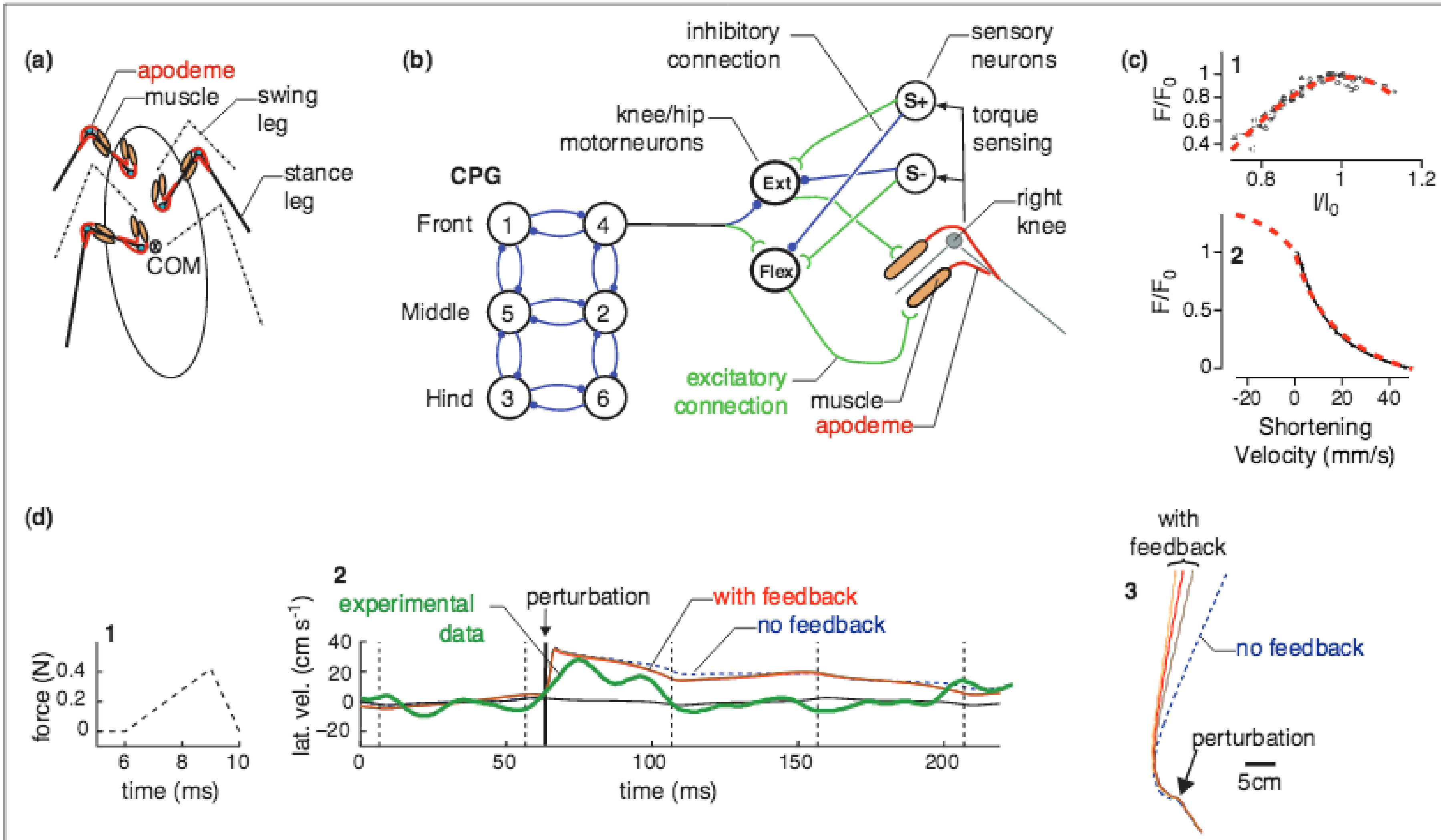
“Spikes alone do not behavior make: why neuroscience needs biomechanics” (II)

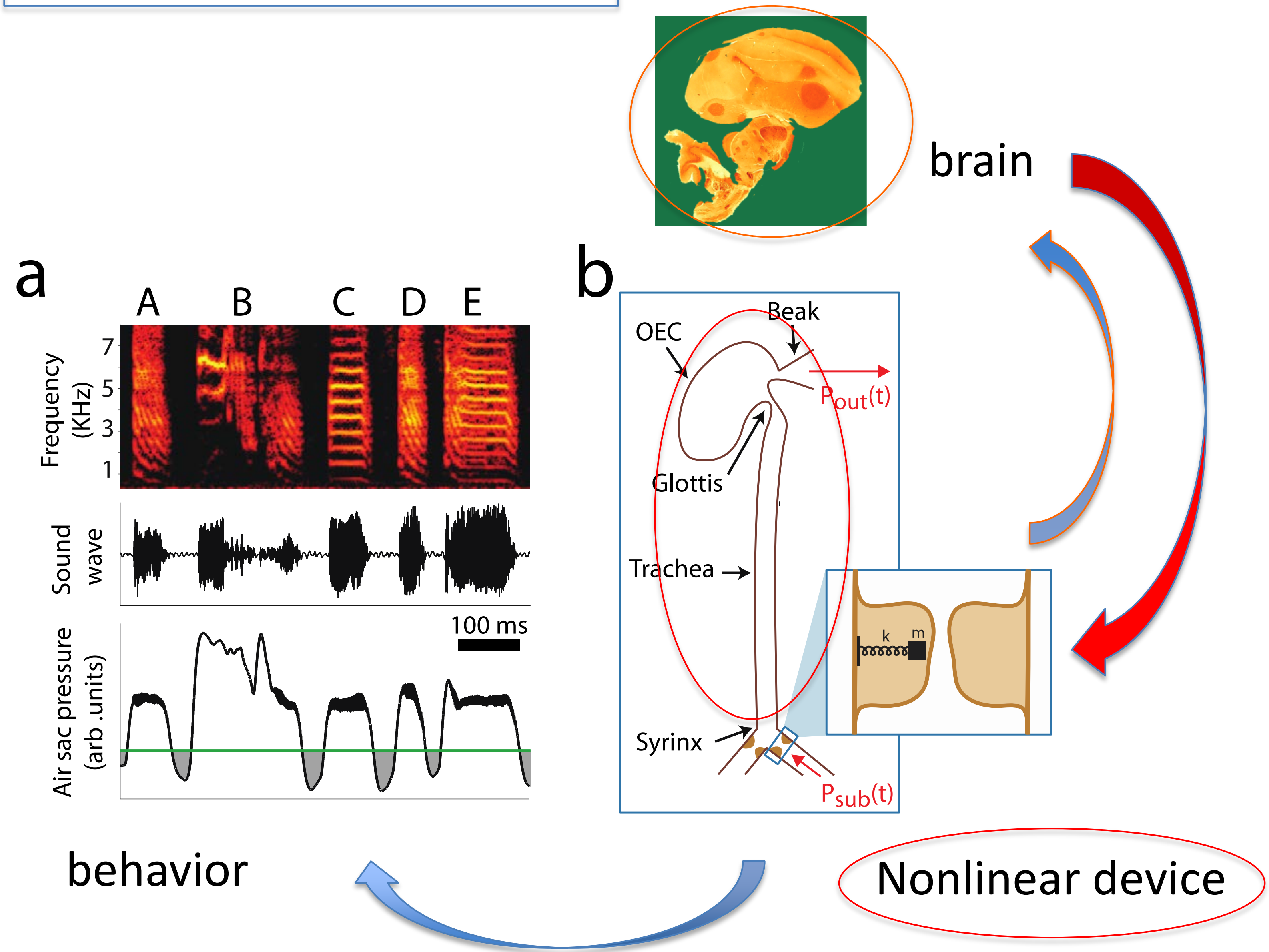
Title borrowed from **Phil Holmes**, ED Tytell and AH Cohen

Gabriel Mindlin, covering P.H.

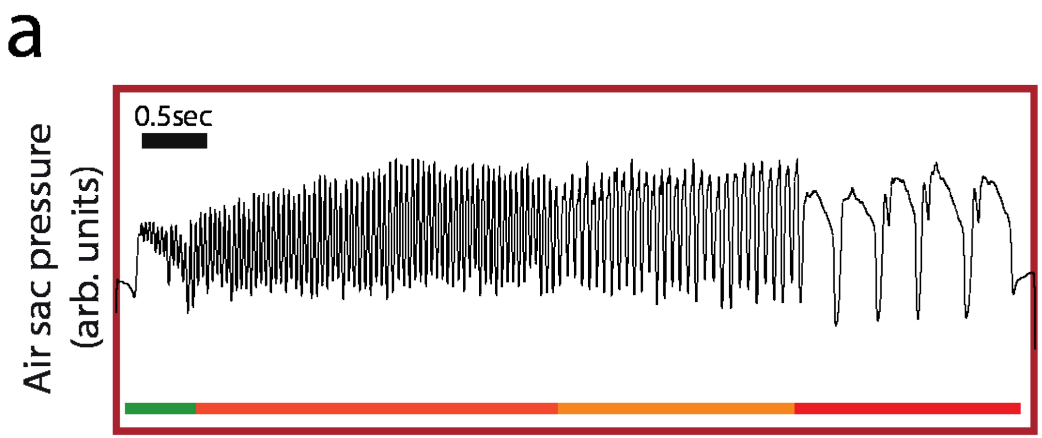


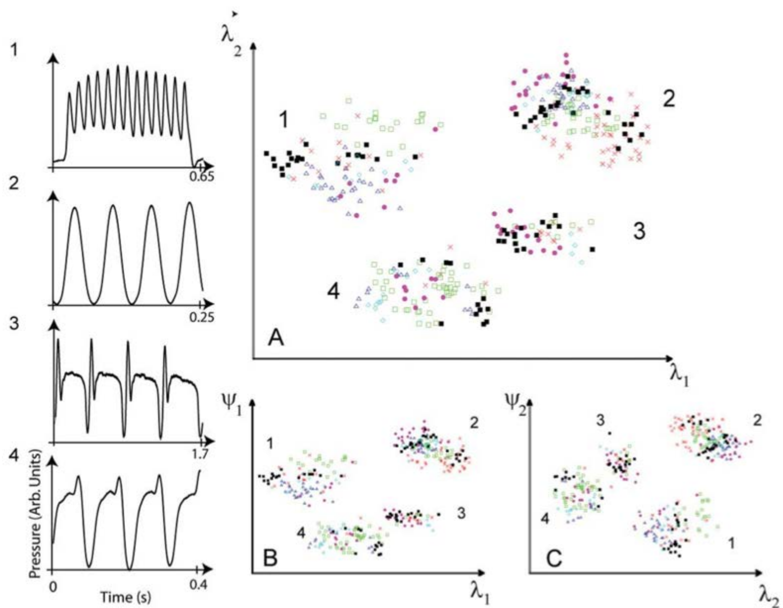
Current Opinion in Neurobiology

We need the circuit, and the coupling



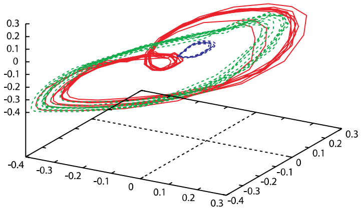
How complex, those instructions? The canary example.
Candidate for simpler gestures…

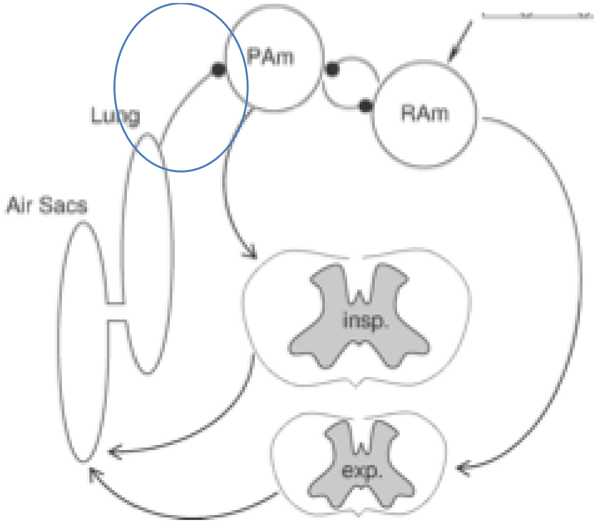




Air sac dynamics

Inspiration is Inhibited by the inflated air sacs

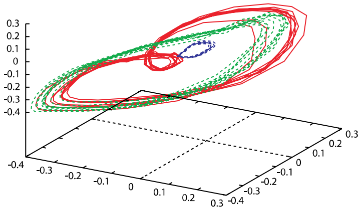


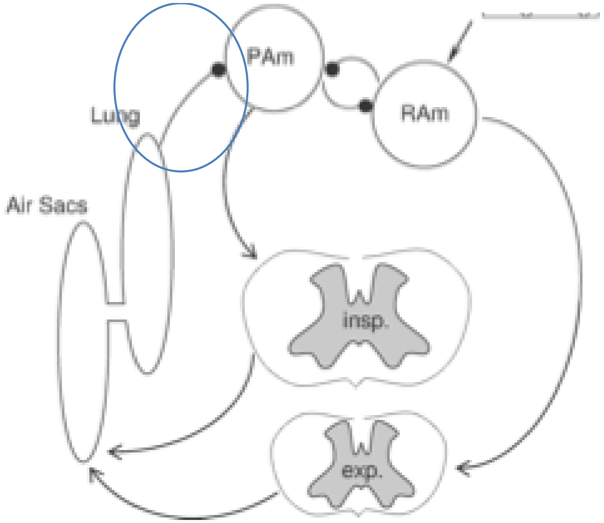


Under normal conditions (no perturbations)
Ram and Pam alone generate the right dynamics

Air sac dynamics

Inspiration is Inhibited by the inflated air sacs



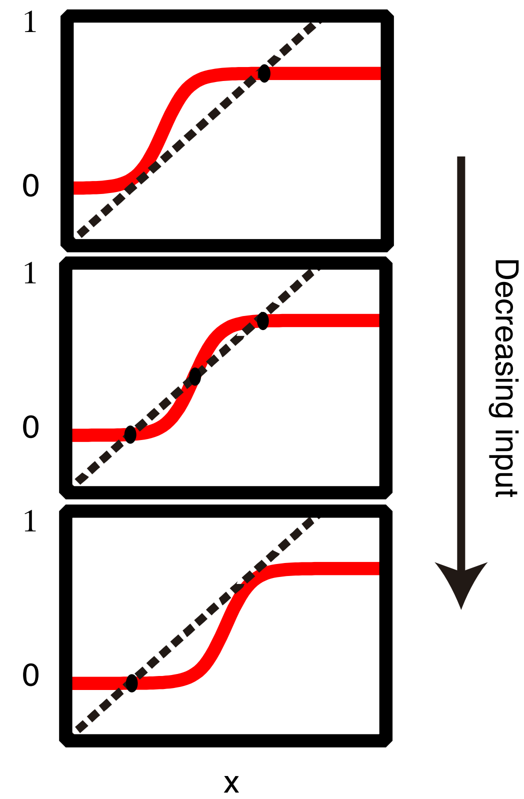


Under normal conditions (no perturbations)
Ram and Pam alone generate the right dynamics

