

# Birdsong as a model for learned, complex behavior

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sistemas dinámicos

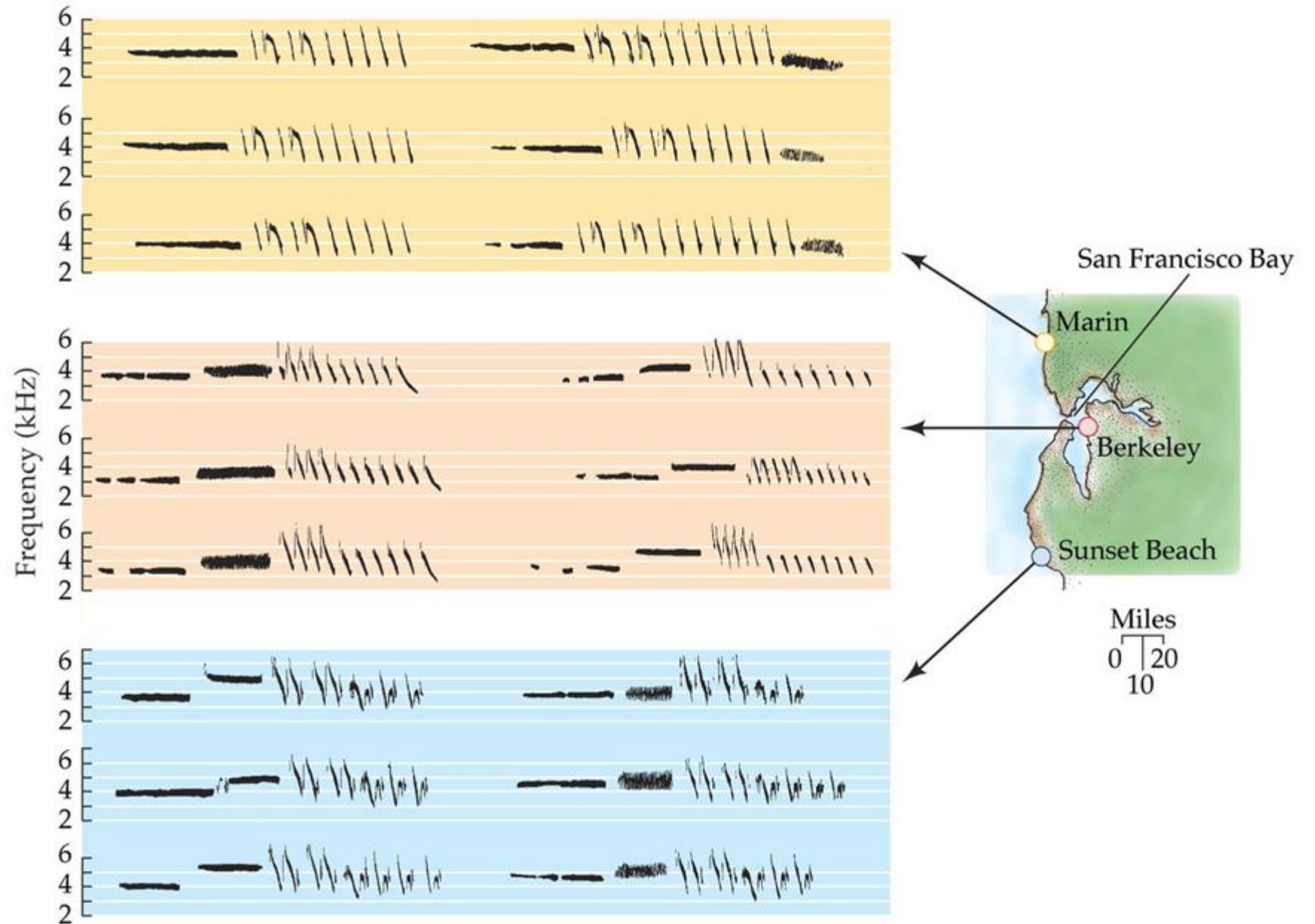


# Why songbirds?

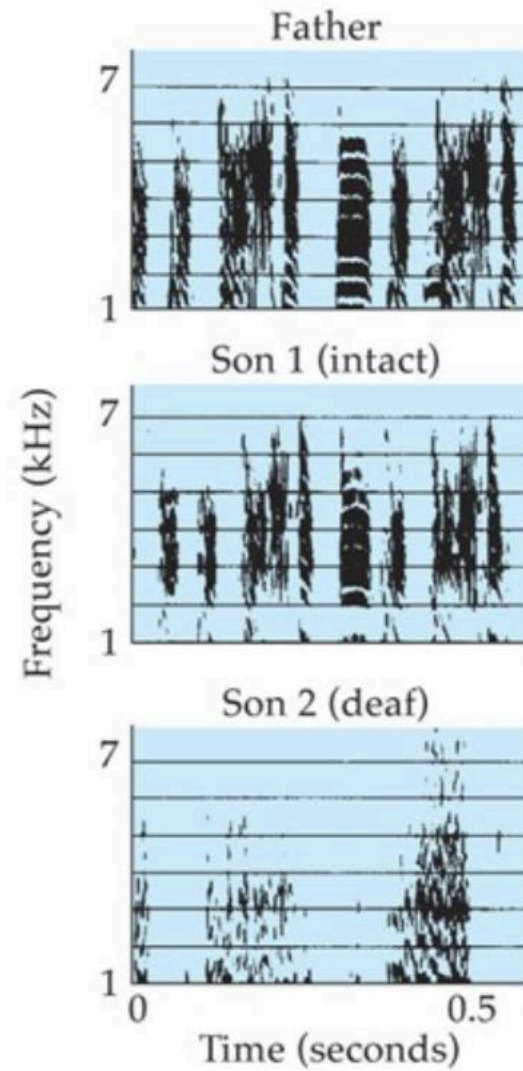
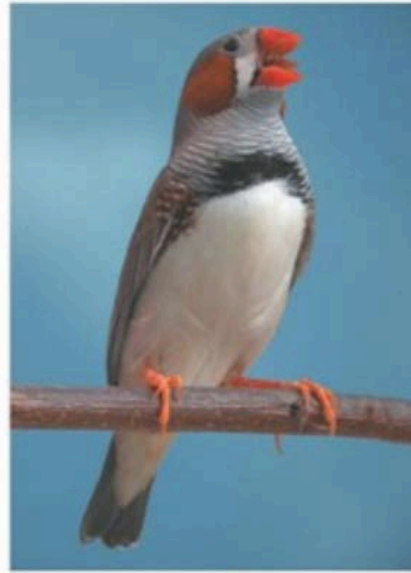
- Well-established animal model to study:
  - mechanisms of vocal learning (not common in mammals).
  - Complex motor control.

## 2.1 Song dialects in white-crowned sparrows from Marin, Berkeley, and Sunset Beach, California

First evidence of learning:  
The existence of **dialects**

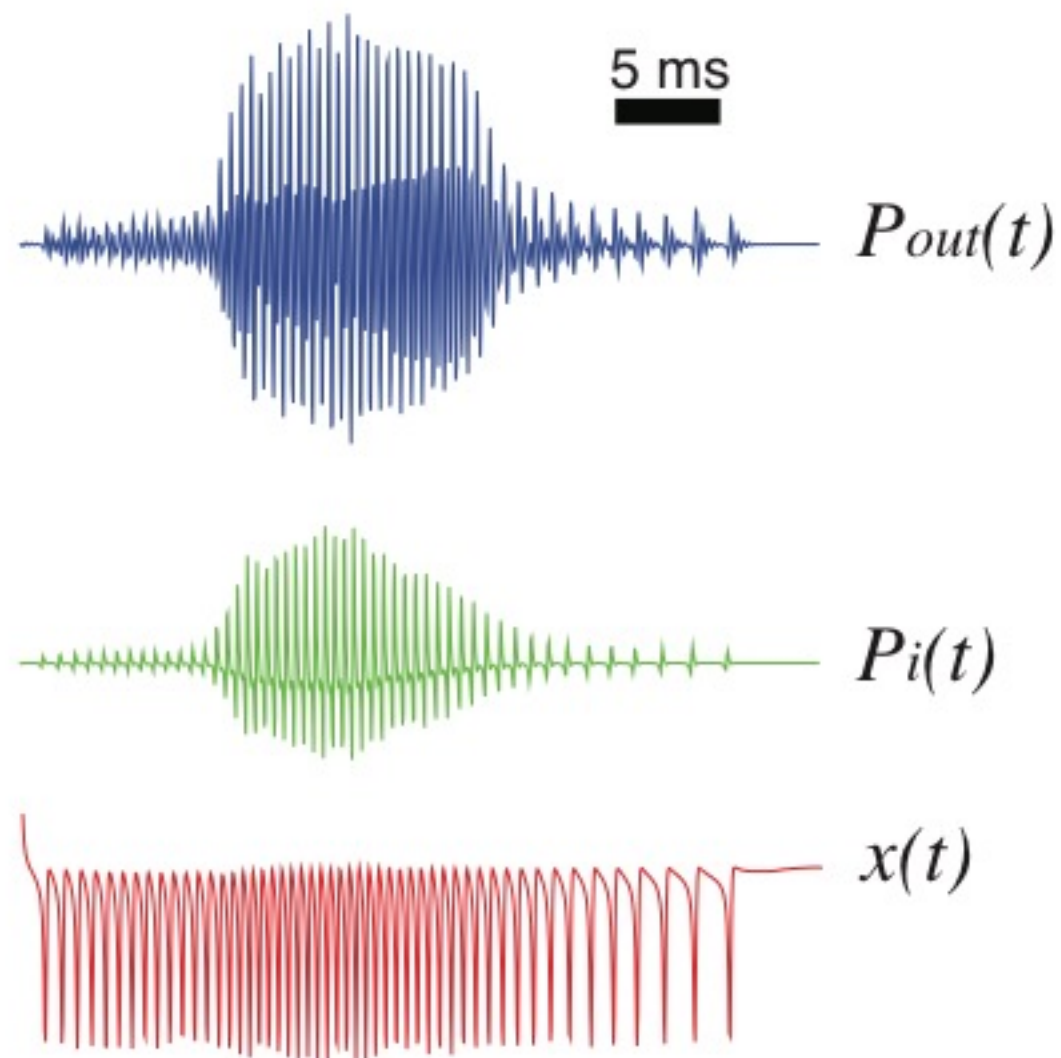
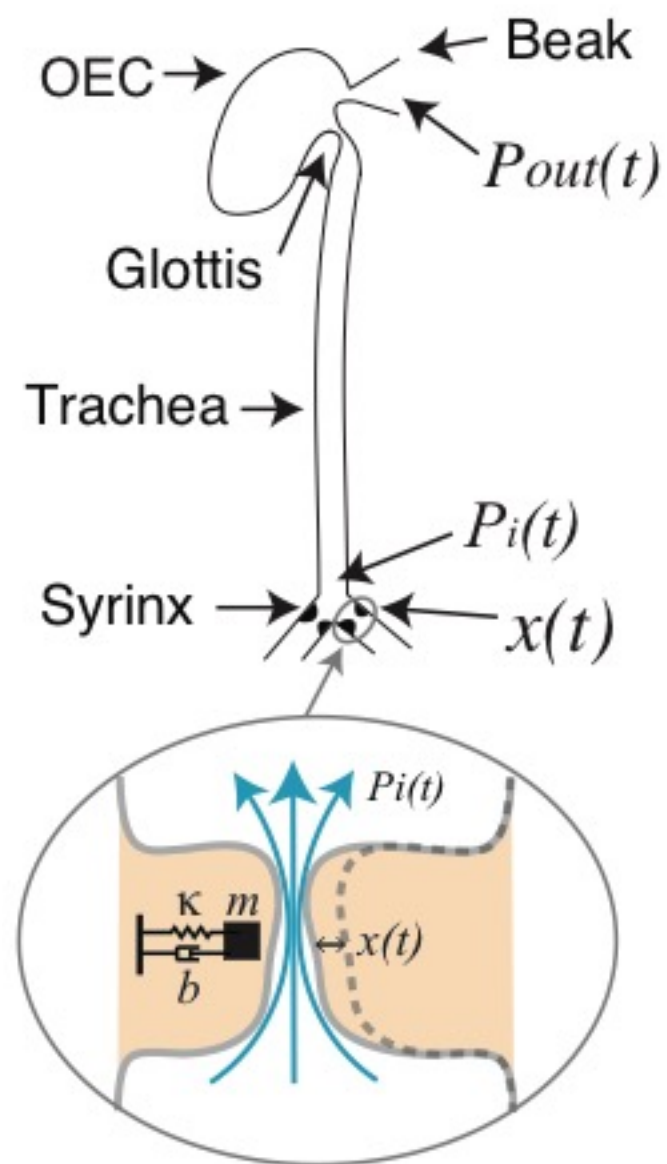


