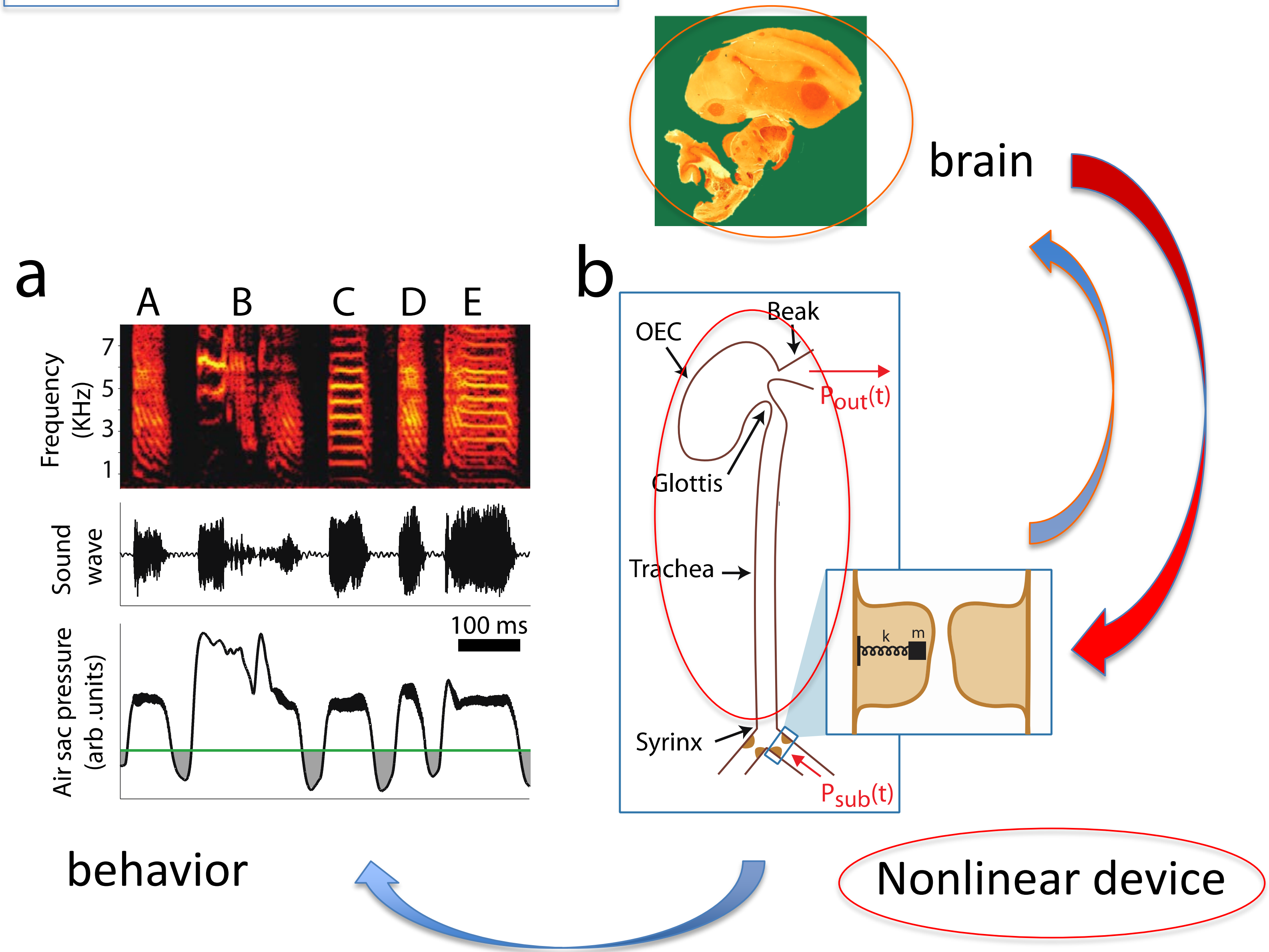
A critical comment on the strategy of testing the way
A neuron codes through studying its response to noise:
Most selective neurons simply won’t respond to exotic
(evolutionary non relevant) inputs.