The additive model

$$\frac{dx}{dt} = -x + S(\rho + cx)$$

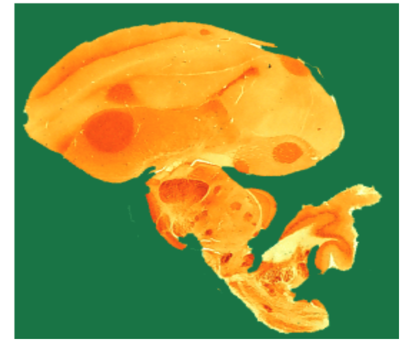
$$s(x) = \frac{1}{1 + e^{-x}}$$



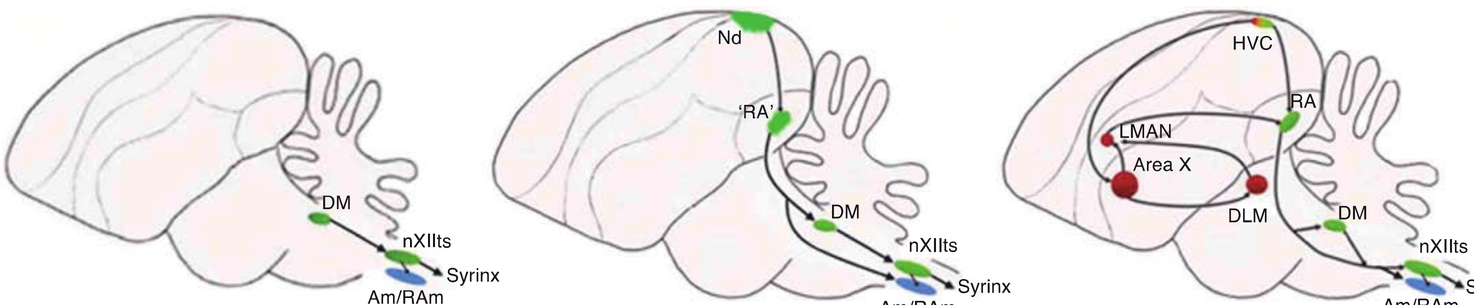
An ICTP initciative

http://www.df.uba.ar/academica/cursos-on-line/105-dinamica-no-lineal-1er-cuatrimestre-2013

How the page works

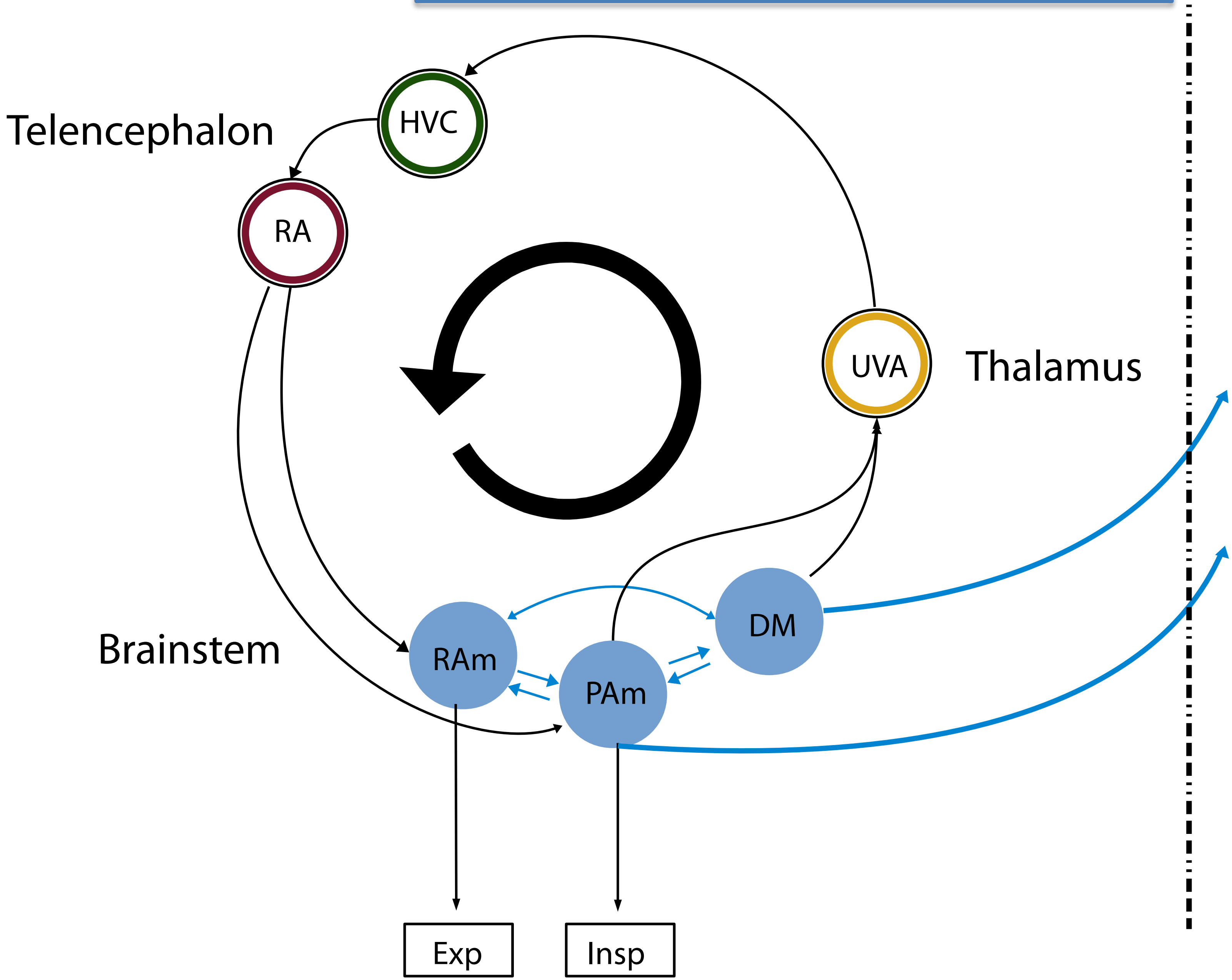


ngbird)

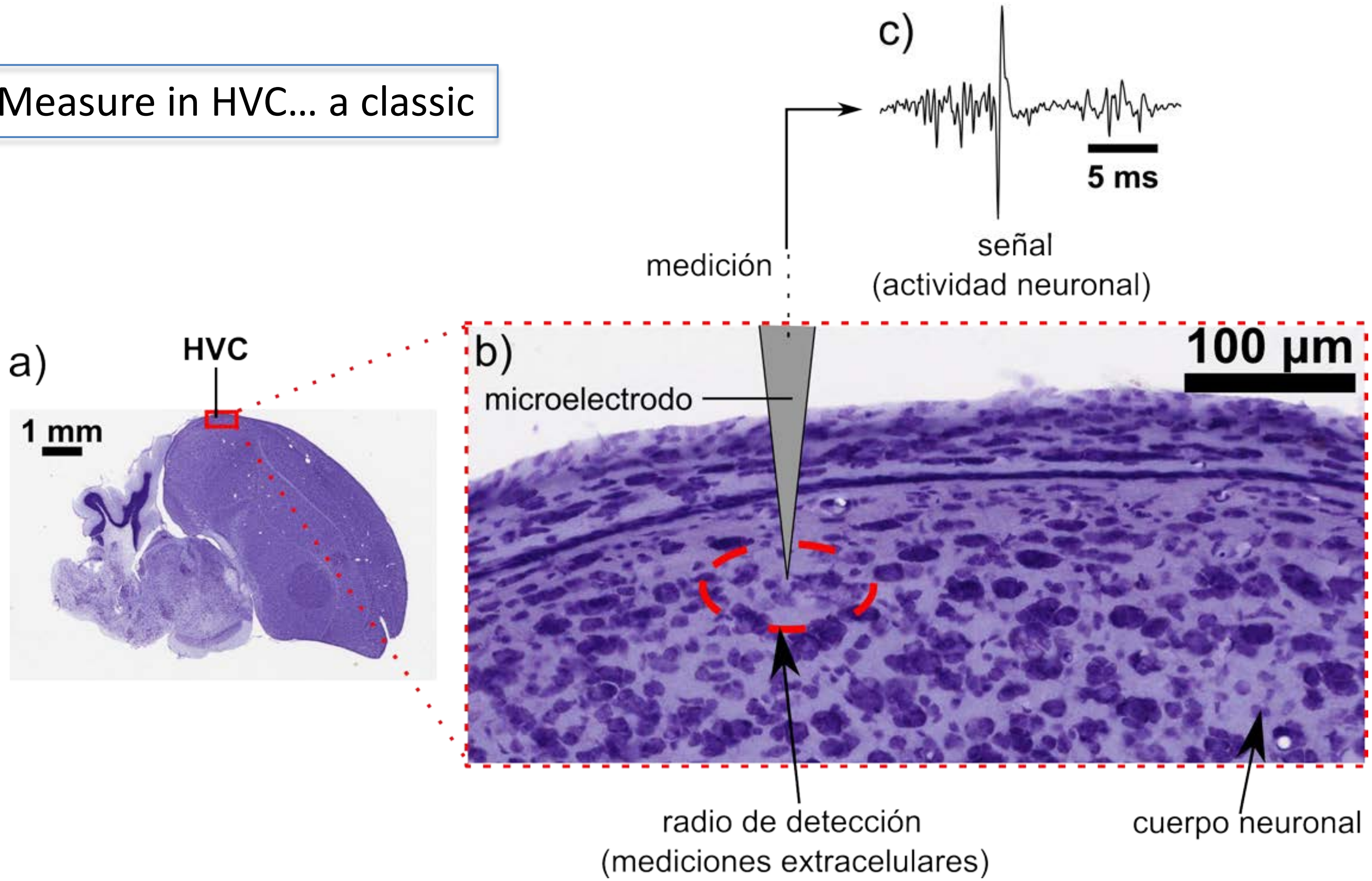


From Nottebohm et al.

First element: it is not a top down architecture;
It is a circular one.

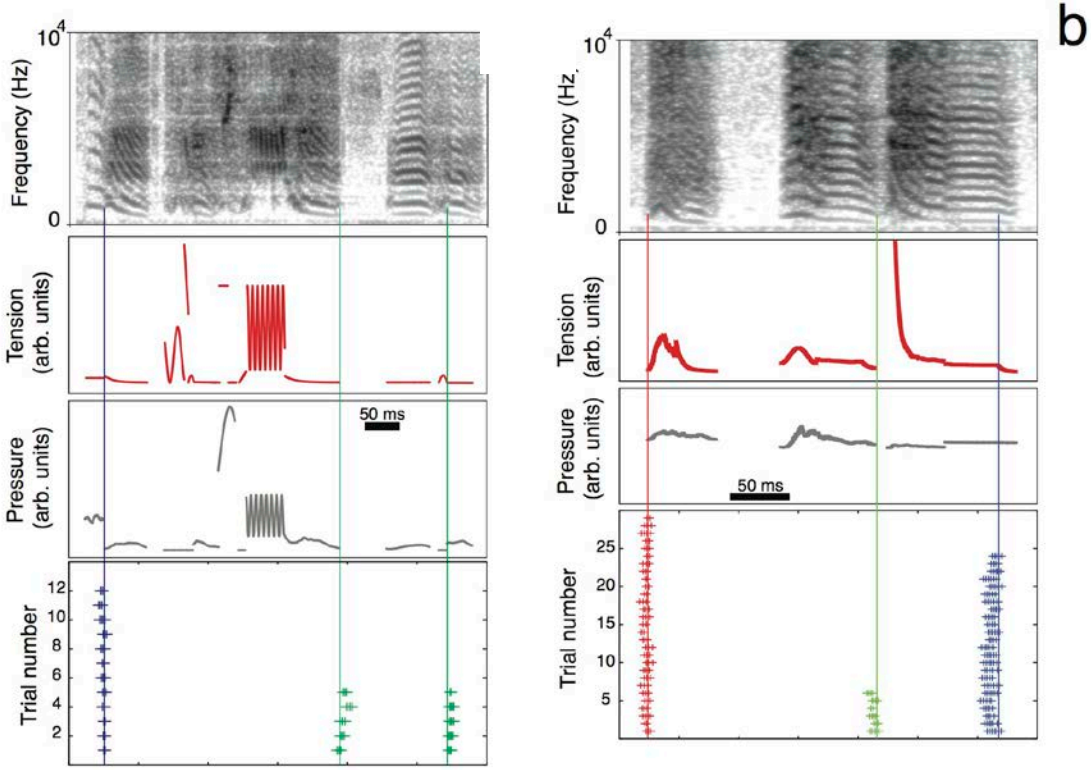


Measure in HVC… a classic



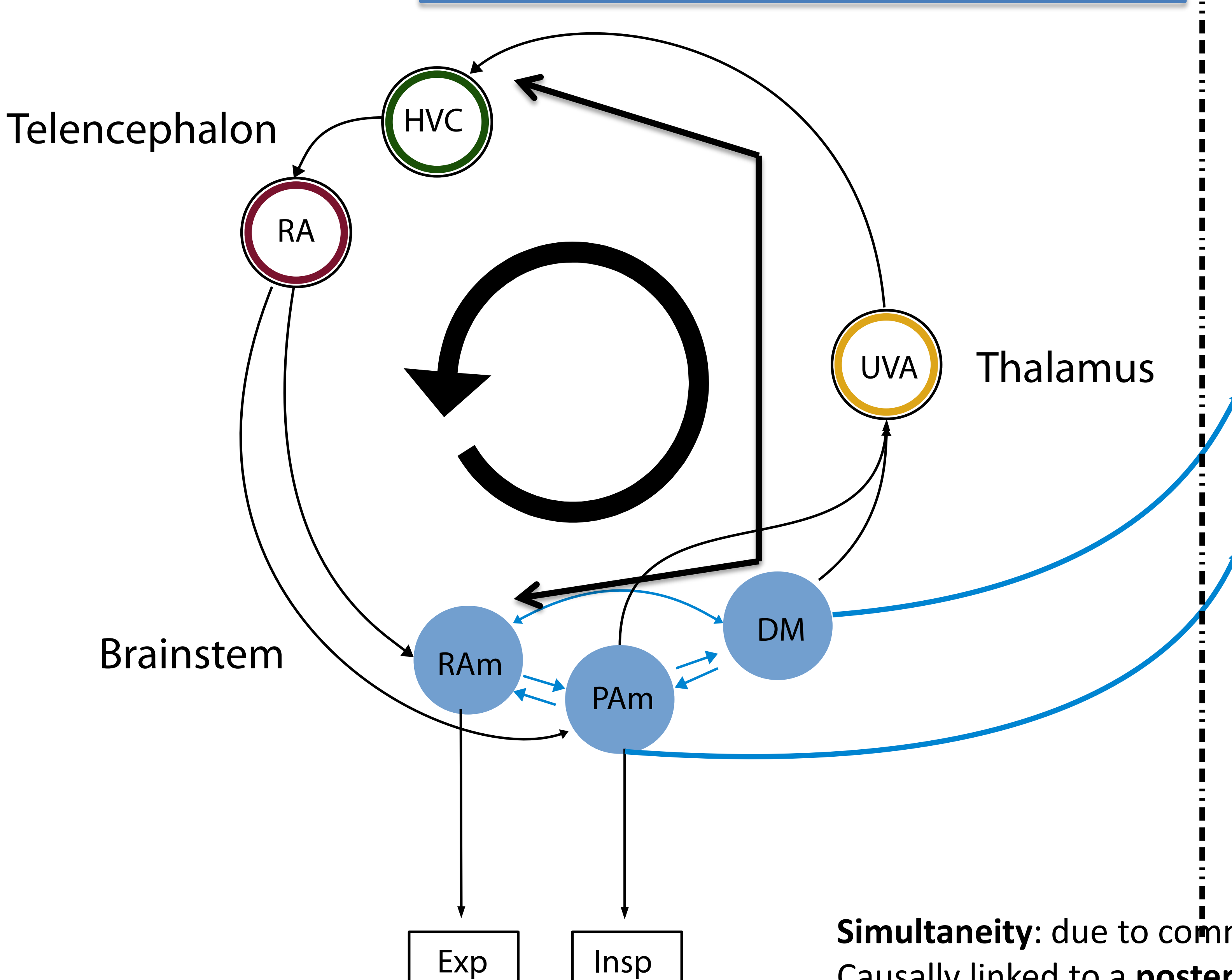
S. Boari

When do the bursts occur in HVC?