At the level of the individual bird

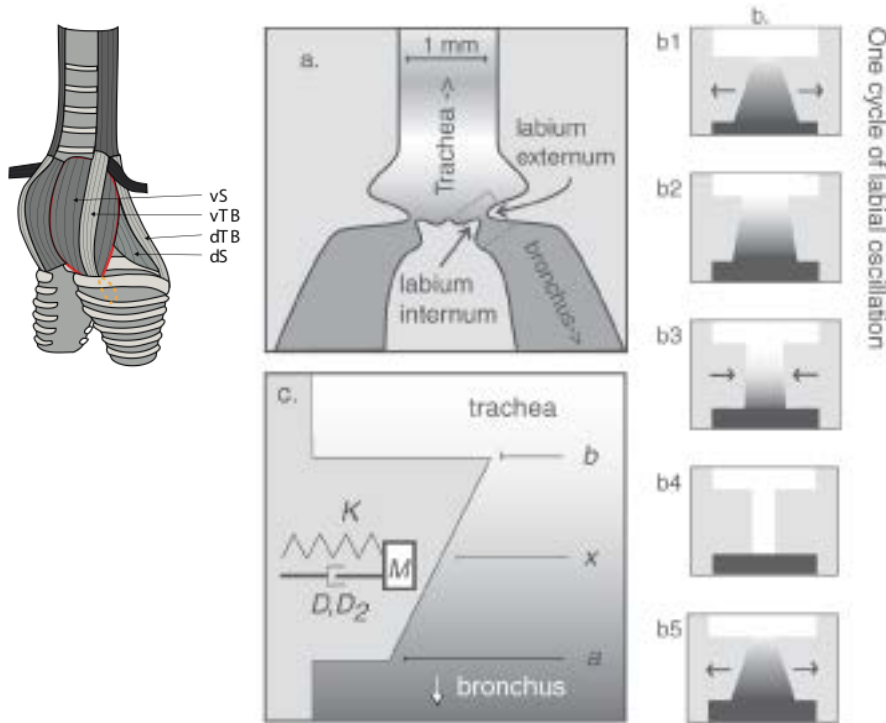


¿How do  
birds  
generate  
their  
songs?





# The biomechanics involved



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

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

The tension of the labia ( $k$ )  
depends on the activity  
of muscle vS

The pressure, depends on  
The activity of respiratory  
muscles

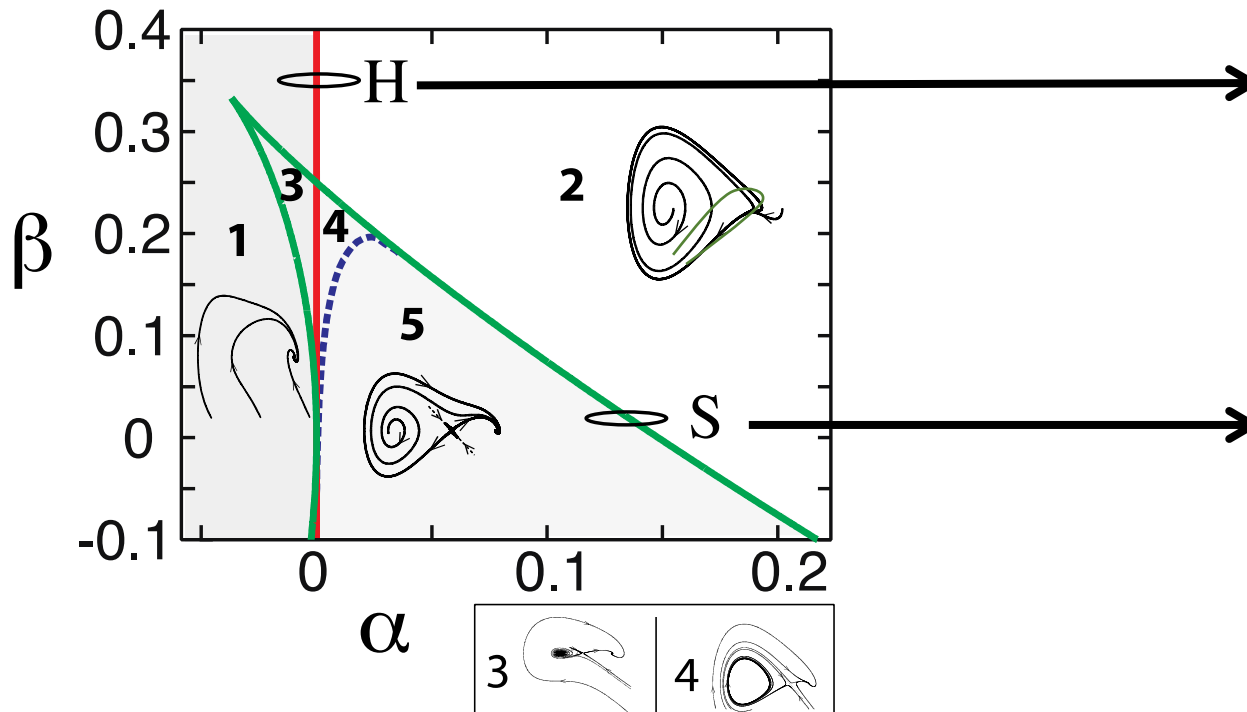


## Further simplifying the model

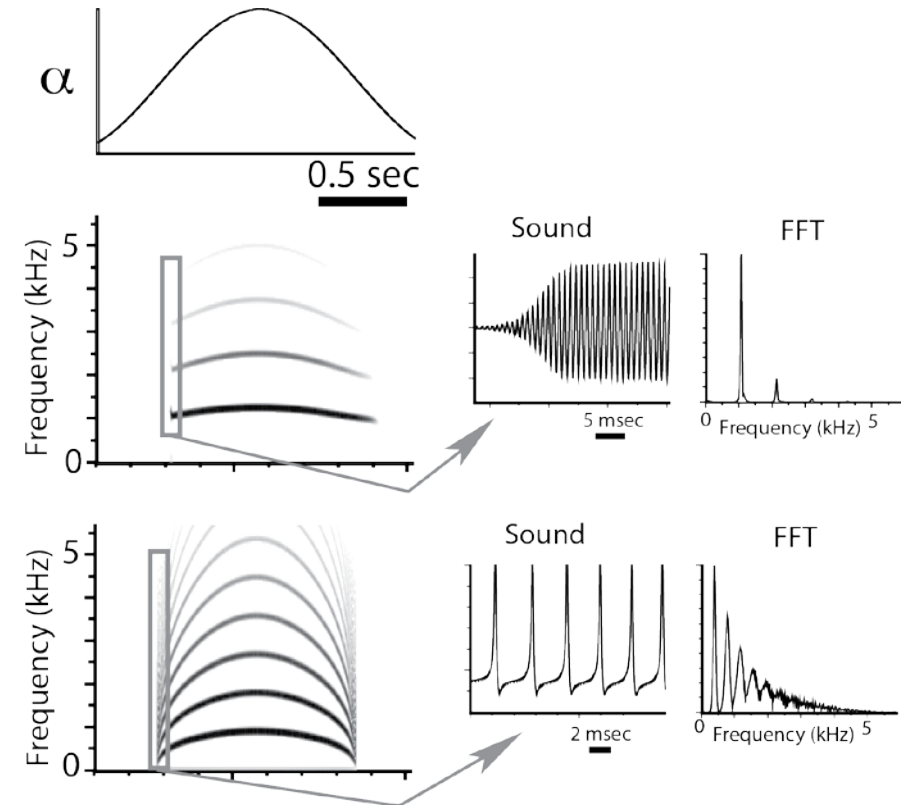
$$\frac{dx}{dt} = y$$

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

$\alpha$ : pressure ;  $\beta$ : tension

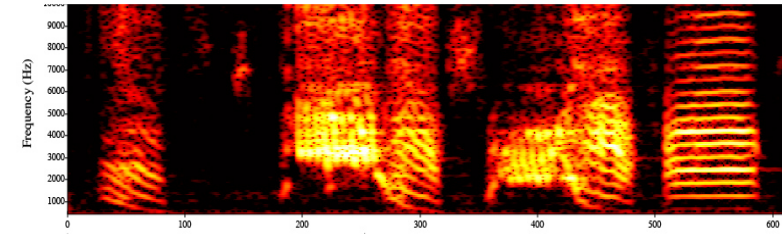


Normal form for the equations of the model

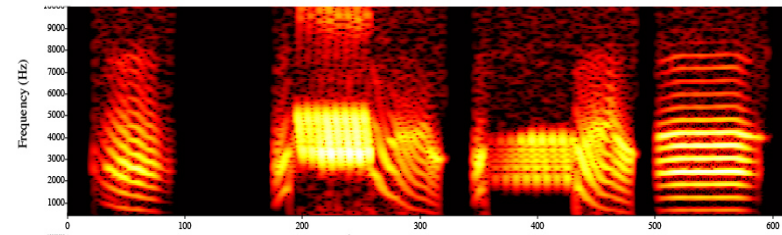
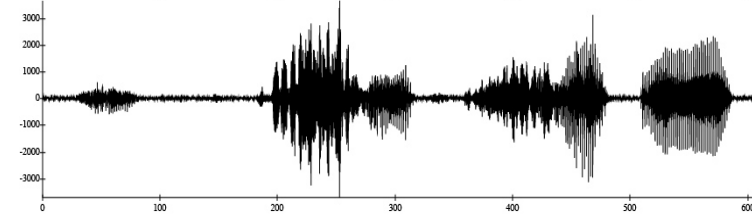