The class of stimuli is therefore crucial, and the variability
Within **must be selected with biologically pertinent criteria**

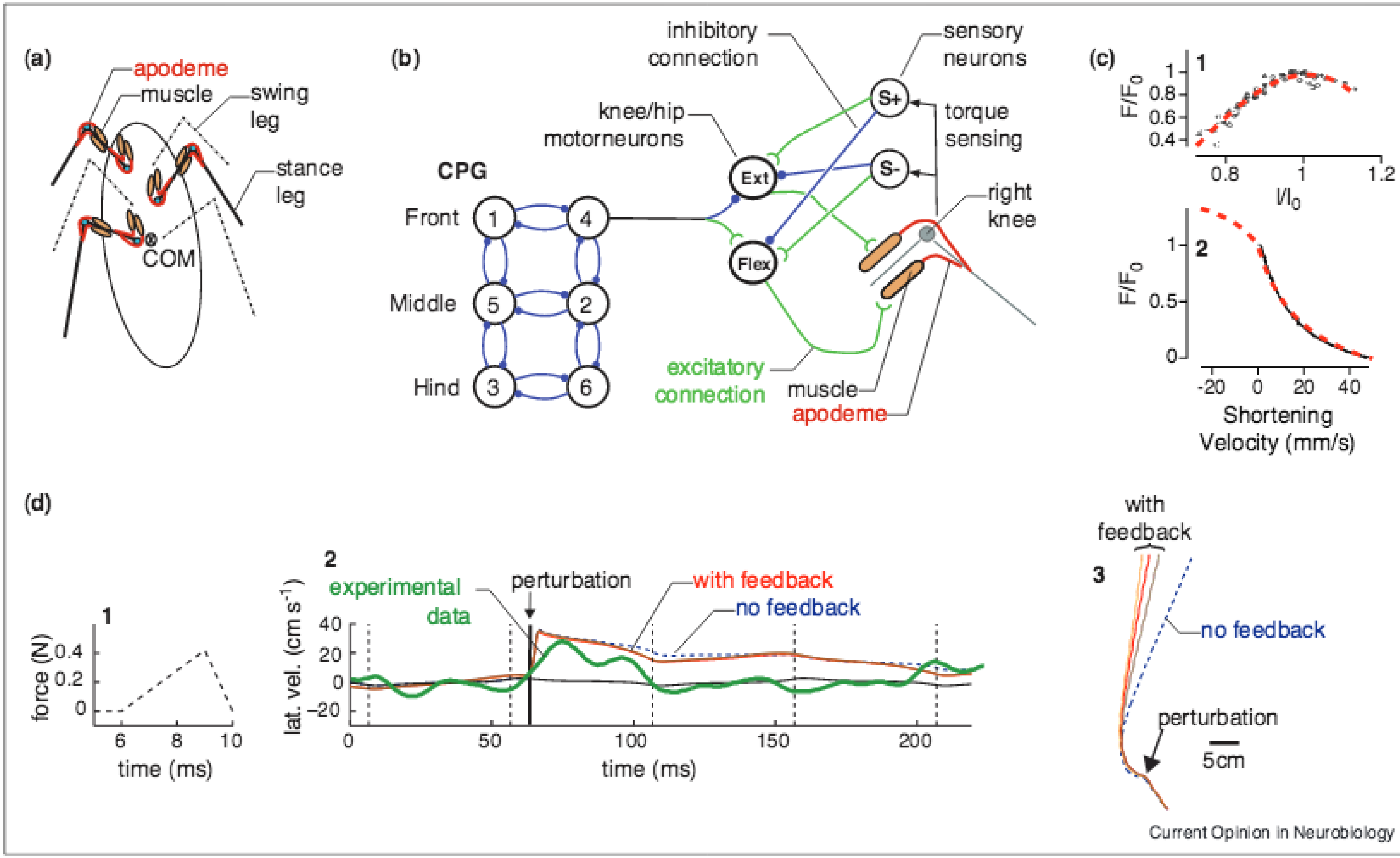
The linear filters were relevant