Data by Ana Amador

First element: it is not a top down architecture;
It is a circular one.



Simultaneity: due to common origin.
Causally linked to a **posterior** feature

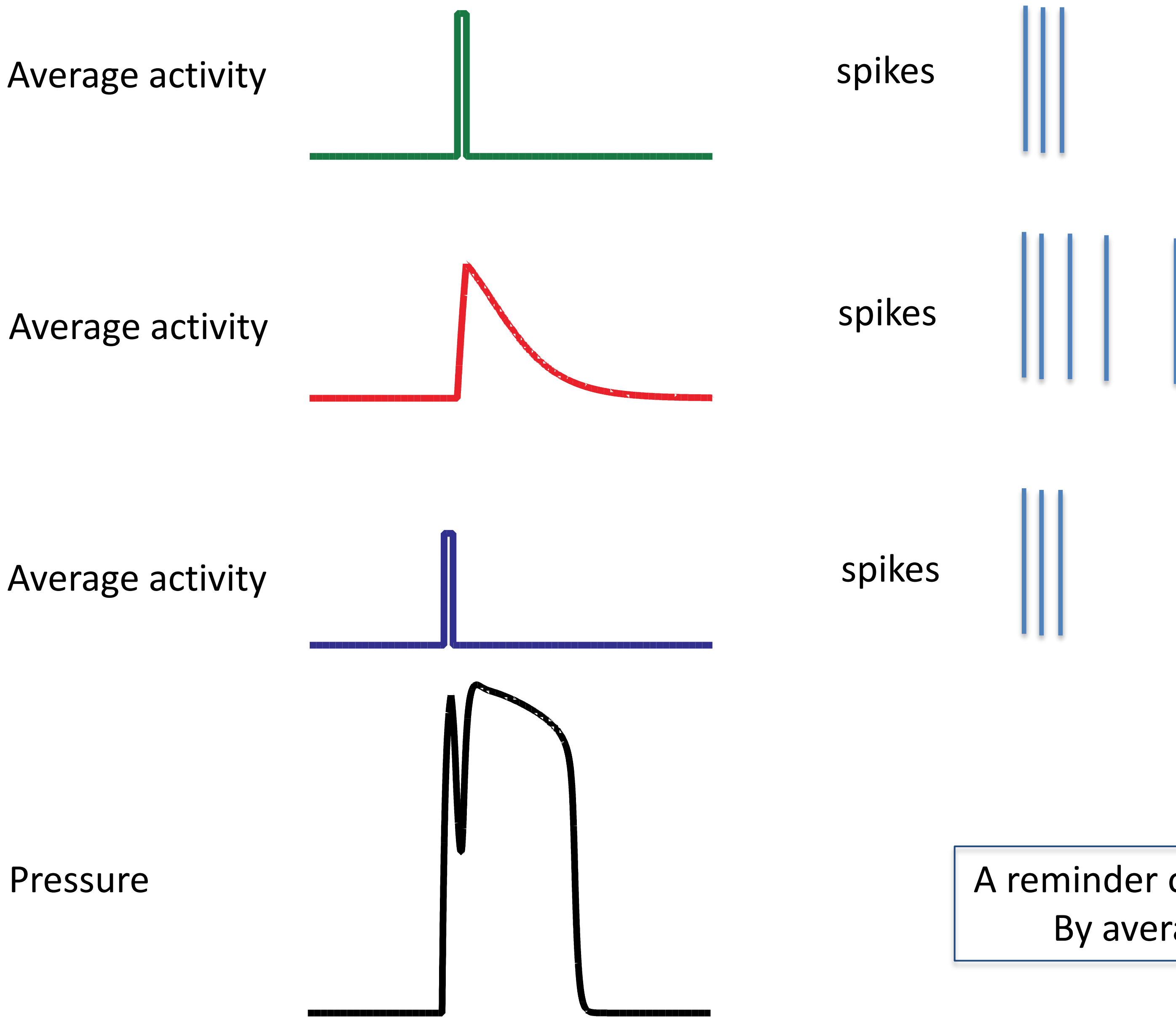
challenge

Is it possible to build a model such that

1. its variables are the activities of different areas of the song system,

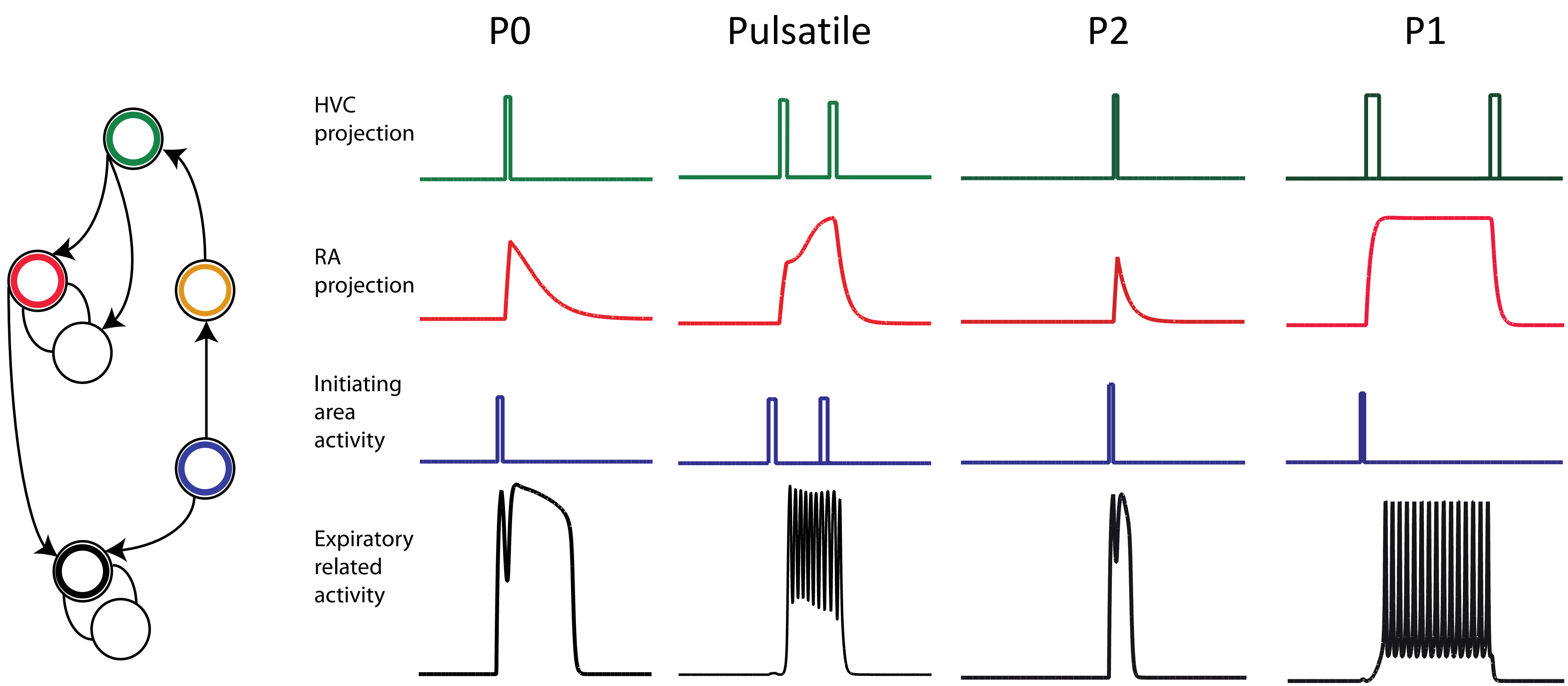
2. With an expiratory related area whose activity fits the recorded pressure patterns,

3. With sparse, bursting activity at a distant area (necessary for motor control) at significant motor instances?

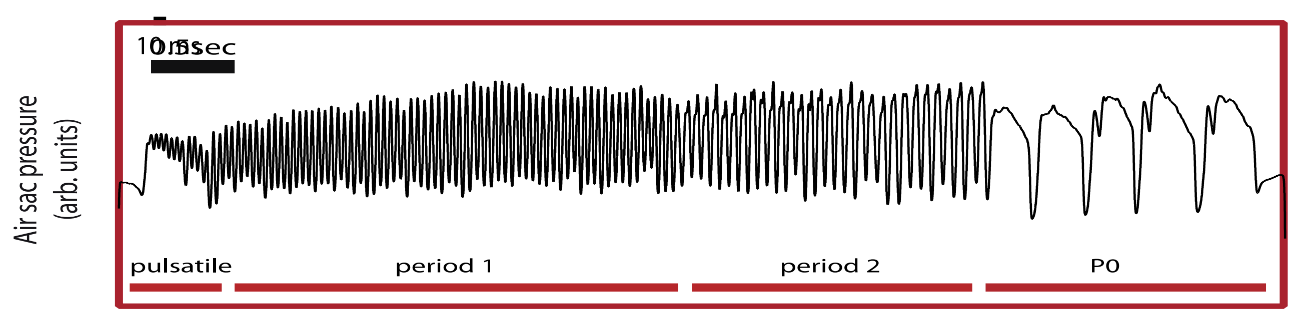


A reminder of what we mean
By average activity.

A circular model

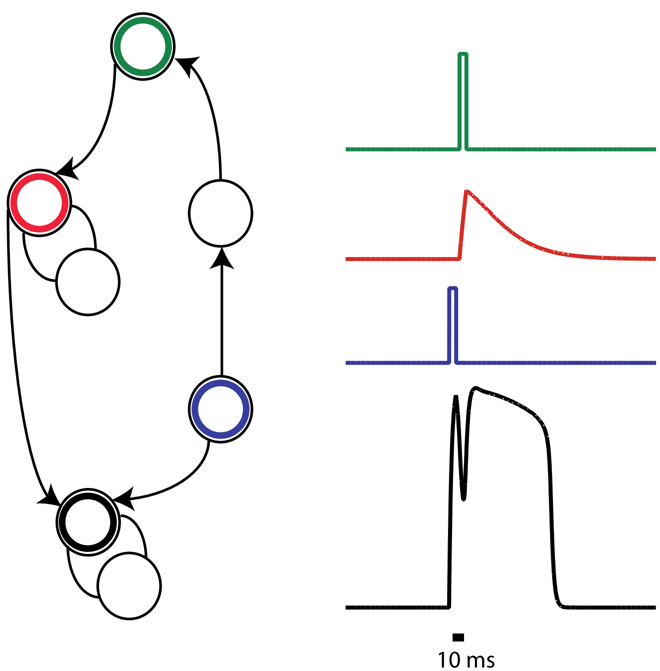


Canary pressure patterns



Additive model
(variables: rates;
Average activities)

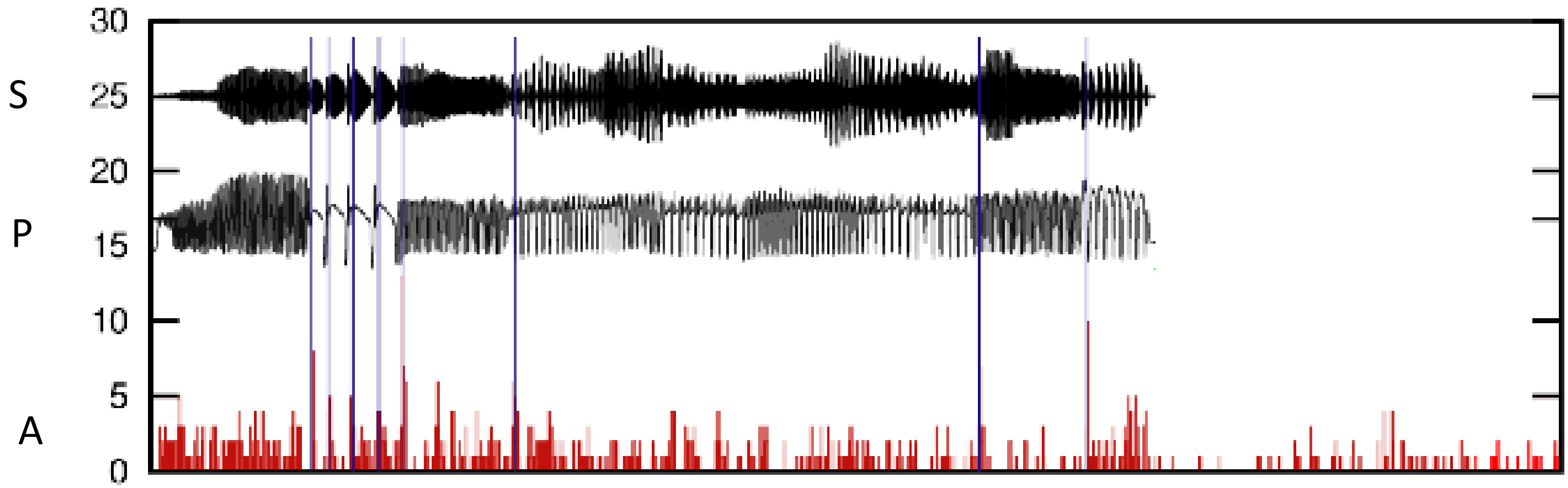
$$
\begin{aligned}
\frac{dx_i}{dt} &= -x_i + S\left(\rho_i + \sum_j a_{ij} x_j\right), \\
S(x) &= \frac{1}{1+e^{-x}}
\end{aligned}
$$