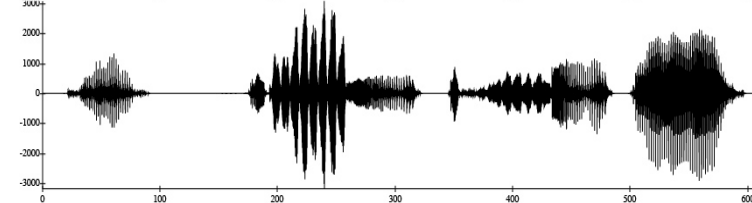
With simple paths in parameter space  
we can generate very realistic sounds  
with the normal form of the problem



BOS

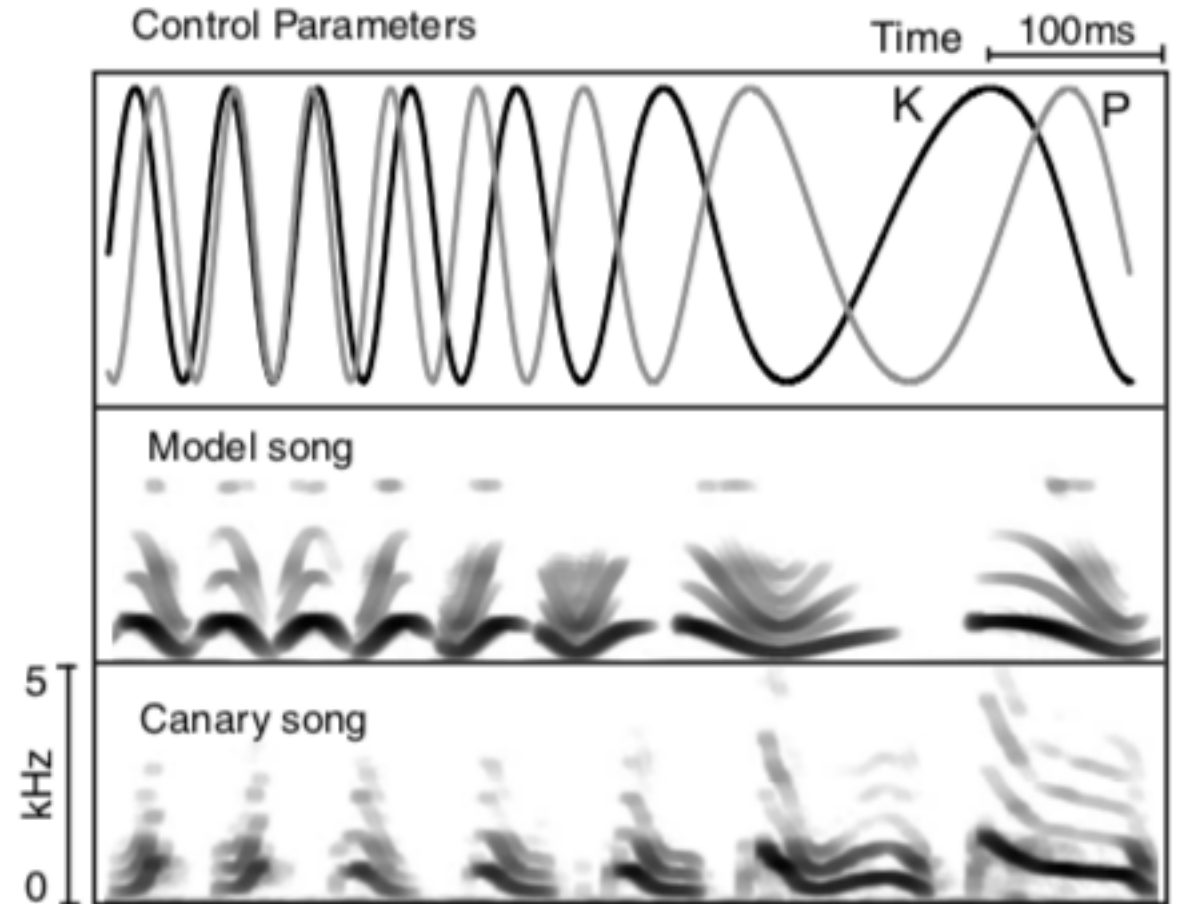
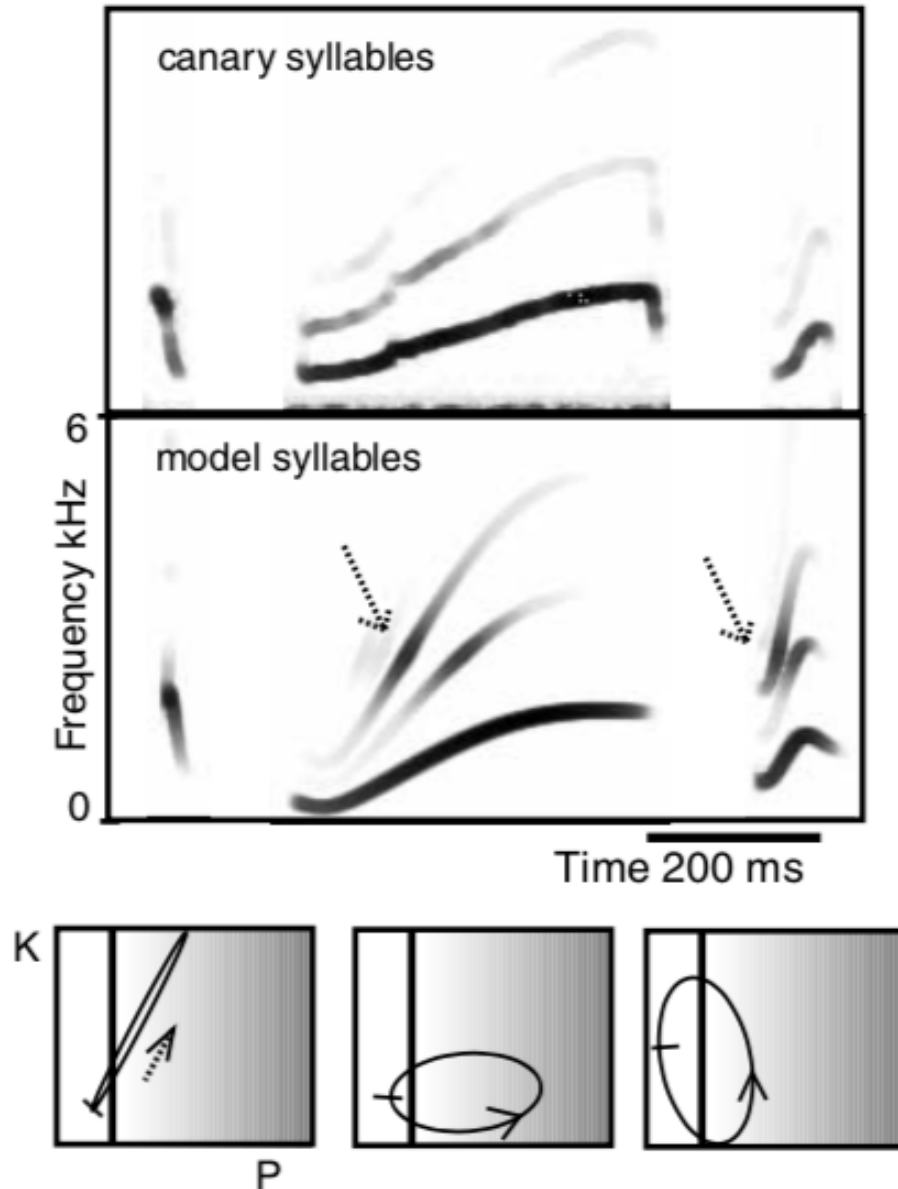


SYNTH



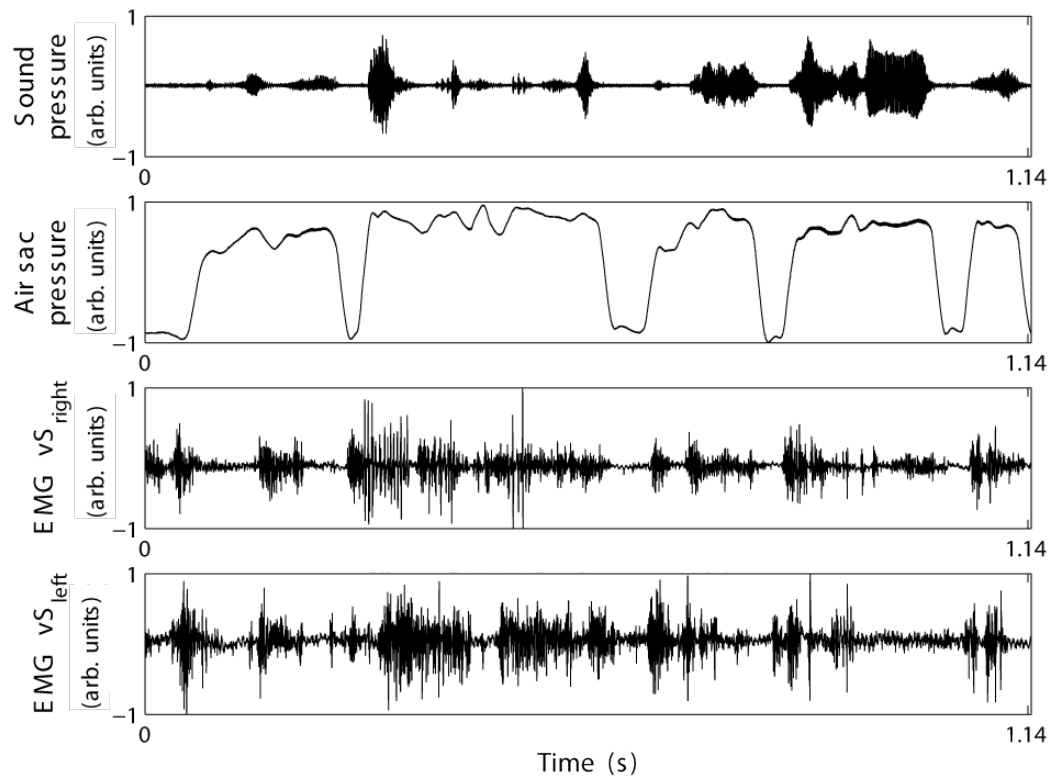
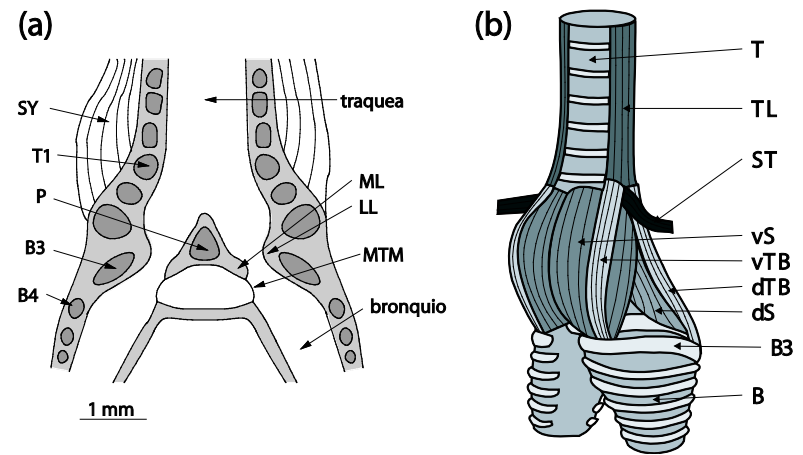
sonido sintetico