We need the circuit, and the coupling



Going back in a different system



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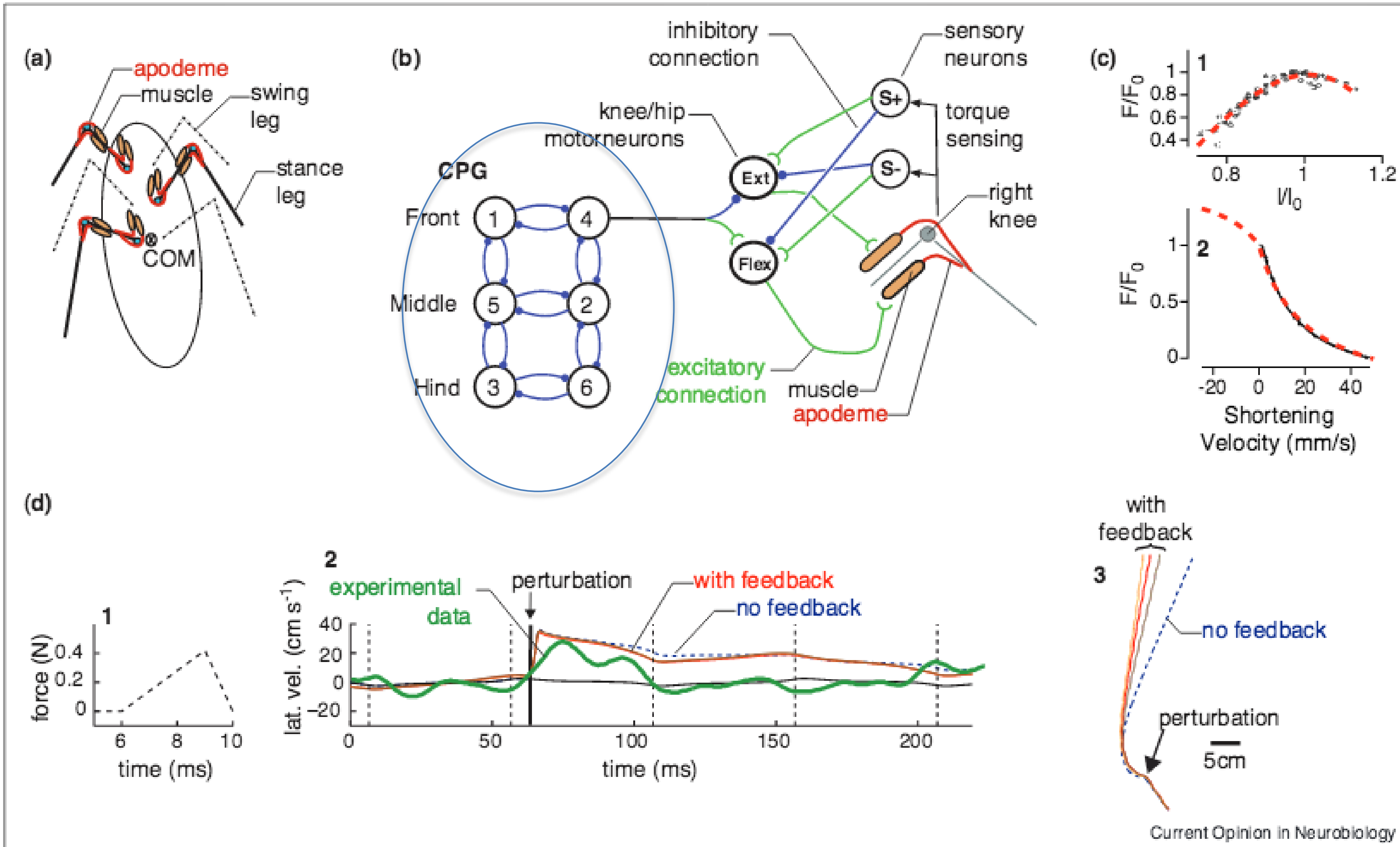