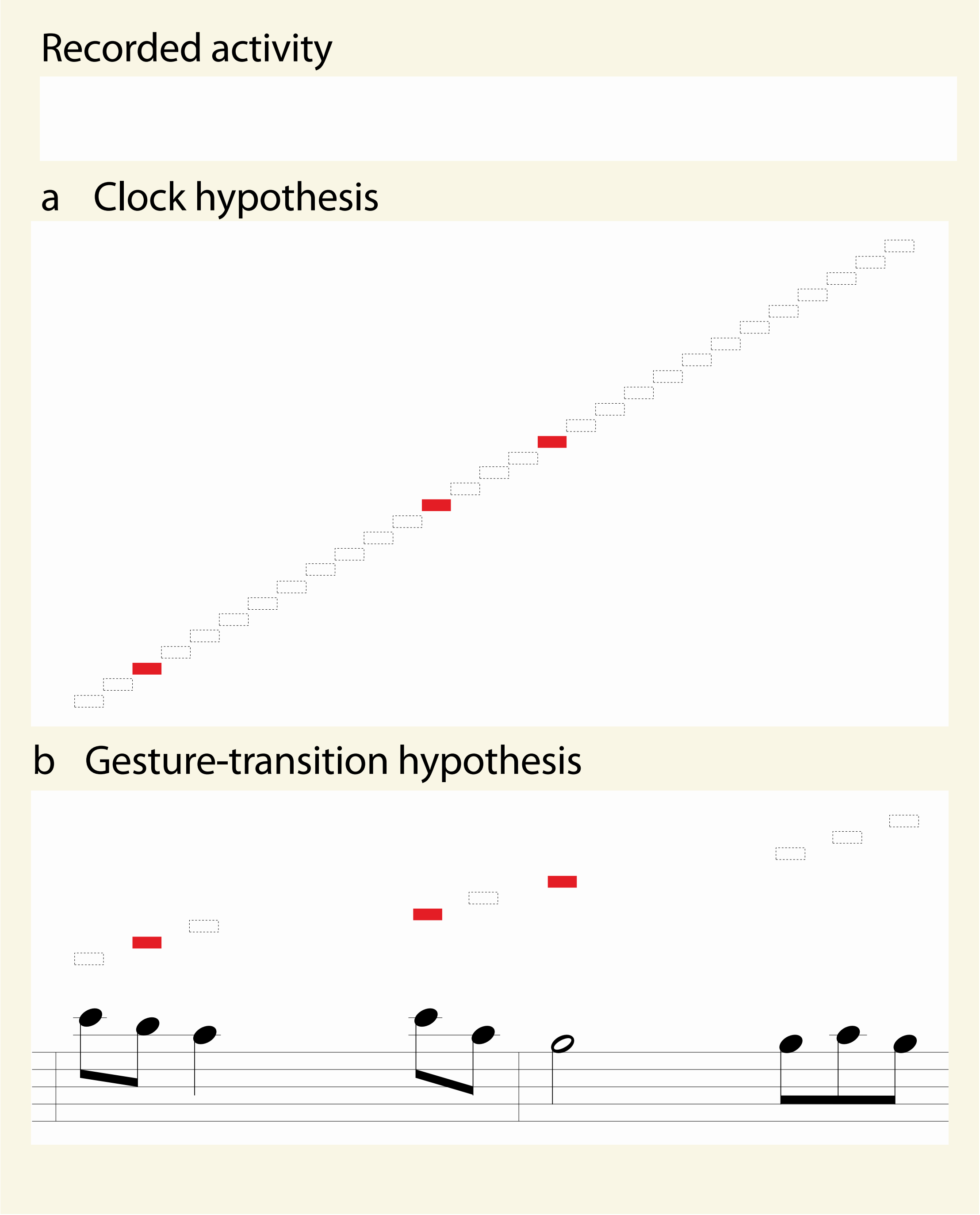
$$
\begin{aligned}
\frac{de_{er}}{dt} &= 149.5\,(-e_{er} + S\,(-7.5+ \\
&\quad \alpha_{eer,ra} e_{ra} + \alpha_{eer,F} F + 10 e_{er} - 10 i_{er})) \\
\frac{di_{er}}{dt} &= 149.5\,(-i_{er} + S\,(-11.5+ \\
&\quad \alpha_{ier,ra} e_{ra} + 10 e_{er} + 2 i_{er})) \\
\frac{de_{ra}}{dt} &= 20\,(-e_{ra} + S\,(\rho_{e,ra} + \alpha_{era,Fd} F_{delayed} + \\
&\quad \alpha_{era,Fd2} F_{delayed2} + \alpha_{era,ra} e_{ra} + \beta_{era,ra} i_{ra})) \\
\frac{di_{ra}}{dt} &= 20\,(-i_{ra} + S\,(\rho_{i,ra} + \alpha_{ira,Fd} F_{delayed} + \\
&\quad \alpha_{ira,Fd2} F_{delayed2} + \alpha_{ira,ra} e_{ra} + \beta_{ira,ra} i_{ra}))
\end{aligned}
$$

preliminary data

1. For P0 solutions, after the first pressure peak
2. At transitions



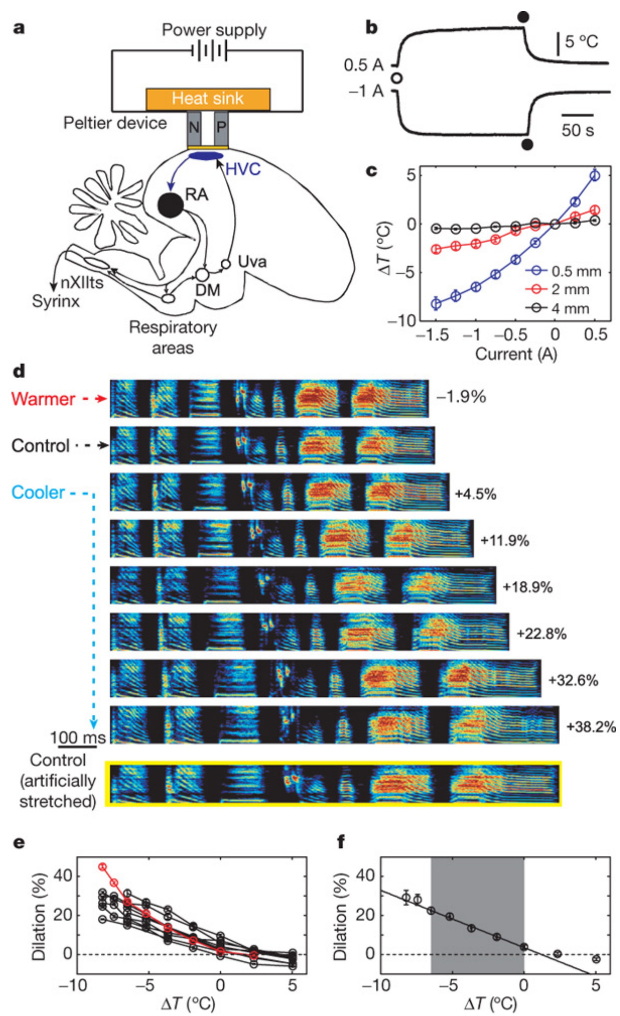
Gogui Alonso


Recorded activity
a Clock hypothesis
b Gesture-transition hypothesis

Troyer

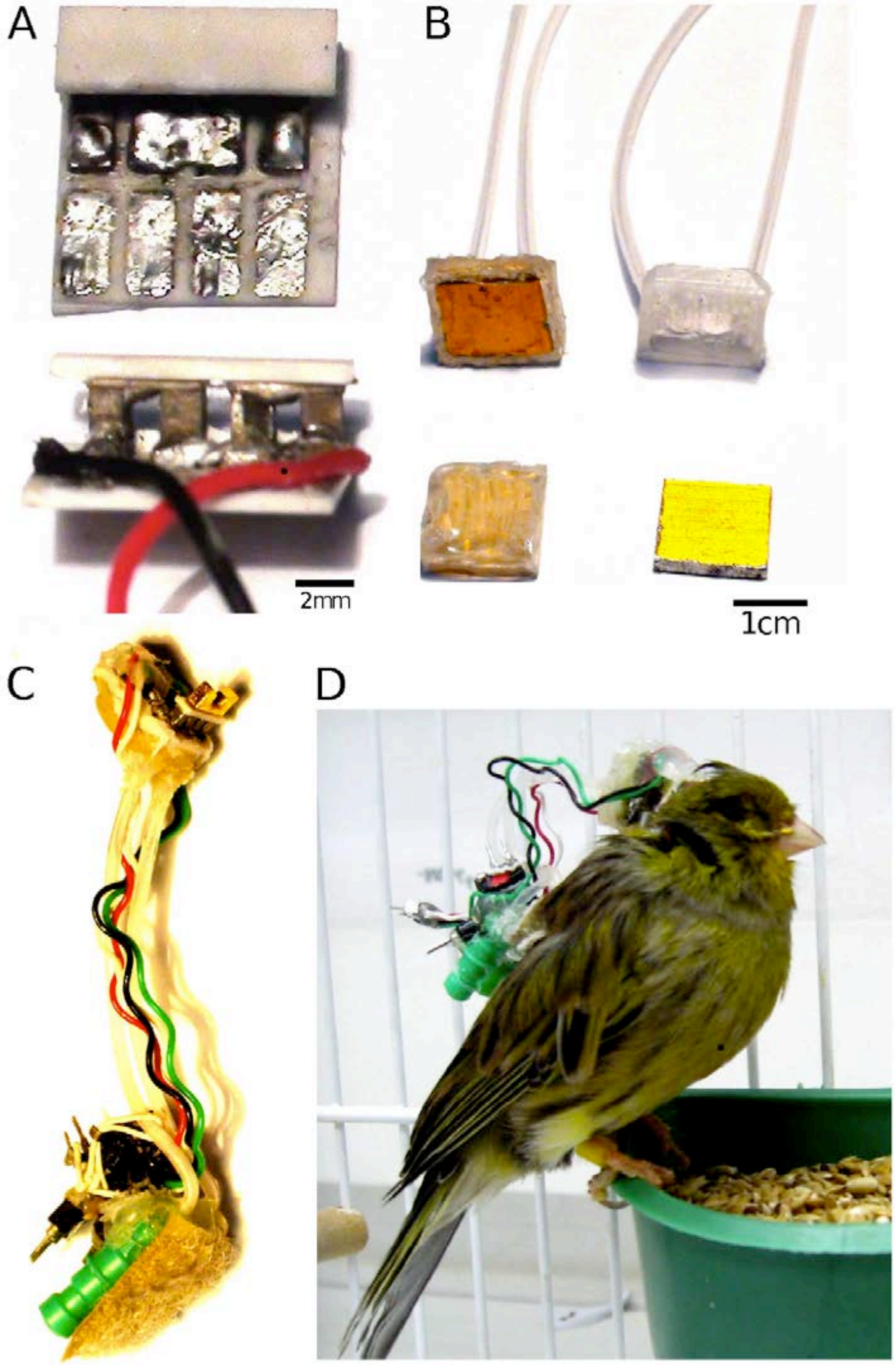
A continuous representation of time at the telencephalon:

“Cool” experiments

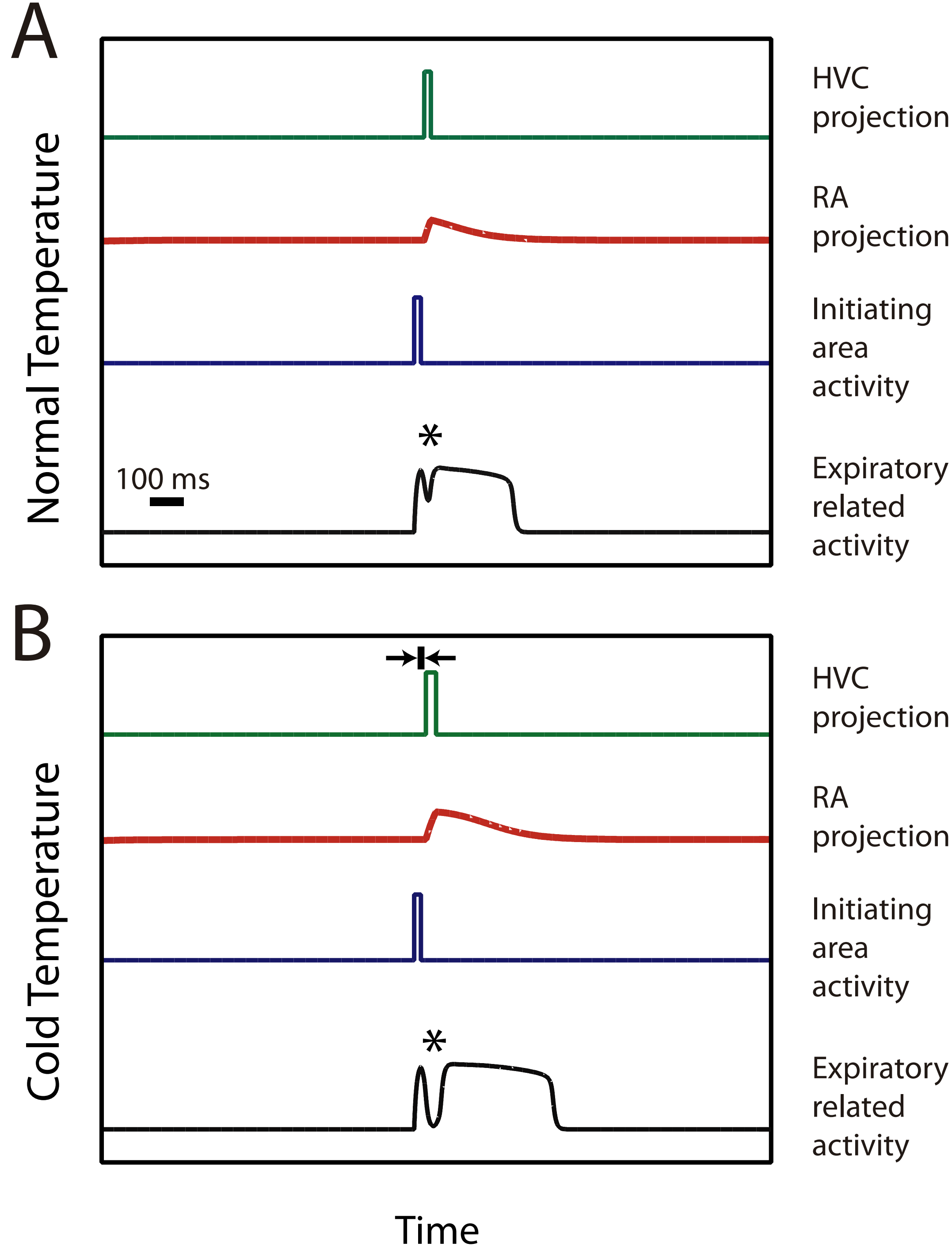


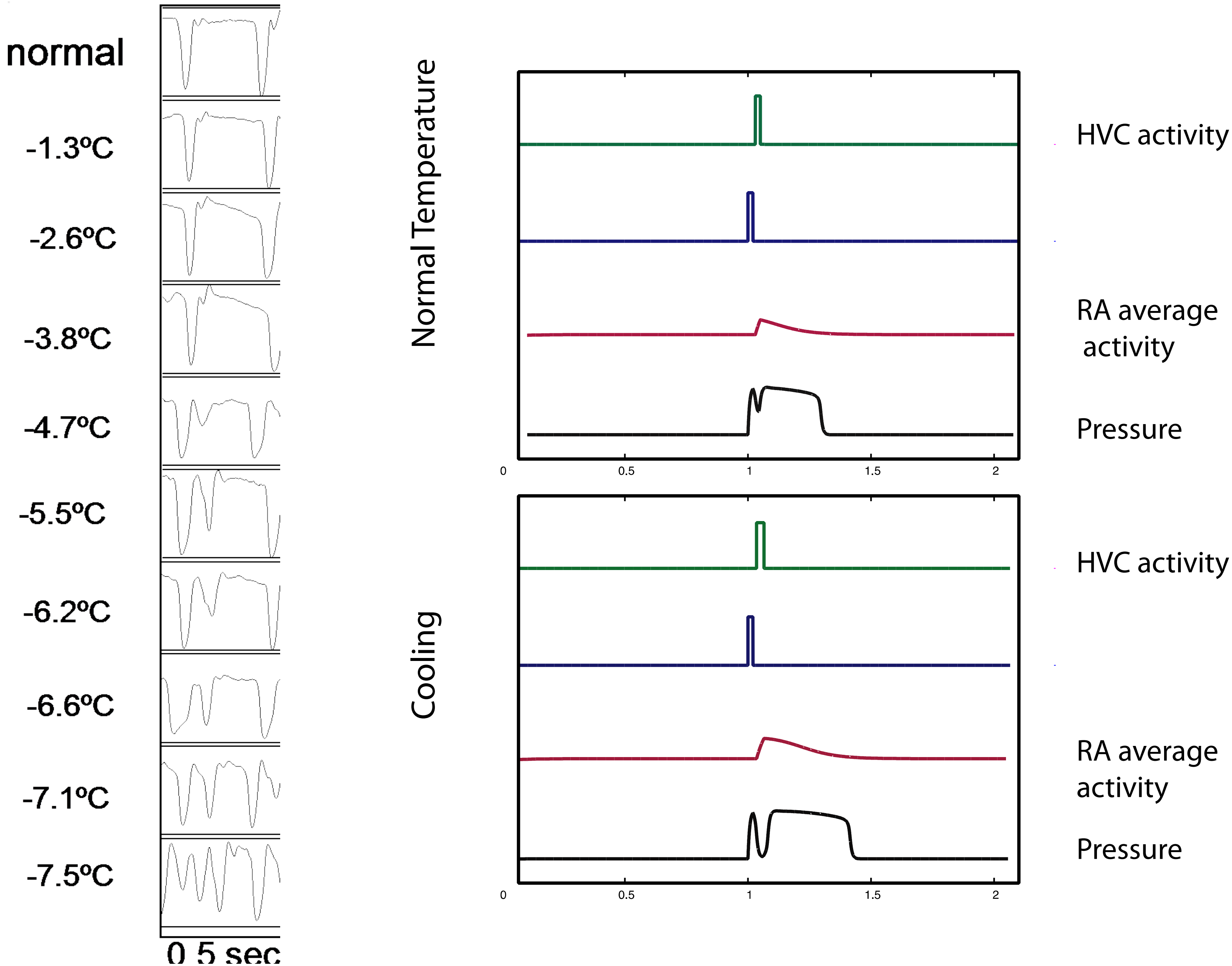
Long & Fee

Consistent with one Time scale…

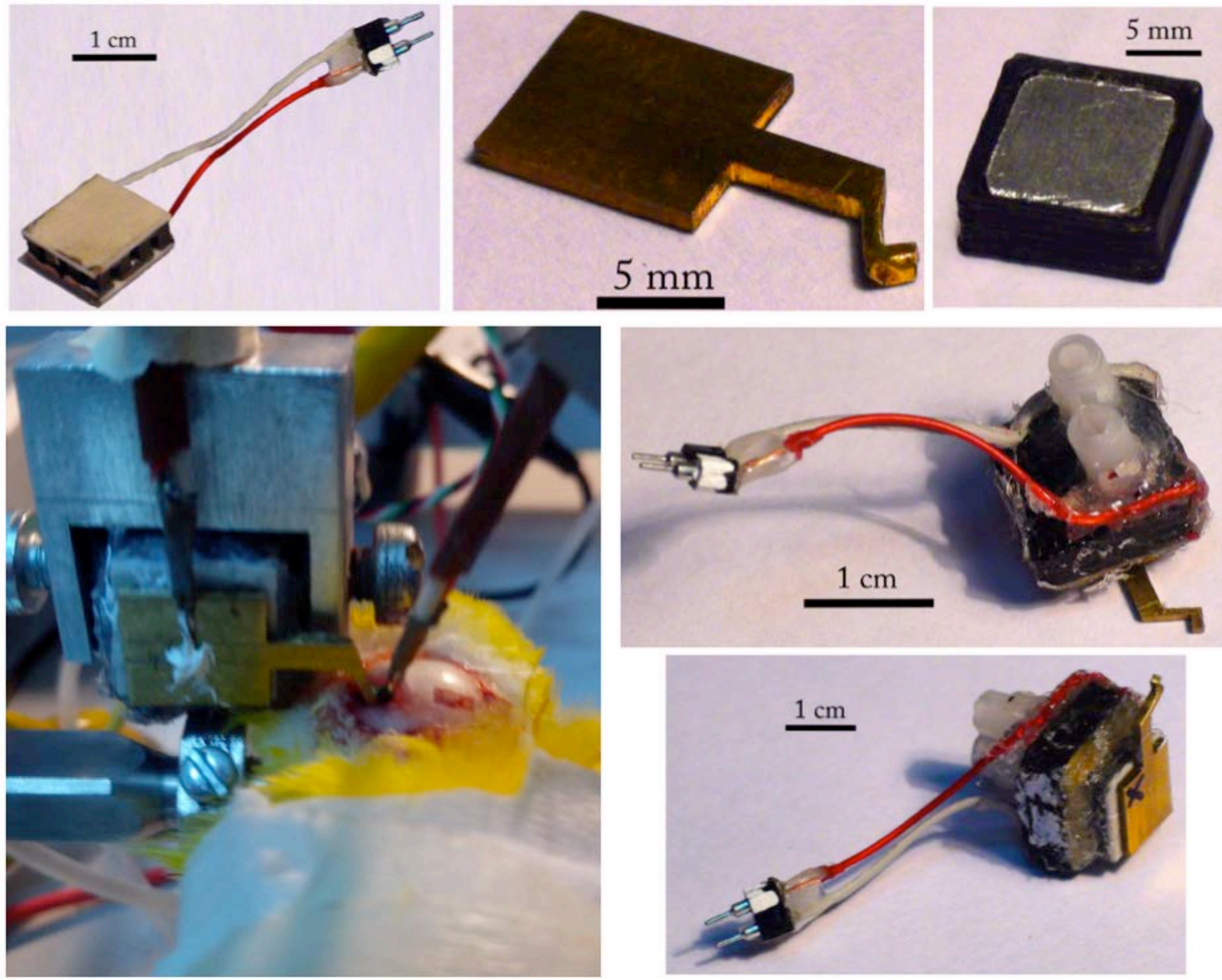


Mati’s thesis


A
Normal Temperature
HVC projection
RA projection
Initiating area activity
Expiratory related activity
*
100 ms
B
Cold Temperature
HVC projection
RA projection
Initiating area activity
Expiratory related activity
*
Time


normal
-1.3ºC
-2.6ºC
-3.8ºC
-4.7ºC
-5.5ºC
-6.2ºC
-6.6ºC
-7.1ºC
-7.5ºC
0.5 sec
Normal Temperature
HVC activity
RA average activity
Pressure
0
0.5
1
1.5
2
Cooling
HVC activity
RA average activity
Pressure
0
0.5
1
1.5
2

How do we introduce the cooling into the model?



Voltage (mV)

Voltage (mV)

1ms

ms)

normal

Time (ms)

Some conclusions.

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)

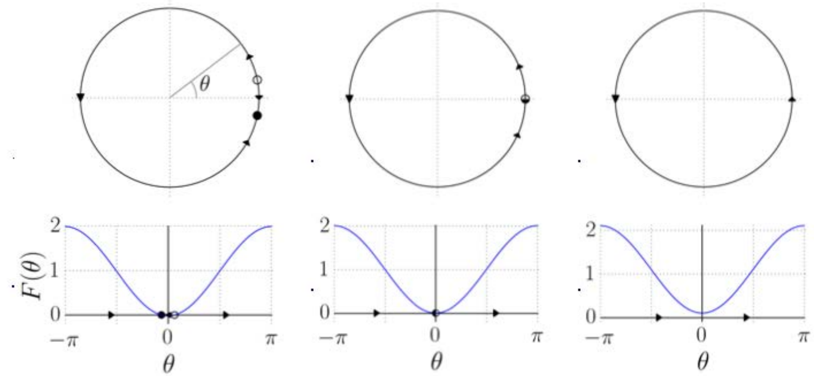
2. Nonlinear dynamics is an appropriate language to describe qualitative
Behavior, regardless of details. Super important in biology, where details
Can take a lifetime to be understood.

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.

Material suplementario:

- Calculo de actividad media para poblaciones de theta neurons.
- Ponemos a prueba la hipotesis de que la actividad promedio muestra los mismos comportamientos dinamicos que las actividades en los modelos de Wilson Cowan
- Derivamos expresiones analiticas para la actividad, a partir de los parametros de orden.

Hacia una teoria de campo medio

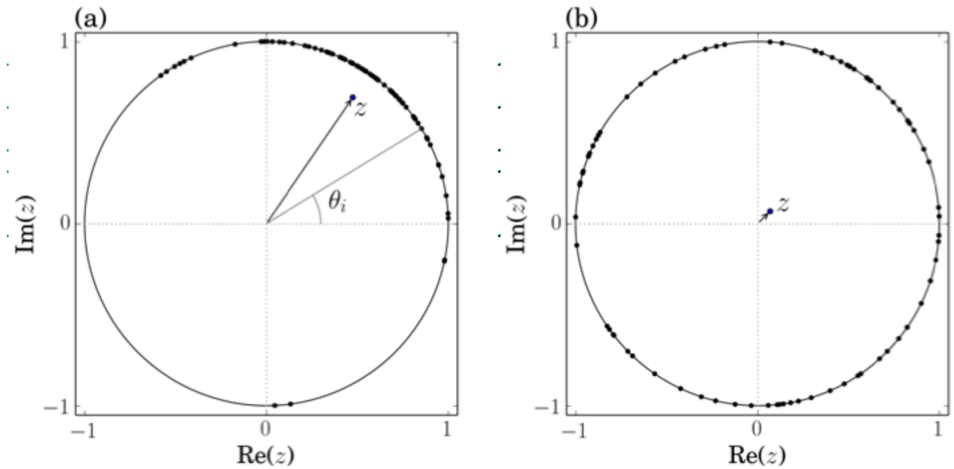


(a) $\omega \lesssim 1$ (b) $\omega = 1$ (c) $\omega > 1$

$$\begin{cases} \dot{\theta}_i(t) = \omega_i - \cos\theta_i(t) + \dfrac{k_E}{N}\displaystyle\sum_{j=0}^{N}(1-\cos\theta_j(t)) - \dfrac{k_I}{\tilde{N}}\sum_{j=1}^{\tilde{N}}(1-\cos\tilde{\theta}_j(t)), \\ \dot{\tilde{\theta}}_i(t) = \tilde{\omega}_i - \cos\tilde{\theta}_i(t) + \dfrac{\tilde{k}_E}{N}\displaystyle\sum_{j=0}^{N}(1-\cos\theta_j(t)) - \dfrac{\tilde{k}_I}{\tilde{N}}\sum_{j=1}^{\tilde{N}}(1-\cos\tilde{\theta}_j(t)), \end{cases}$$

$$z(t) = \frac{1}{N}\sum_{j=0}^{N} e^{i\theta_j(t)},$$

$$\tilde{z}(t) = \frac{1}{\tilde{N}}\sum_{j=0}^{\tilde{N}} e^{i\tilde{\theta}_j(t)}.$$



$$\begin{cases} \dot{\theta}_i(t) = \omega_i - \cos\theta_i(t) + k_E\big(1 - \operatorname{Re} z(t)\big) - k_I\big(1 - \operatorname{Re}\tilde{z}(t)\big), \\ \dot{\tilde{\theta}}_i(t) = \tilde{\omega}_i - \cos\tilde{\theta}_i(t) + \tilde{k}_E\big(1 - \operatorname{Re} z(t)\big) - \tilde{k}_I\big(1 - \operatorname{Re}\tilde{z}(t)\big). \end{cases}$$

$$\int_{-\infty}^{\infty}\int_{0}^{2\pi} f(\theta,\omega,t)\,d\theta d\omega = 1,$$

$$\int_{-\infty}^{\infty}\int_{0}^{2\pi} \tilde{f}(\theta,\omega,t)\,d\theta d\omega = 1.$$