## Basic idea behind this model



The phase difference between these gestures is key the basic frequency modulation

We actually measure these parameters

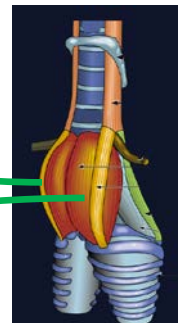
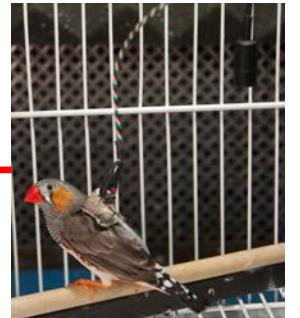


(a) sound

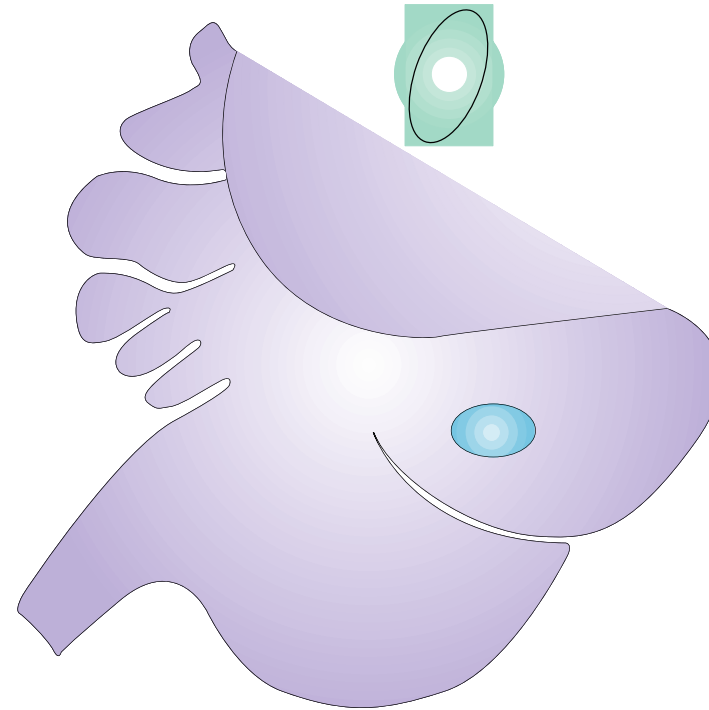
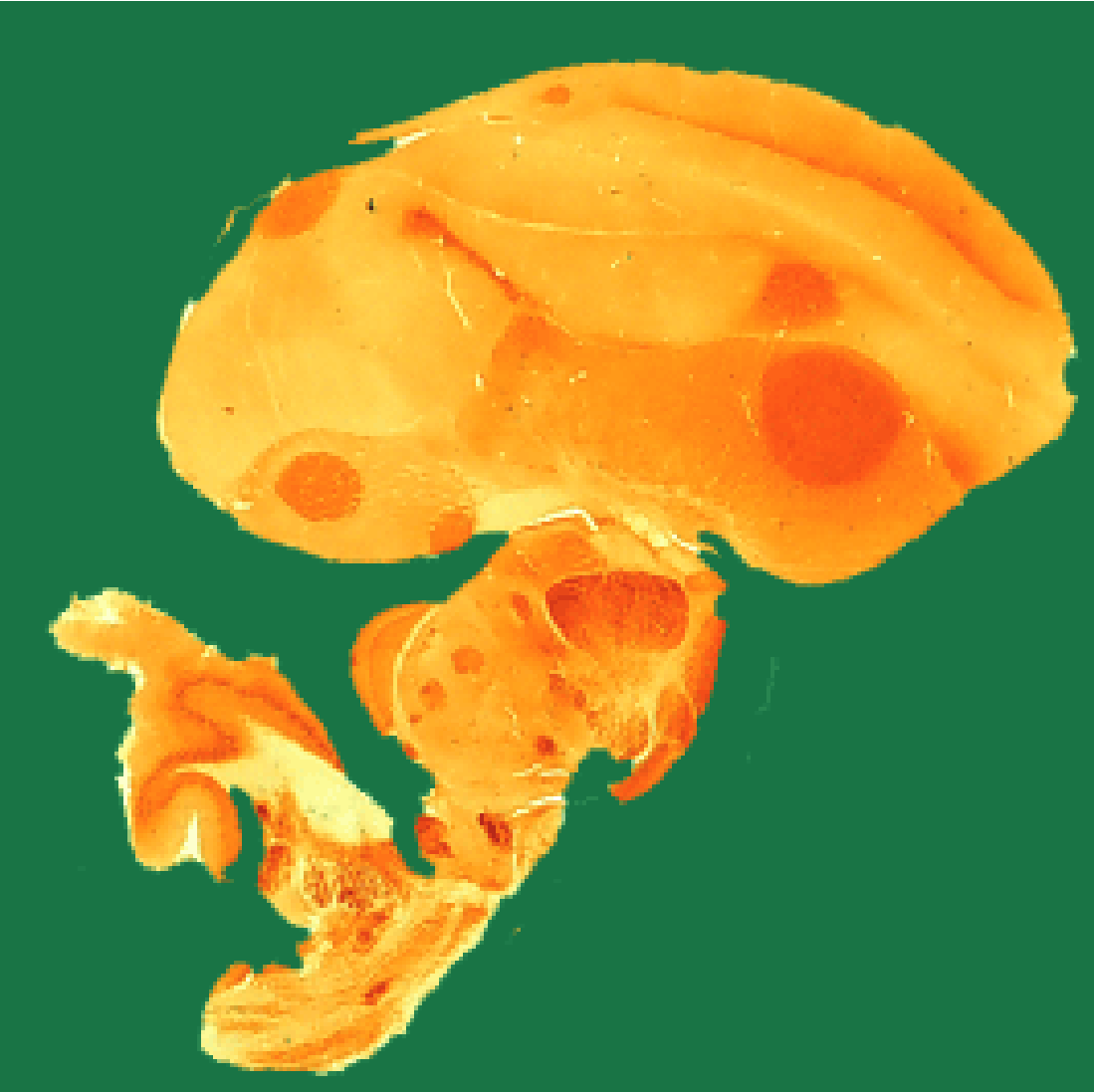
(b) pressure

(c) Tension (right)

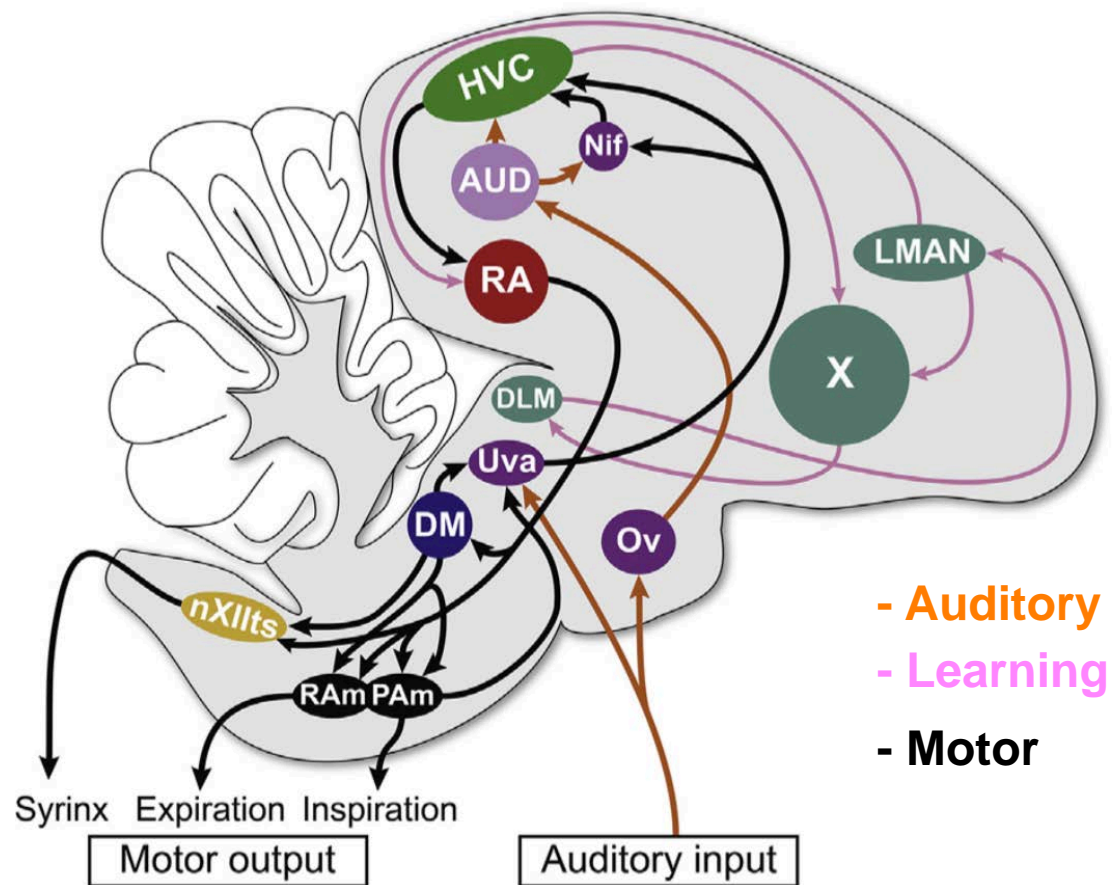
(d) Tension (left)



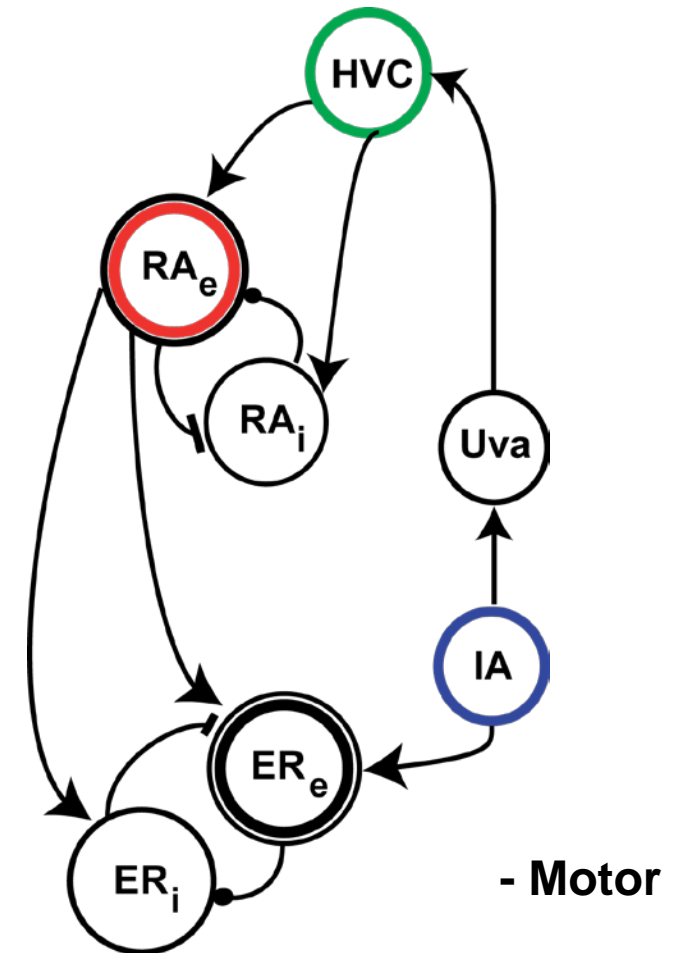
How and where are these instructions generated?