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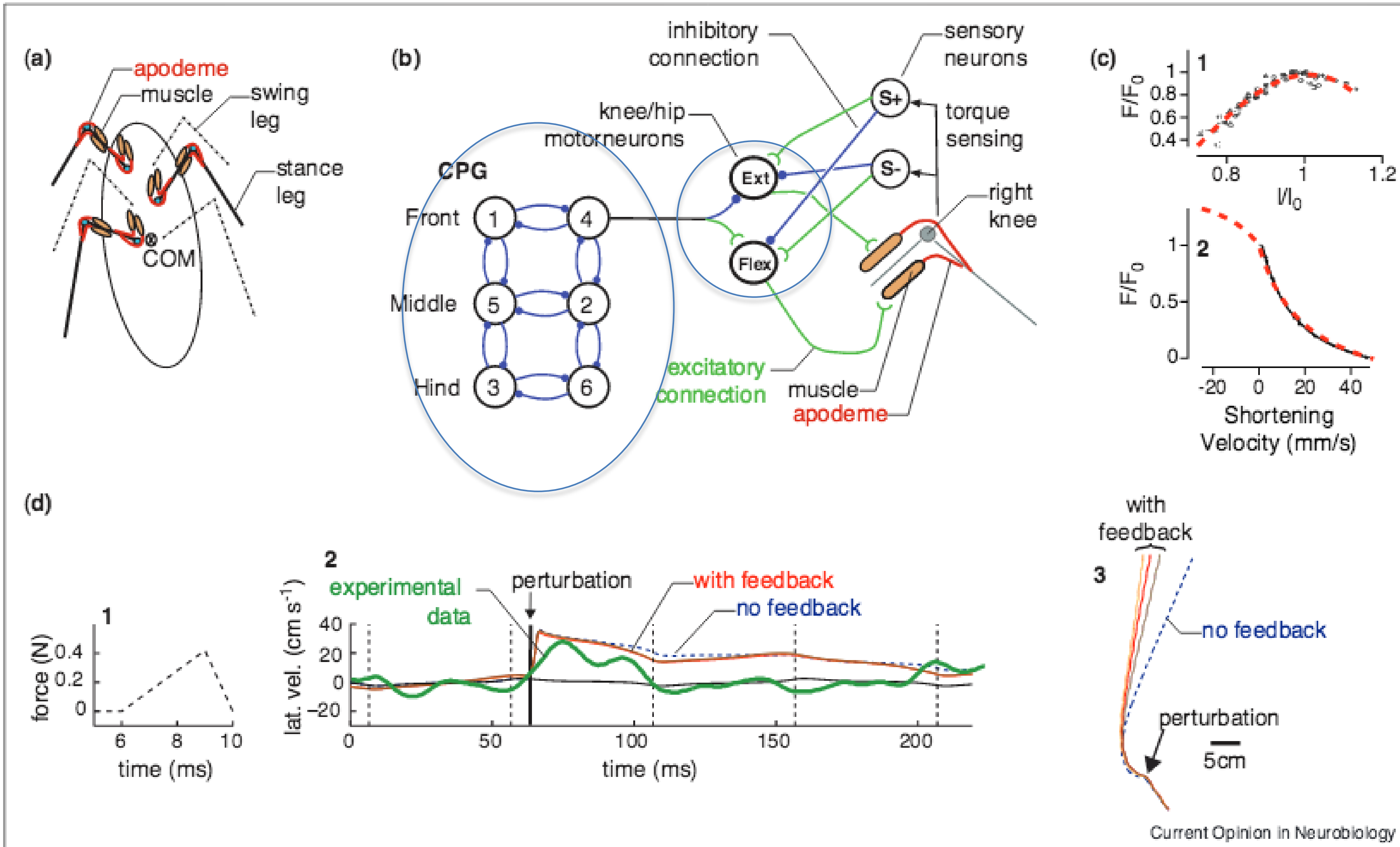
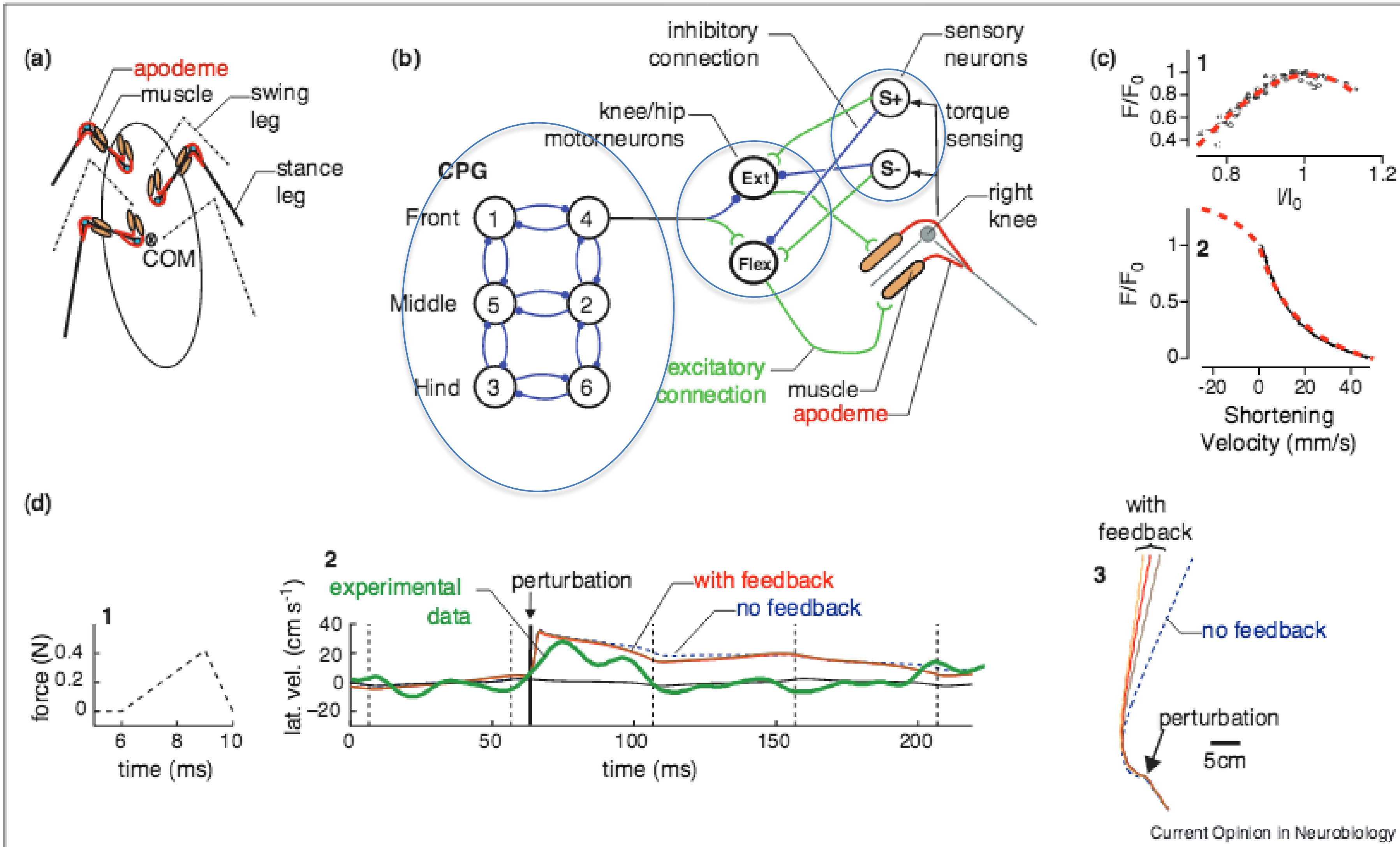


Going back in a different system



We’ll see how this works in birdsong next class.

Some things to take home:

1. CNS alone does not determine behavior (example to remember:
The oscillations of labia depend on the biomechanical interaction of
Tissue and the airflow; nothing spikes at 3 kHz controlling labial motion)

2. Nonlinear dynamics is an appropriate language to describe qualitative
Behavior, regardless of details. Super important in biology, where details
Can take a lifetime to be understood.

3. Most sensory neurons are really picky, and won’t respond to “noise”,
“pure tones” or anything a physicist would consider fair, complete or
Representative. They evolve to interpret the pertinence through evolution.