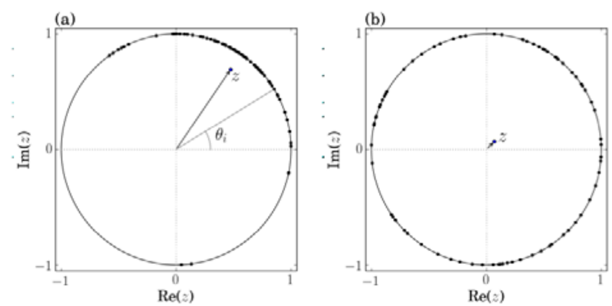
$$\int_{0}^{2\pi} f(\theta,\omega,t)\,d\theta = g(\omega).$$

$$v(\theta,\omega,t) = \omega - \frac{e^{i\theta} + e^{-i\theta}}{2} + k_E\big(1 - \operatorname{Re} z(t)\big) - k_I\big(1 - \operatorname{Re}\tilde{z}(t)\big),$$

$$z(t) = \int_{-\infty}^{\infty} \int_{0}^{2\pi} f(\theta, \omega, t) e^{i\theta} d\theta d\omega,$$

$$\tilde{z}(t) = \int_{-\infty}^{\infty} \int_{0}^{2\pi} \tilde{f}(\theta, \omega, t) e^{i\theta} d\theta d\omega.$$

$$\boxed{\frac{\partial f}{\partial t} + \frac{\partial}{\partial \theta}(f v) = 0.}$$



$$f(\theta, \omega, t) = \sum_{n=-\infty}^{\infty} a_n(\omega, t) \frac{e^{in\theta}}{\sqrt{2\pi}},$$

$$a_n(\omega, t) = \int_{-\infty}^{\infty} f(\theta, \omega, t) \frac{e^{-in\theta}}{\sqrt{2\pi}} d\theta.$$

$$
\begin{aligned}
0 &= \frac{\partial f}{\partial t} + v\frac{\partial f}{\partial \theta} + \frac{\partial v}{\partial \theta} f \\
&= \sum_{n=-\infty}^{\infty} \frac{\partial a_n}{\partial t}\frac{e^{in\theta}}{\sqrt{2\pi}} + \Big(\omega - \frac{e^{i\theta}}{2} + \frac{e^{-i\theta}}{2} + k_E(1-\operatorname{Re} z) - k_I(1-\operatorname{Re}\tilde{z})\Big) i n a_n \frac{e^{in\theta}}{\sqrt{2\pi}} + \\
&\qquad + \Big(\frac{-i}{2}e^{i\theta} + \frac{i}{2}e^{-i\theta}\Big) a_n \frac{e^{in\theta}}{\sqrt{2\pi}} \\
&= \sum_{n=-\infty}^{\infty} \Big(\frac{\partial a_n}{\partial t} + in\Big(\omega + k_E(1-\operatorname{Re} z) - k_I(1-\operatorname{Re}\tilde{z})\Big) a_n\Big) \frac{e^{in\theta}}{\sqrt{2\pi}} + \\
&\qquad - \frac{i}{2}(n+1) a_n \frac{e^{i(n+1)\theta}}{\sqrt{2\pi}} - \frac{i}{2}(n-1) a_n \frac{e^{i(n-1)\theta}}{\sqrt{2\pi}} \\
&= \sum_{n=-\infty}^{\infty} \Big[\frac{\partial a_n}{\partial t} + in\Big(\omega + k_E(1-\operatorname{Re} z) - k_I(1-\operatorname{Re}\tilde{z})\Big) a_n - \frac{i}{2} n a_{n-1} - \frac{i}{2} n a_{n+1}\Big] \frac{e^{in\theta}}{\sqrt{2\pi}}.
\end{aligned}
$$

$$\frac{\partial a_n}{\partial t}(\omega,t) = -in\Big(\omega + k_E\big(1-\operatorname{Re} z(t)\big) - k_I\big(1-\operatorname{Re}\tilde{z}(t)\big)\Big)a_n(\omega,t) + \\ + \frac{i}{2}n\big(a_{n-1}(\omega,t) + a_{n+1}(\omega,t)\big).$$

$$\begin{aligned} f(\theta,\omega,t) &= \frac{g(\omega)}{2\pi}\left(1 + \sum_{n\geqslant 1}\frac{\sqrt{2\pi}}{g(\omega)}a_n(\omega,t)e^{in\theta} + \frac{\sqrt{2\pi}}{g(\omega)}a_n^*(\omega,t)e^{-in\theta}\right) \\ &= \frac{g(\omega)}{2\pi}\left(1 + \sum_{n\geqslant 1}\alpha_n(\omega,t)e^{in\theta} + \alpha_n^*(\omega,t)e^{-in\theta}\right), \end{aligned}$$

$$\alpha_n(\omega,t) = \frac{\sqrt{2\pi}}{g(\omega)}a_n(\omega,t).$$

$$\frac{\partial \alpha_n}{\partial t}(\omega,t) = -\,in\Big(\omega + k_E\big(1-\operatorname{Re} z(t)\big) - k_I\big(1-\operatorname{Re}\tilde{z}(t)\big)\Big)\alpha_n(\omega,t) + \\ + \frac{i}{2}n\big(\alpha_{n-1}(\omega,t)+\alpha_{n+1}(\omega,t)\big).$$

$$\alpha_n(\omega,t) = \big[\alpha(\omega,t)\big]^n,$$

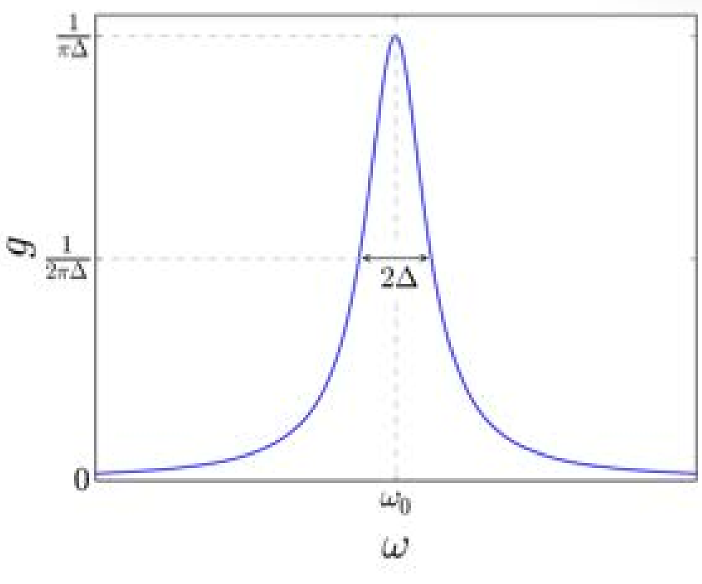
$$\begin{aligned} \alpha(\omega,t) &= \alpha_1(\omega,t) \\ &= \frac{1}{g(\omega)}\int_0^{2\pi} f(\theta,\omega,t)e^{-i\theta}d\theta. \end{aligned}$$

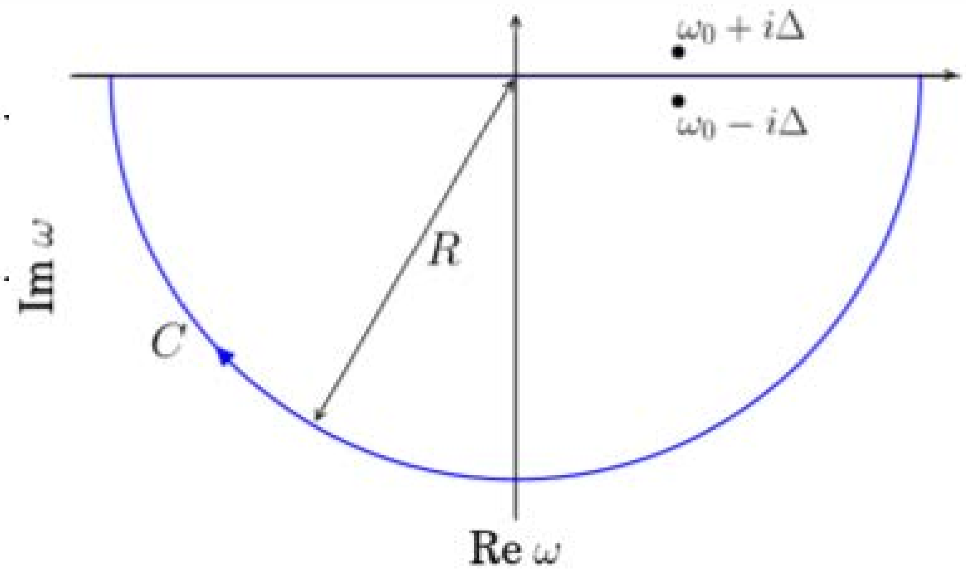
$$\frac{\partial \alpha^n}{\partial t} = n\alpha^{n-1}\frac{\partial \alpha}{\partial t} = -in\Big(\omega + k_E(1-\operatorname{Re} z) - k_I(1-\operatorname{Re}\tilde{z})\Big)\alpha^n + \frac{i}{2}n\big(\alpha^{n-1}+\alpha^{n+1}\big)$$

$$\frac{\partial \alpha}{\partial t}(\omega,t) = -i\Big(\omega + k_E\big(1-\operatorname{Re} z(t)\big) - k_I\big(1-\operatorname{Re}\tilde{z}(t)\big)\Big)\alpha(\omega,t) + \frac{i}{2}\big(1+\alpha^2(\omega,t)\big).$$

$$\int_{-\infty}^{\infty} g(\omega)\alpha(\omega, t)d\omega = \int_{-\infty}^{\infty}\int_{0}^{2\pi} f(\theta,\omega,t)e^{-i\theta}d\theta d\omega$$
$$= z^*(t).$$

$$g(\omega) = \frac{\Delta}{\pi}\frac{1}{(\omega-\omega_0)^2+\Delta^2} = \frac{\Delta}{\pi}\frac{1}{(\omega-\omega_0+i\Delta)(\omega-\omega_0-i\Delta)}$$





$$
\begin{aligned}
z^*(t) =& \int_{-\infty}^{\infty} \frac{\Delta}{\pi} \frac{1}{(\omega-\omega_0+i\Delta)(\omega-\omega_0-i\Delta)} \alpha(\omega,t) d\omega \\
=& -2i\pi \operatorname{Res}\left[\frac{\Delta}{\pi}\frac{\alpha(\omega,t)}{(\omega-\omega_0+i\Delta)(\omega-\omega_0-i\Delta)}\right]_{\omega=\omega_0-i\Delta} + \\
& \qquad - \lim_{R\to\infty}\int_0^{-\pi} \frac{\Delta}{\pi}\frac{\alpha(Re^{i\varphi},t)}{R^2e^{2i\varphi}\left(1+\mathcal{O}\left(\frac{1}{R}\right)\right)} iRe^{i\varphi} d\varphi \\
=& -2i\pi\left[\frac{\Delta}{\pi}\frac{\alpha(\omega_0-i\Delta,t)}{(-2i\Delta)}\right] + 0 \\
=& \alpha(\omega_0-i\Delta,t).
\end{aligned}
$$

$$
\begin{cases}
\dot{z} = i\big(\omega_0 + i\Delta + k_E(1 - \operatorname{Re} z) - k_I(1 - \operatorname{Re} \tilde{z})\big)z - \dfrac{i}{2}\big(1 + z^2\big), \\
\dot{\tilde{z}} = i\big(\tilde{\omega}_0 + i\tilde{\Delta} + \tilde{k}_E(1 - \operatorname{Re} z) - \tilde{k}_I(1 - \operatorname{Re} \tilde{z})\big)\tilde{z} - \dfrac{i}{2}\big(1 + \tilde{z}^2\big).
\end{cases}
$$

$$
\lim_{\operatorname{Im} \omega \to -\infty} \alpha(\omega, t) = 0
$$

$$
\frac{\partial |\alpha|}{\partial t}(\omega, t) = \operatorname{Im} \omega \cdot \big|\alpha(\omega, t)\big| - \frac{1 - |\alpha(\omega, t)|^2}{2} \operatorname{sen} \psi(\omega, t),
$$

$$
\begin{aligned}
\phi(t) &= \int_{-\infty}^{\infty} f(\theta, \omega, t) v(\theta, \omega, t)\Big|_{\theta = \pi} d\omega, \\
\tilde{\phi}(t) &= \int_{-\infty}^{\infty} \tilde{f}(\theta, \omega, t) \tilde{v}(\theta, \omega, t)\Big|_{\theta = \pi} d\omega.
\end{aligned}
$$

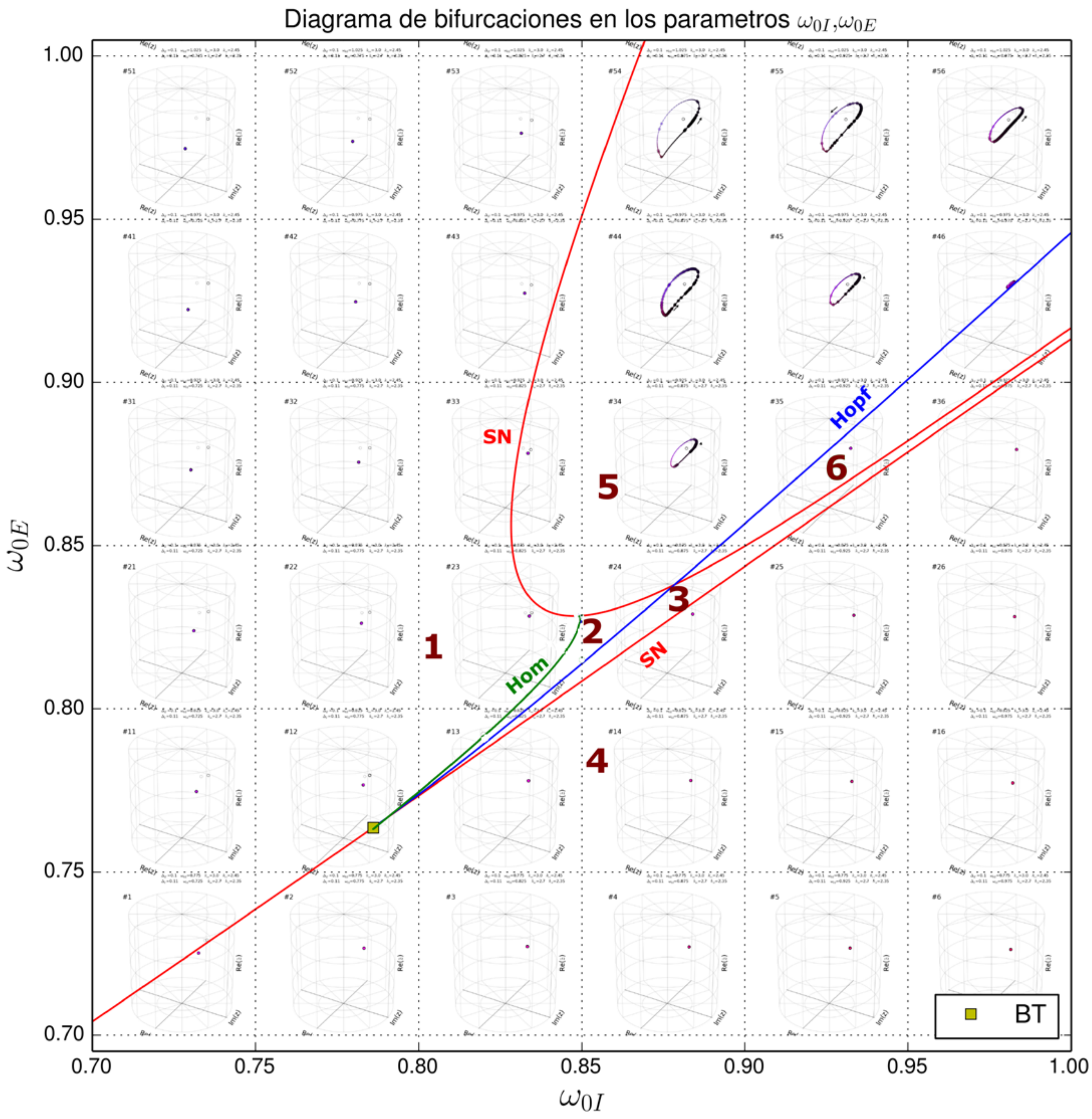
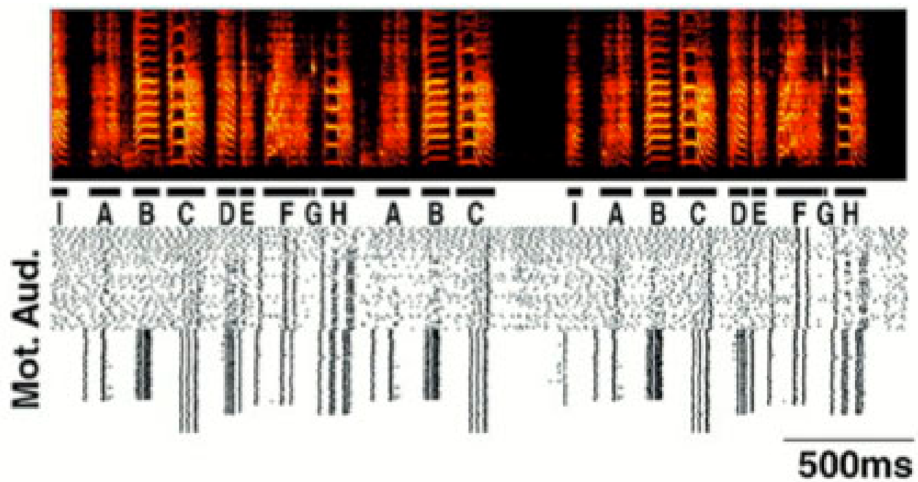