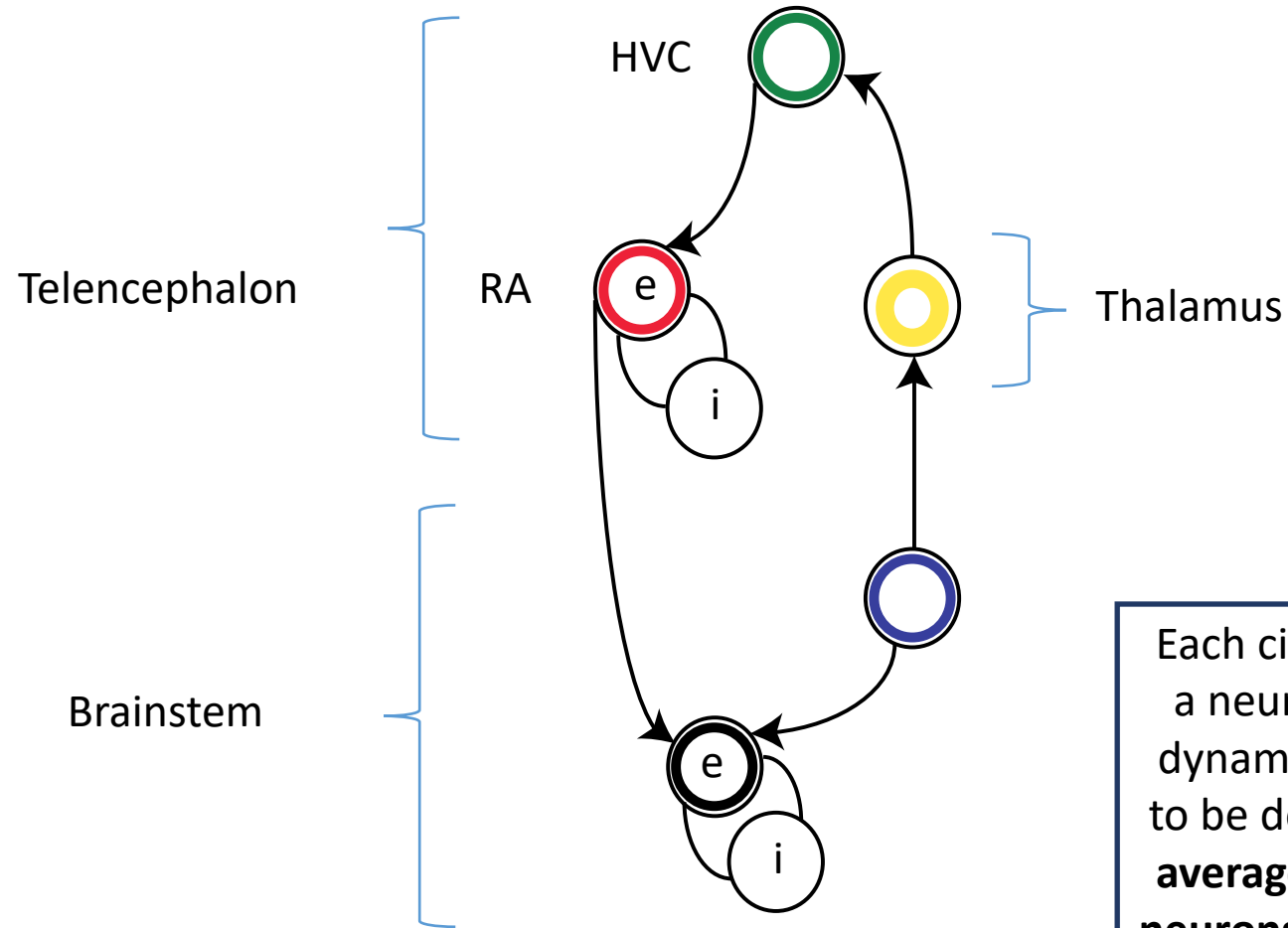
Neural network dedicated to **song perception**, **song learning** and **song production**



Simplified model of the neural network for **song production**



This architecture is capable of generating the observables, with the known neural nuclei

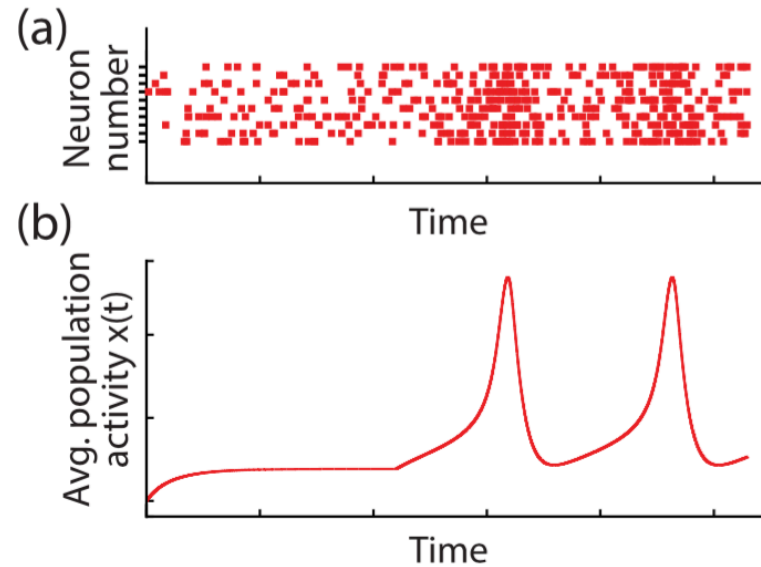
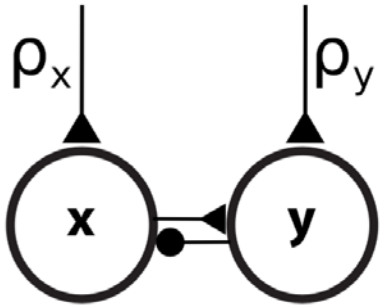


Each circle represents a neural nucleus, its dynamics is assumed to be described by **the average activity of its neurons**, and for those, we propose a simple **additive model**

$$\frac{dx_i}{dt} = -x_i + S\left(\rho_i + \sum_j a_{ij}x_j\right),$$

$$S(x) = \frac{1}{1 + e^{-x}}$$

Additive model:  
What do the variables indicate?



$$\dot{x} = -x + S(\rho_x + a x - b y)$$

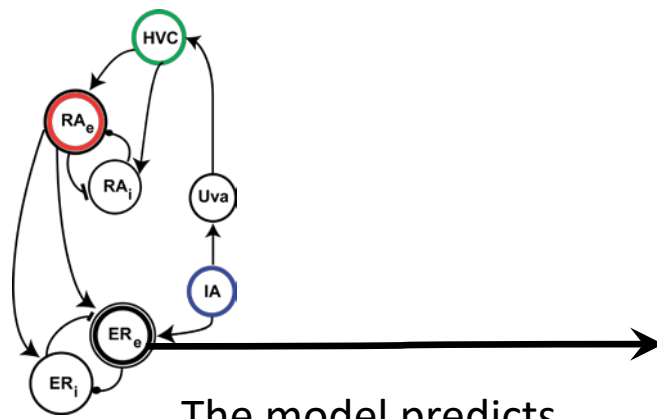
$$\dot{y} = -y + S(\rho_y + c x - d y)$$

$$\text{with } S(x) = (1 + e^{-x})^{-1}$$

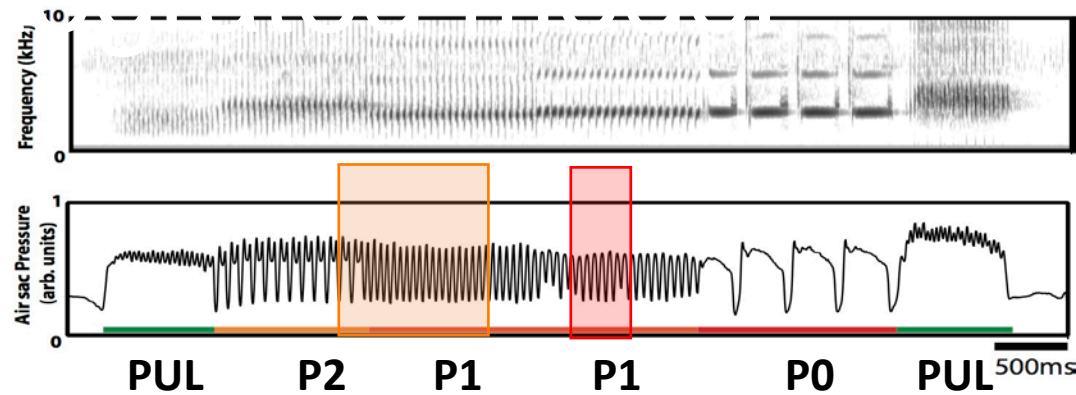
$x$  : activity of a population  
of excitatory units