Diagrama de bifurcaciones en los parametros ω_{0I},ω_{0E}
ω_{0E}
ω_{0I}
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.70
0.75
0.80
0.85
0.90
0.95
1.00
SN
SN
Hopf
Hom
1
2
3
4
5
6
BT

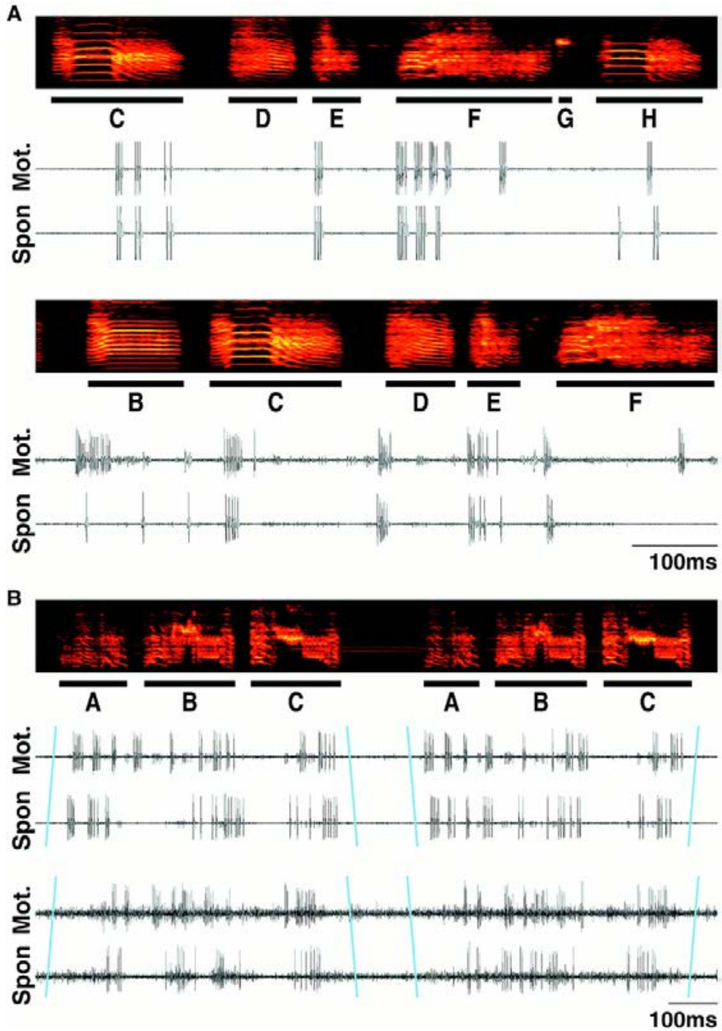
How did we get interested In sleeping birds…

It was the ultimate validation tool:
To use the selectivity of the auditory responses to BOS, in order to compare it with the responses to SYN



Amish S. Dave, and Daniel Margoliash Science 2000;290:812-816

Unexpected by-product:
Neuronal replay during
Undisturbed sleep

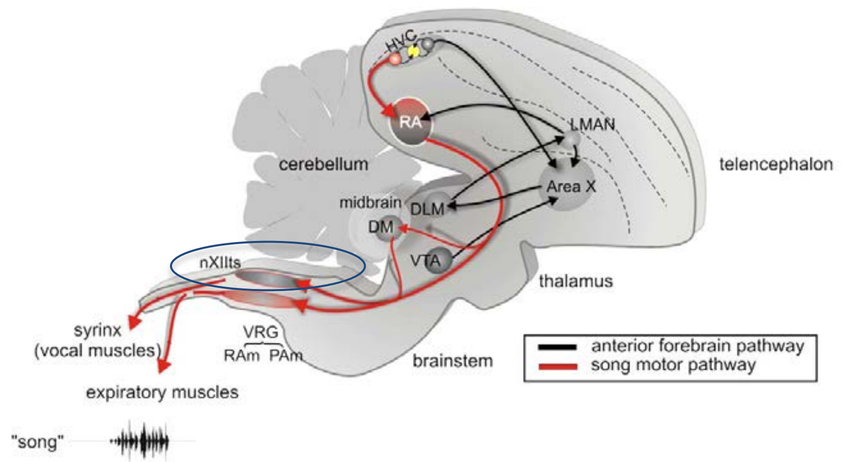


Amish S. Dave, and Daniel Margoliash Science 2000;290:812-816

The similarity induced to think in terms of "consolidation" (learning and maintenance)

The **problem** though: **How to interpret The patterns which Are not "identical" to the ones used to sing**

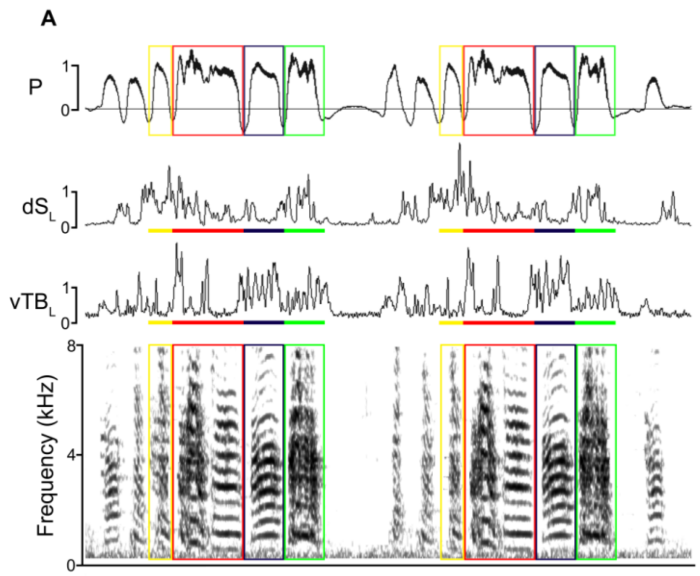
Can we use the activity controlling the periphery to inspect the CNS?



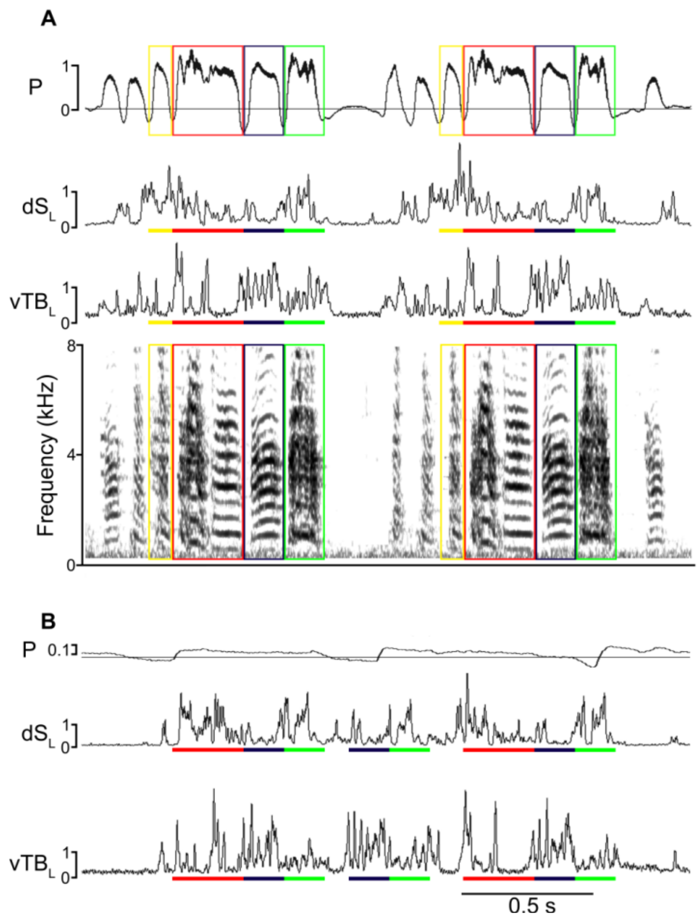
Once at the level of
Activity patterns controlling the
Avian vocal organ, **we can transduce Activity to behaviour.**

The question is:
Does the replay reach the muscles?

Patterns controlling
The periphery
During **song**



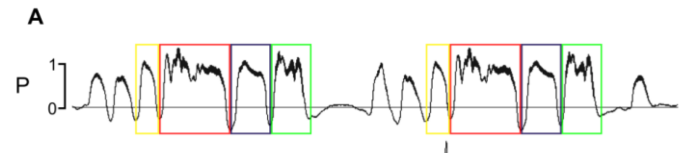
Patterns controlling
The periphery
During **song**



The patterns
during **sleep**

We can read the replay
From the muscles!

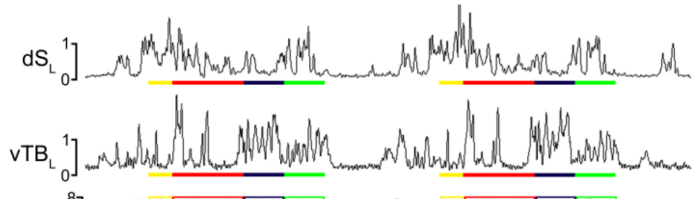
Patterns controlling
The periphery
During **song:**
Pressure



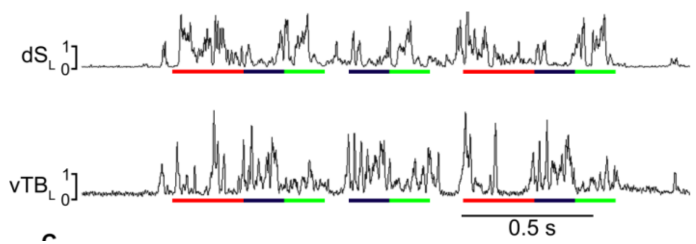
The patterns
during **sleep:**
Pressure

During the night,
The respiratory patterns
Stay at regular rates with
No significant fluctuations:
(That is the reason
there is no sound)

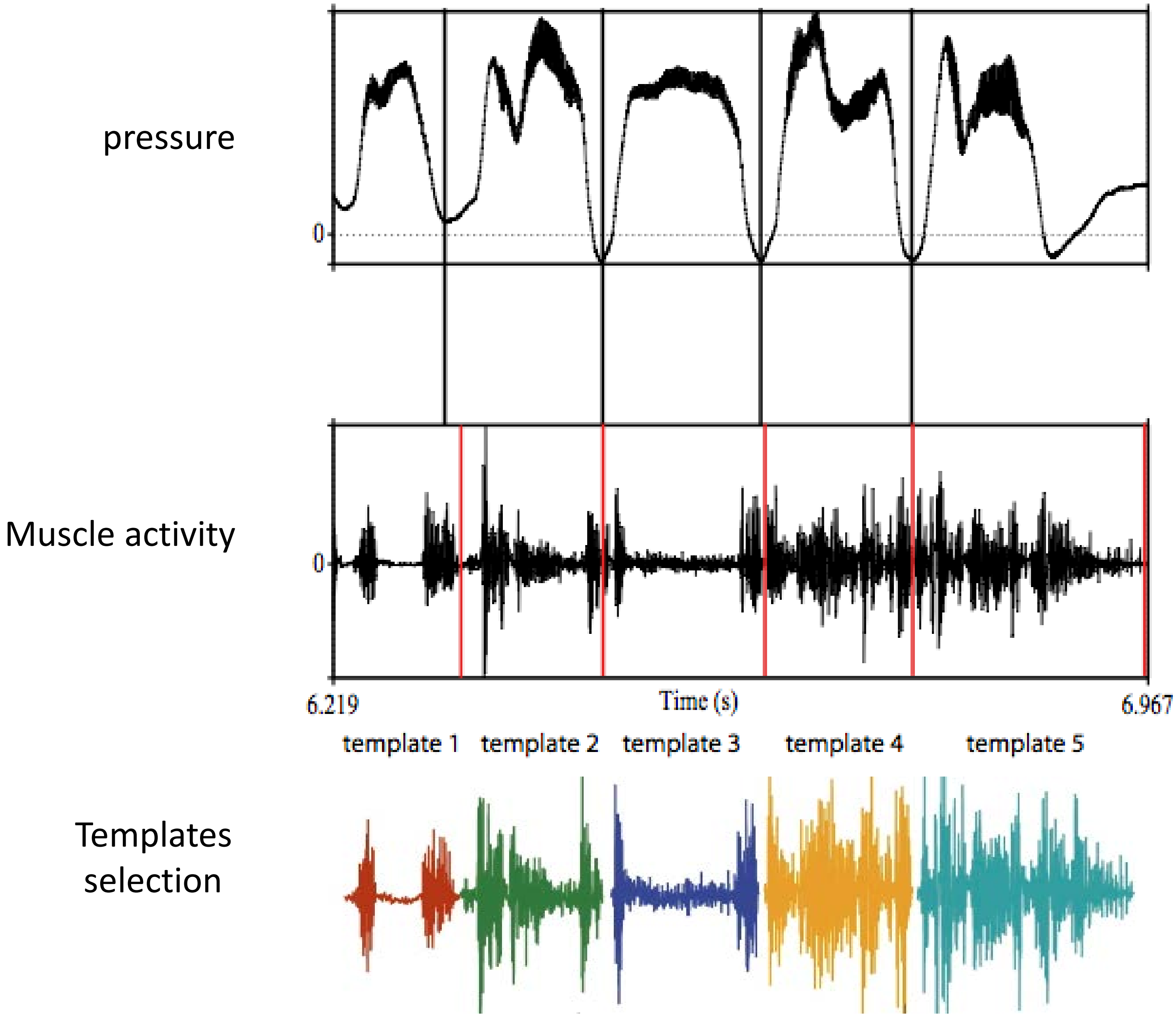
Patterns controlling
The perisphery
During **song:**
tension