$y$  : activity of a population  
of inhibitory units

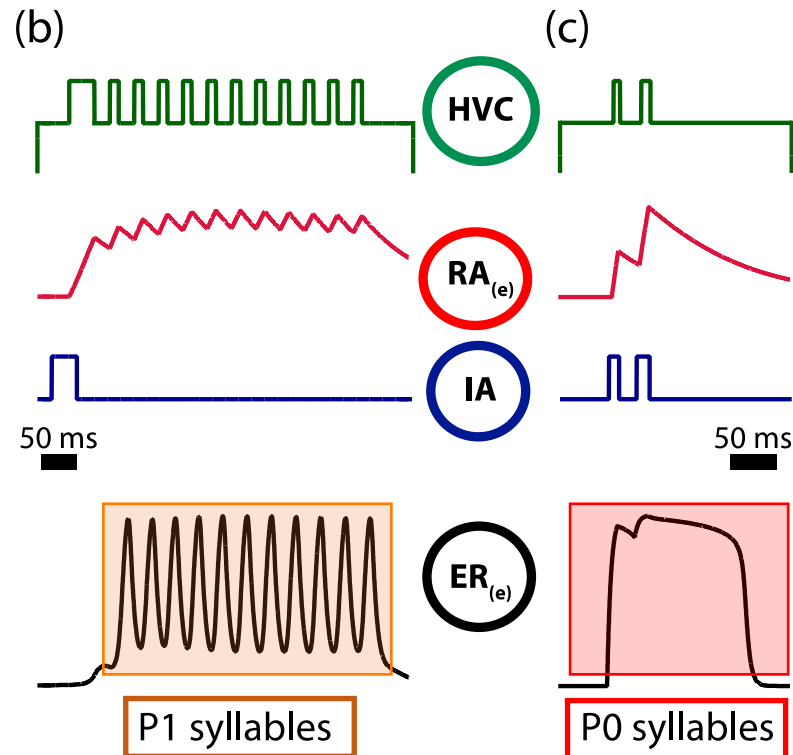
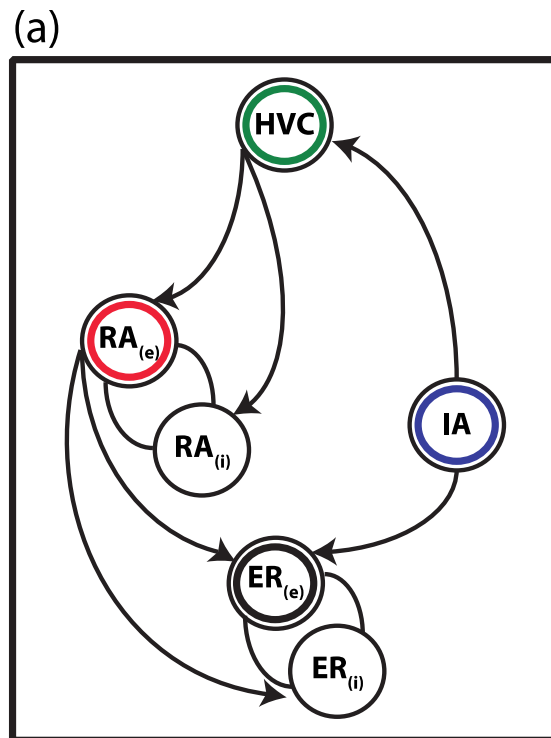




The model predicts a synthetic pressure

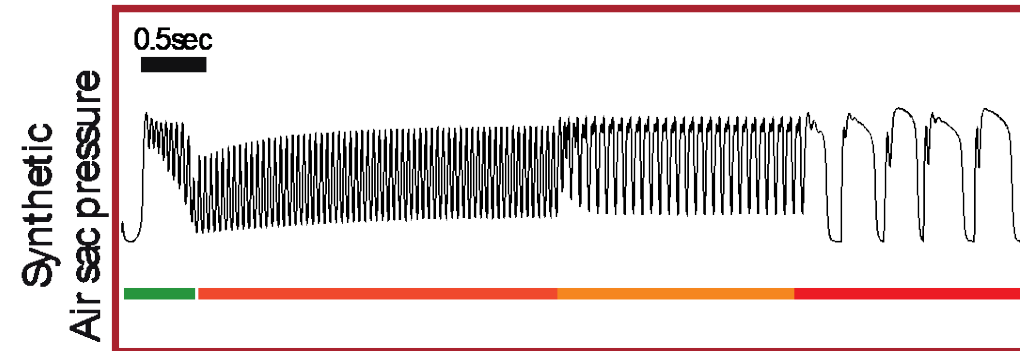
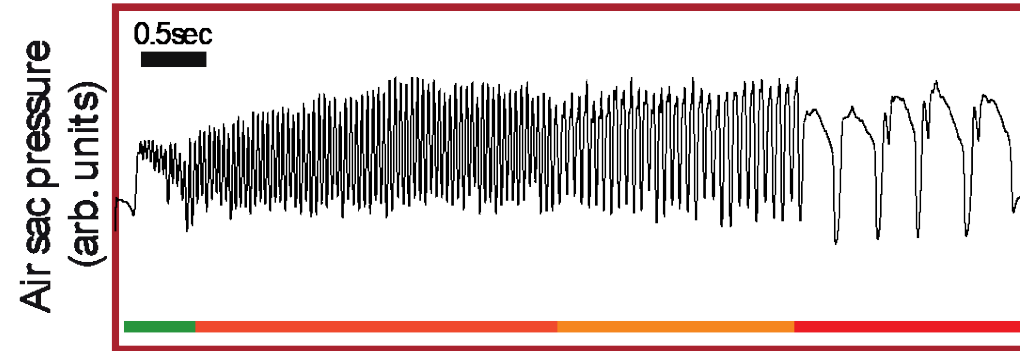


Measurements of pressure



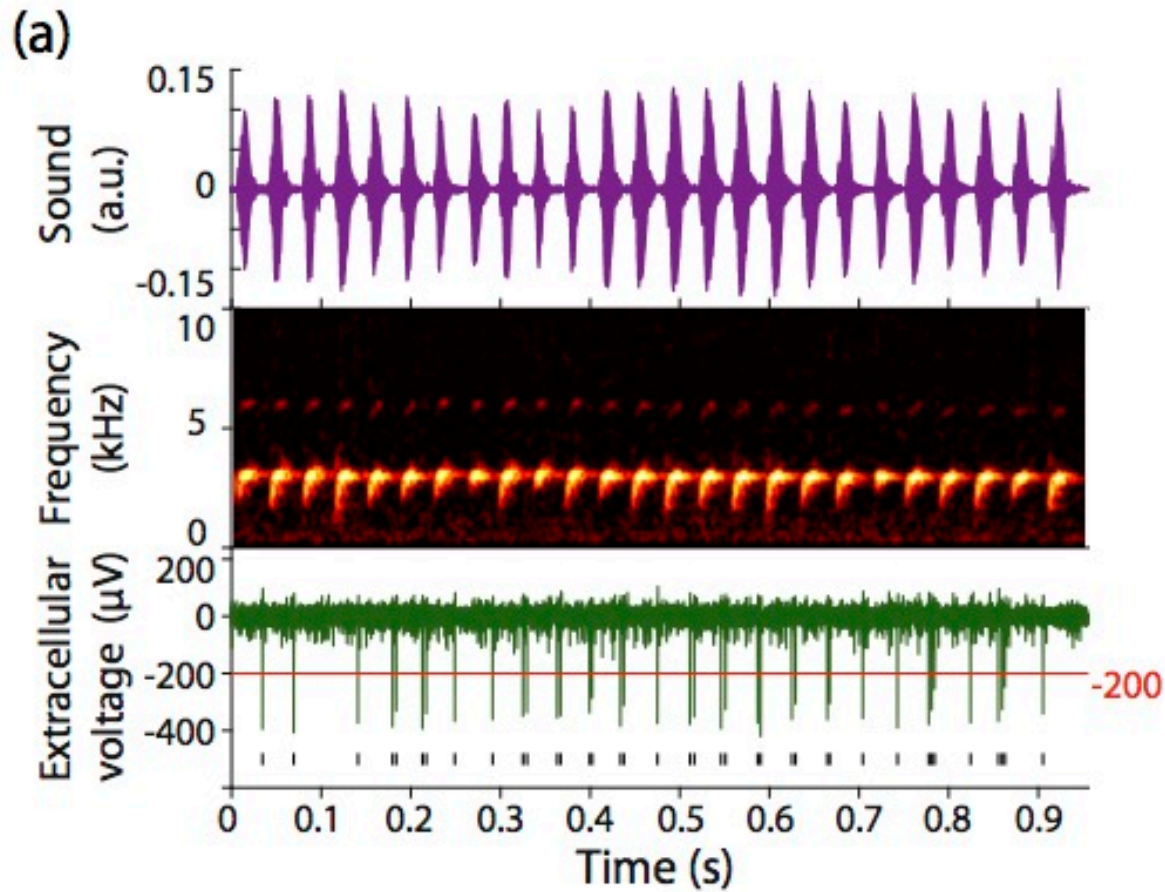
Predictions of the neural model so that the synthetic pressure are properly reproduced

How close can the synthetic pressure and the measured one be with these models?

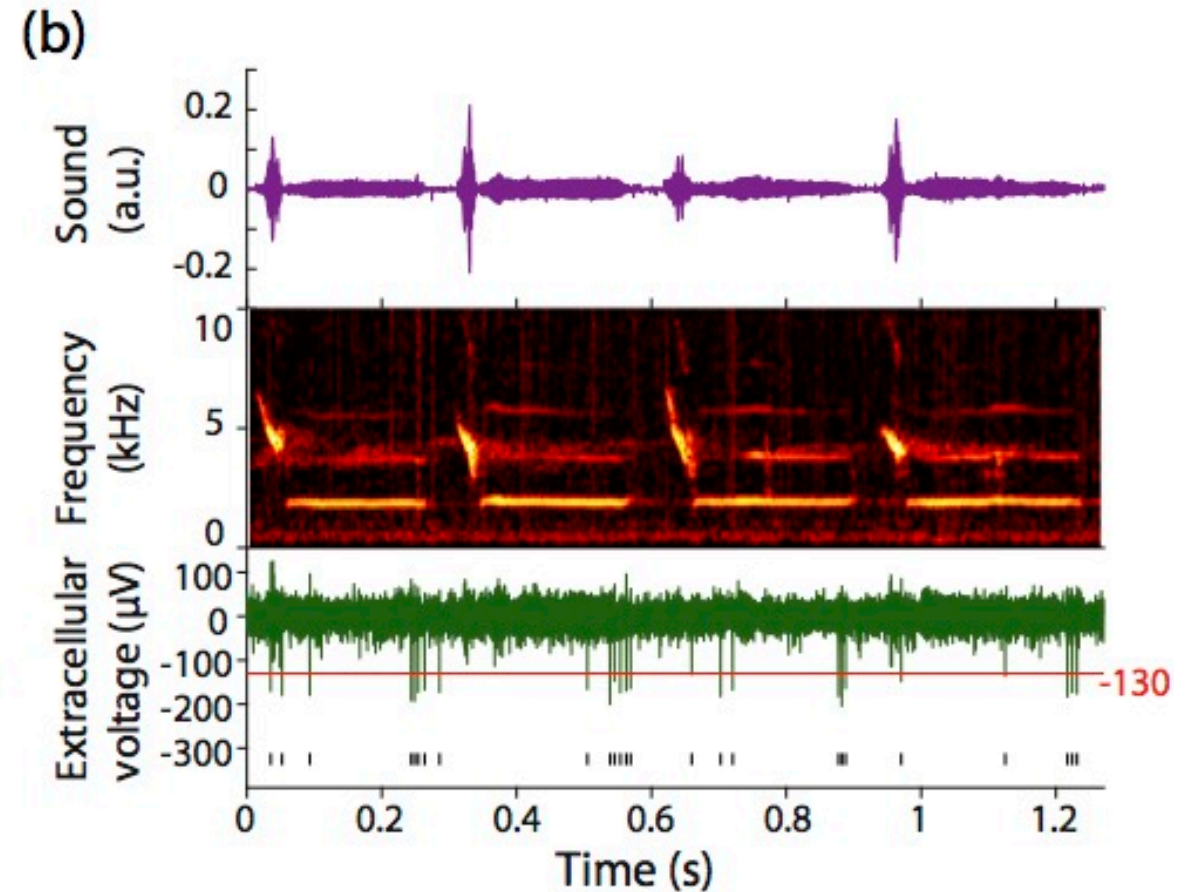


# HVC extracellular recordings in singing canaries

By **Ana Amador** in our lab



P1 syllables

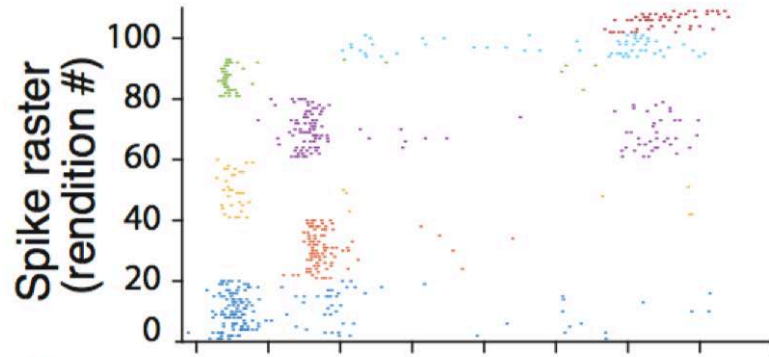


P0 syllables

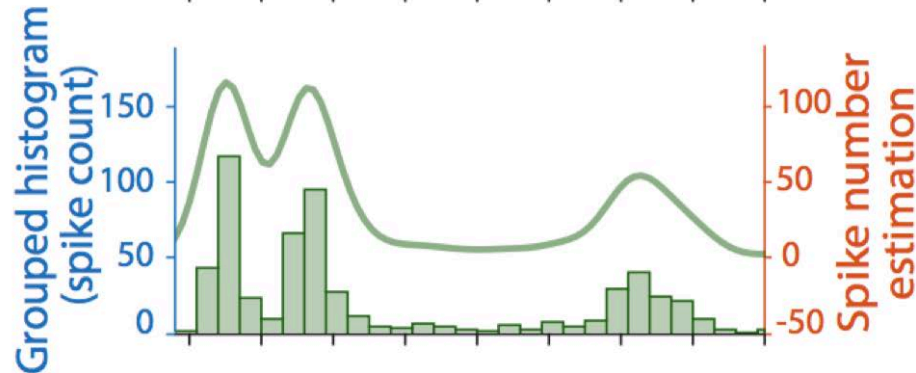
For P0 syllables

## Spikes

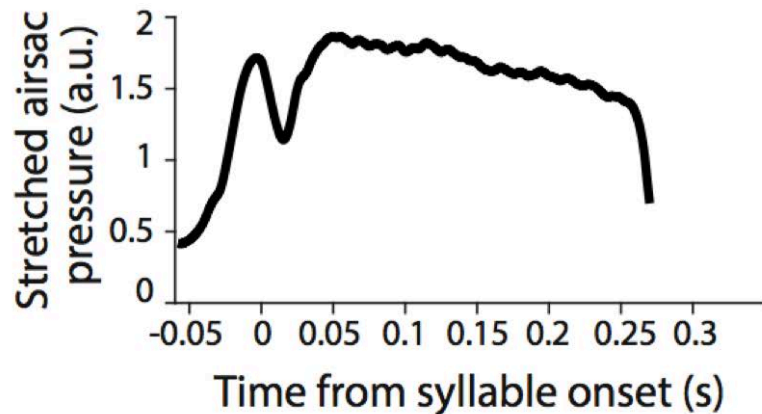
Spikes per syllable  
*One colour per neuron*



Population neural activity



Air sac Pressure



## Predictions of the model

Model

HVC

$RA_{(e)}$

IA

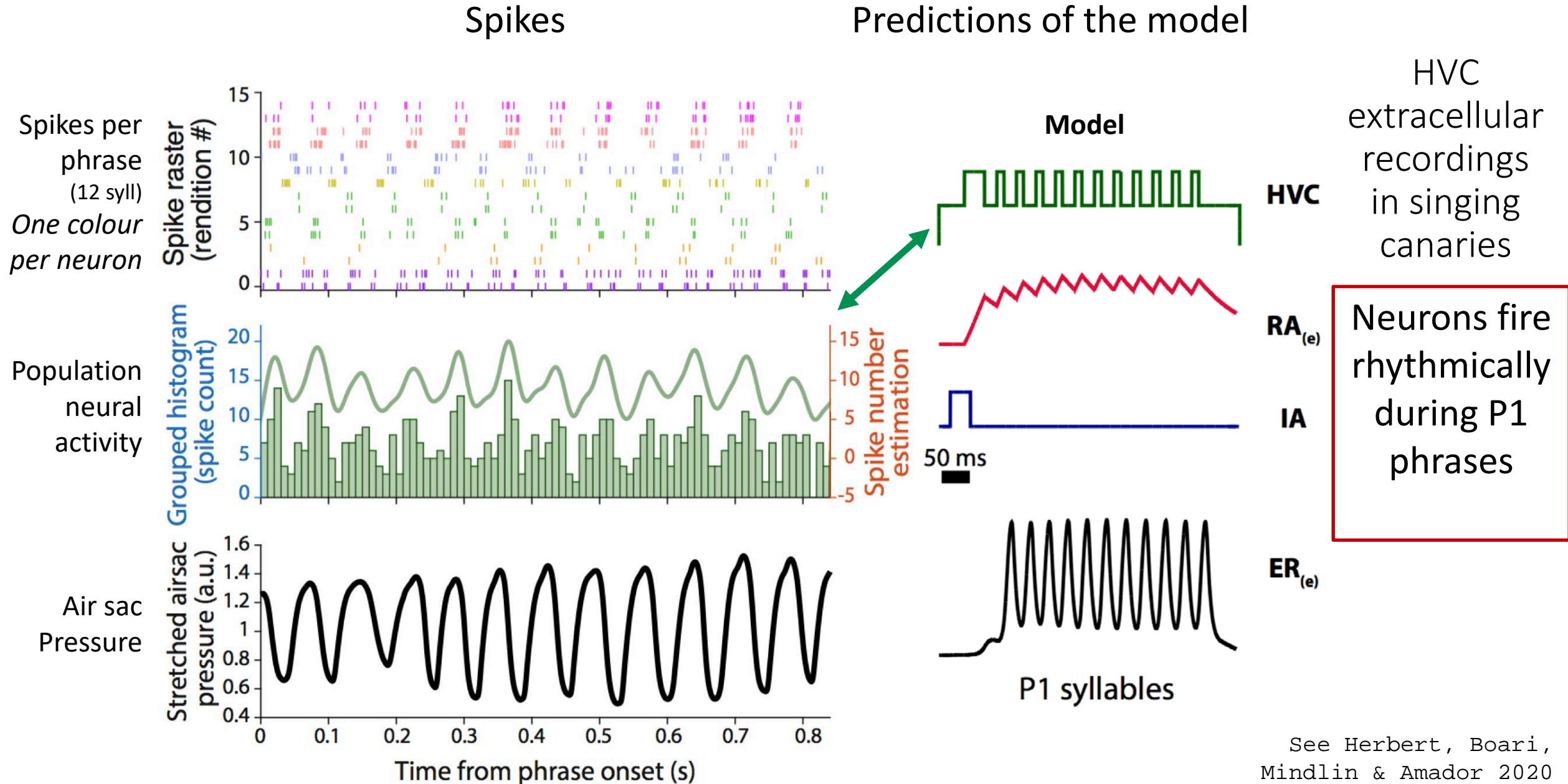
$ER_{(e)}$

50 ms

P0 syllables

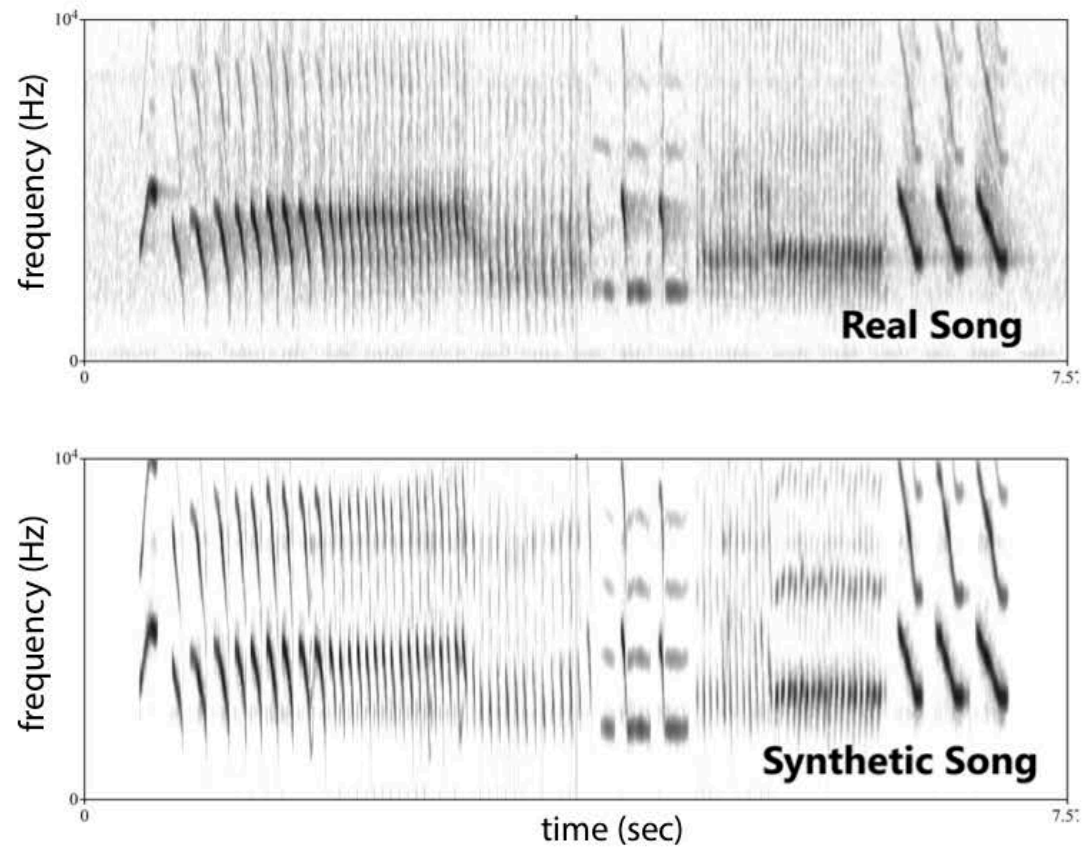
Neurons  
fire  
at specific  
instances of  
P0 syllables

For P1 syllables

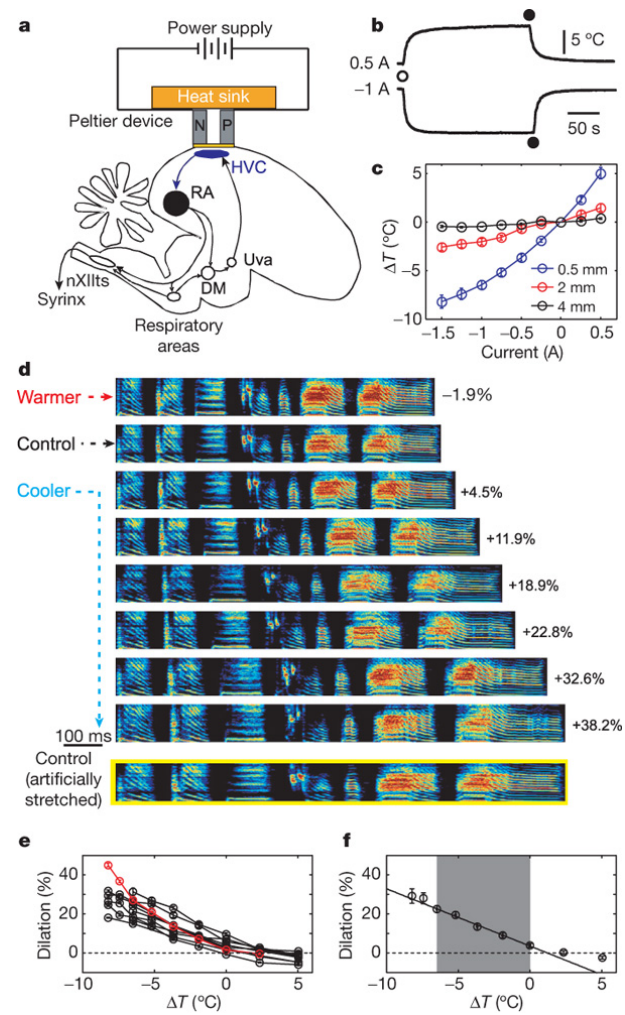




How realistic can the synthetic sound be, when the model of the Physiological instructions drives the model for the birdsong production?

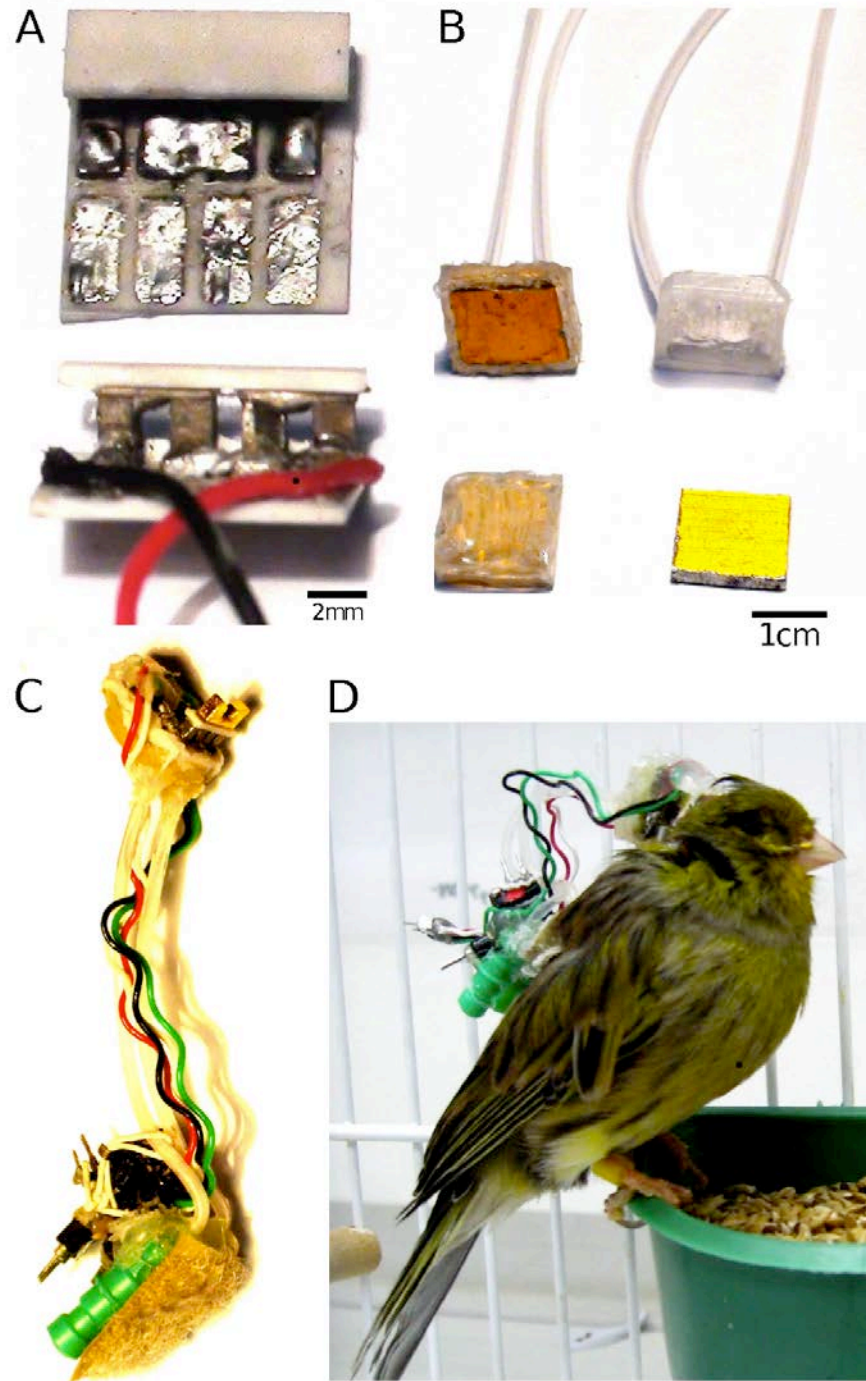


# “Cool” experiment to test the model





In our lab, we reproduced the experiment for canaries



normal

-1.3°C

-2.6°C

-3.8°C

-4.7°C

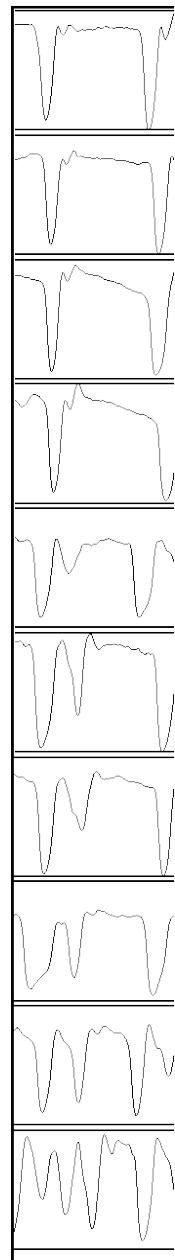
-5.5°C

-6.2°C

-6.6°C

-7.1°C

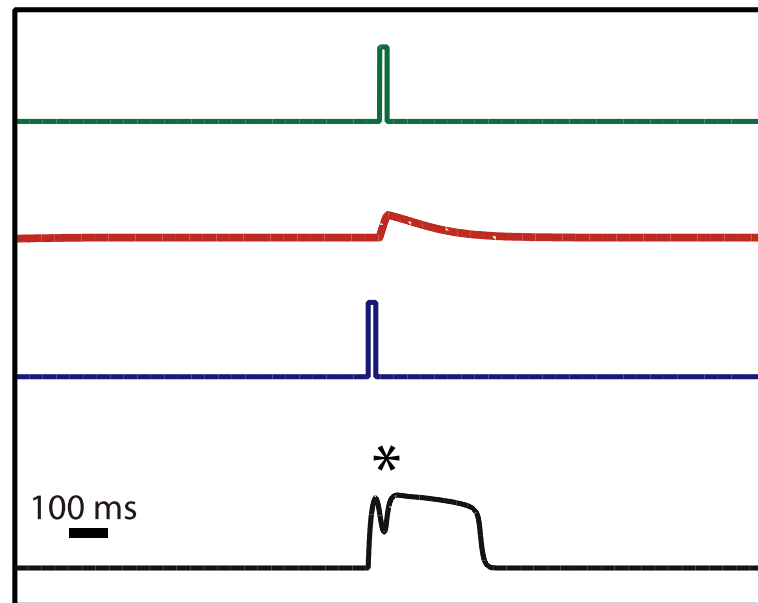
-7.5°C



0 5 sec

**A**

Normal Temperature



HVC  
projection

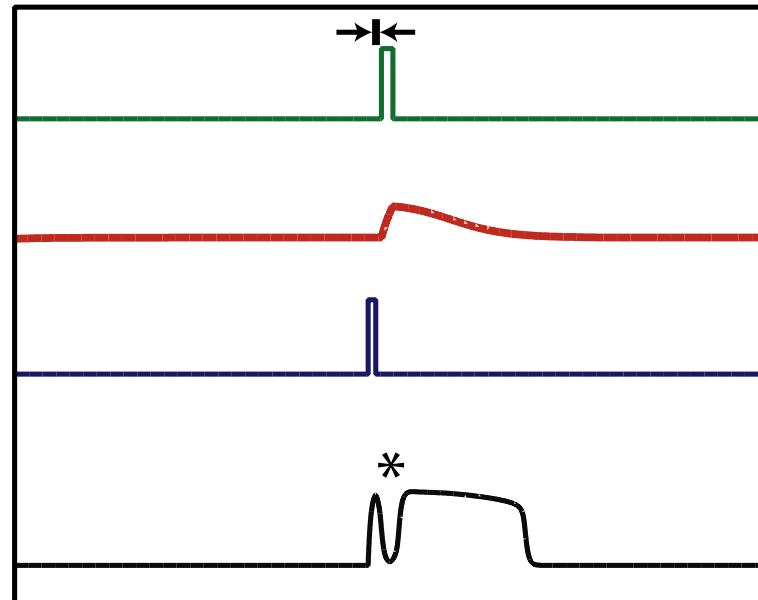
RA  
projection

Initiating  
area  
activity

Expiratory  
related  
activity

**B**

Cold Temperature



HVC  
projection

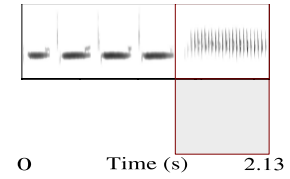
RA  
projection

Initiating  
area  
activity

Expiratory  
related  
activity

Time

# The experimental data



- **Conclusions**

- Birdsong is an ideal model for the study of how a complex behavior is learned and generated
- There is evidence of low dimensional dynamics in the generation of the physiological instructions
- The biomechanics, and its nonlinearities, allow a good reconstruction of the behavior with relatively simple physiological instructions

## pentagrama

sonidos  
agudos

sonidos  
graves

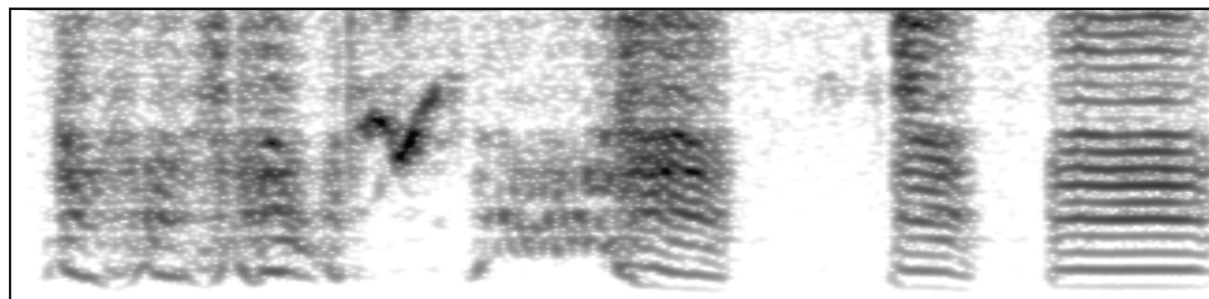


tiempo

## sonograma

sonidos  
agudos

sonidos  
graves



tiempo