The patterns
during **sleep:**
tension



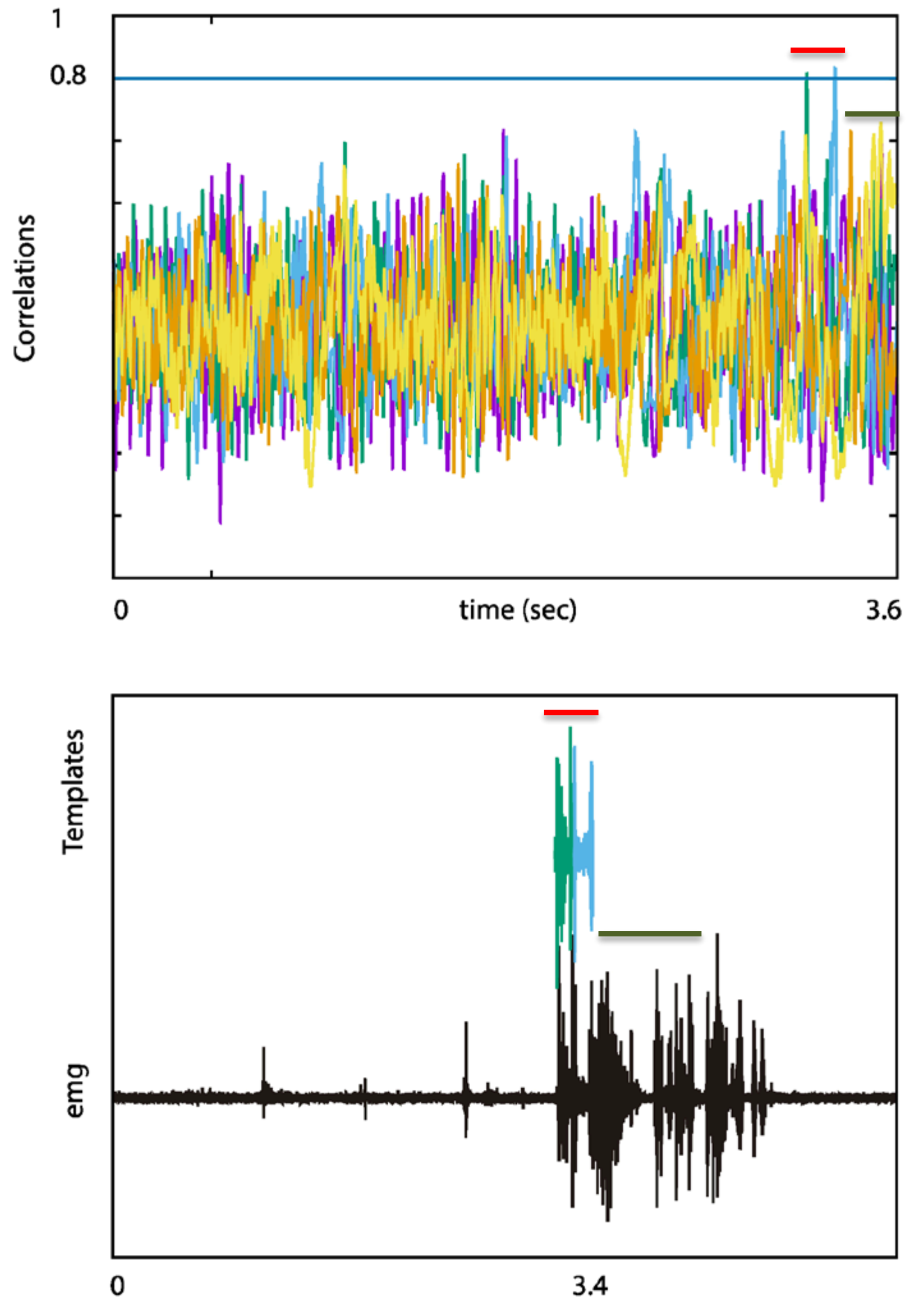
We can read the replay
In the syringeal muscles!


pressure
Muscle activity
Templates selection
0
0
6.219
Time (s)
6.967
template 1
template 2
template 3
template 4
template 5

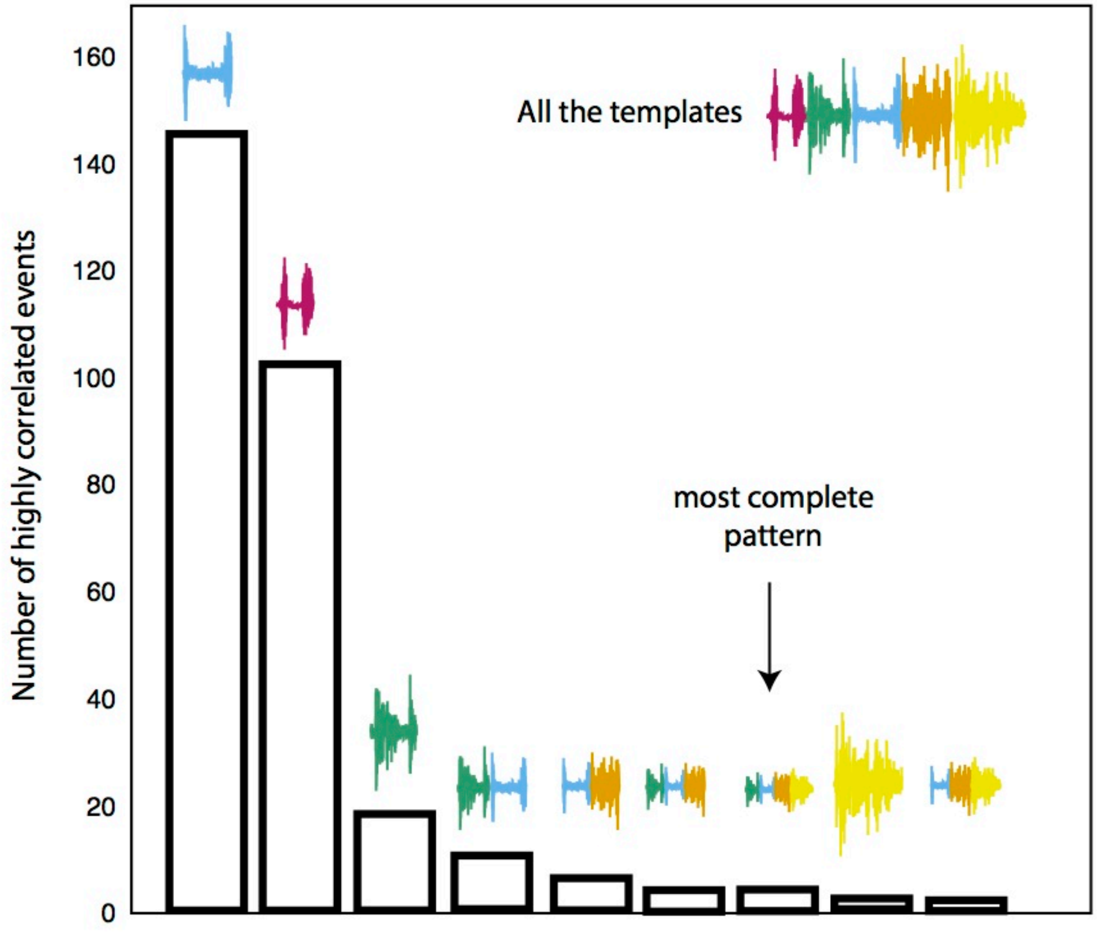
Identifying the patterns

High correlation

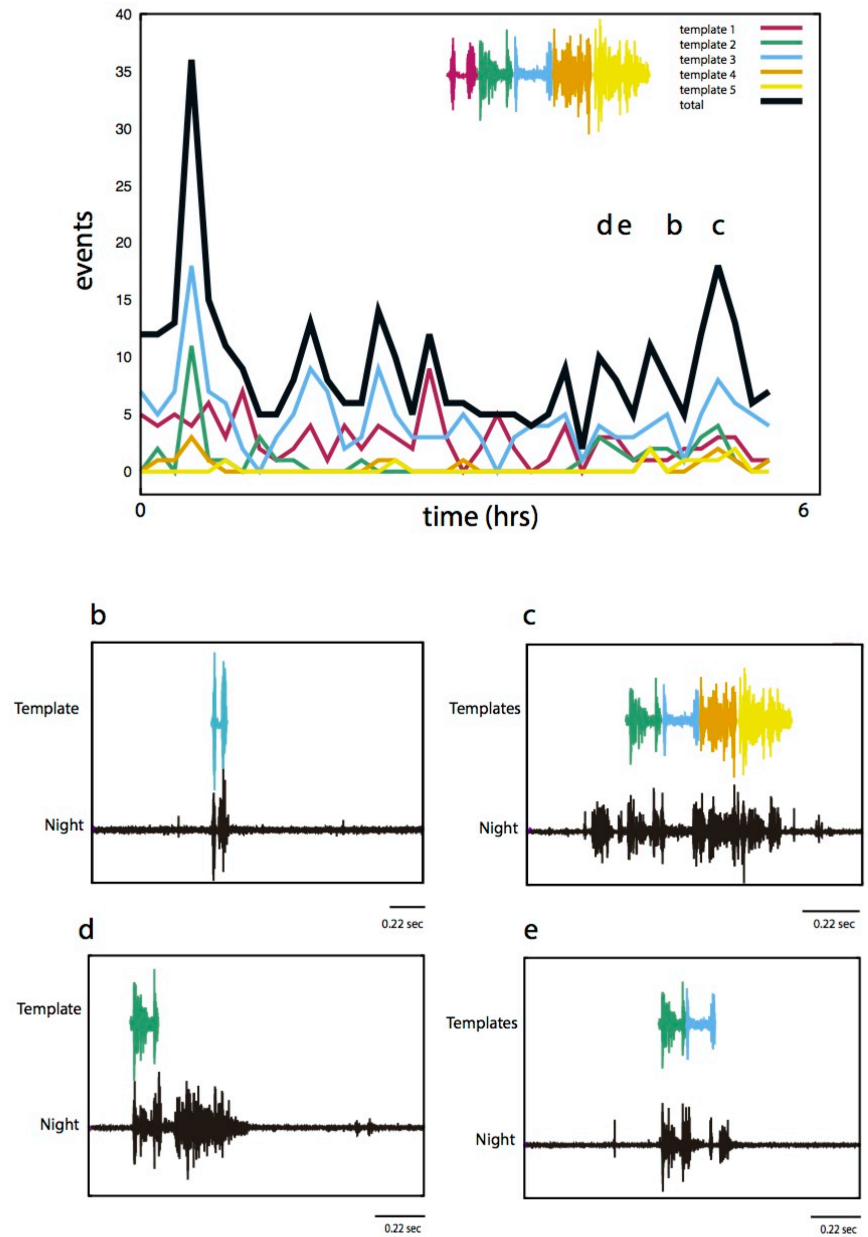
Low correlation



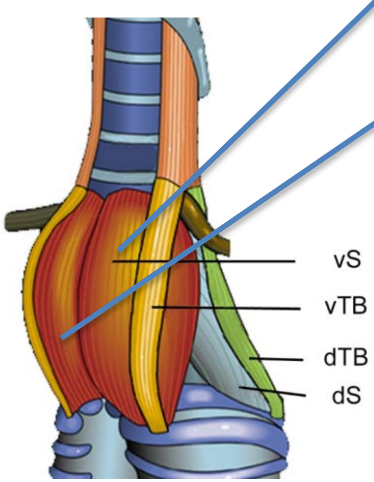
Distribution of the patterns during one night

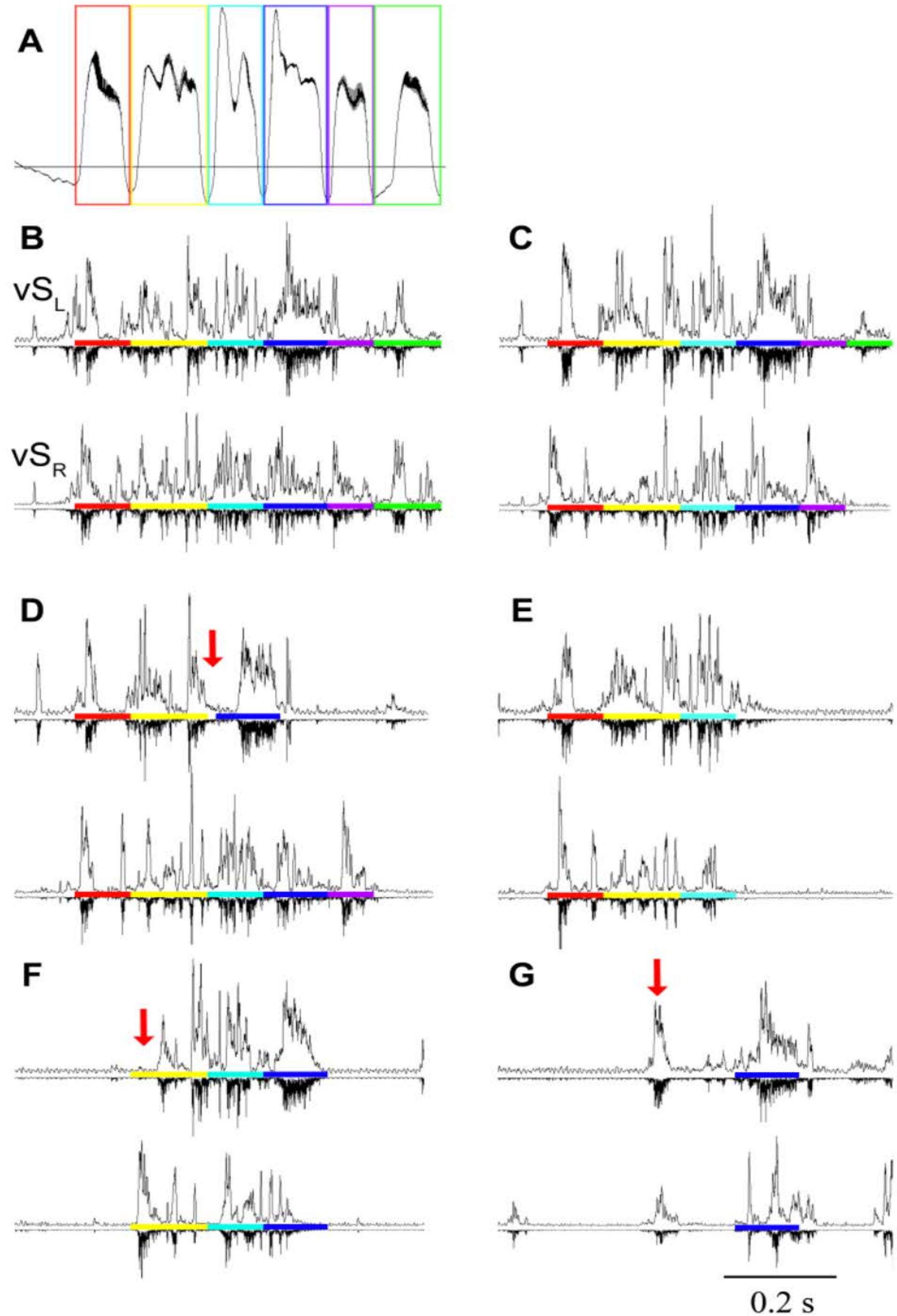


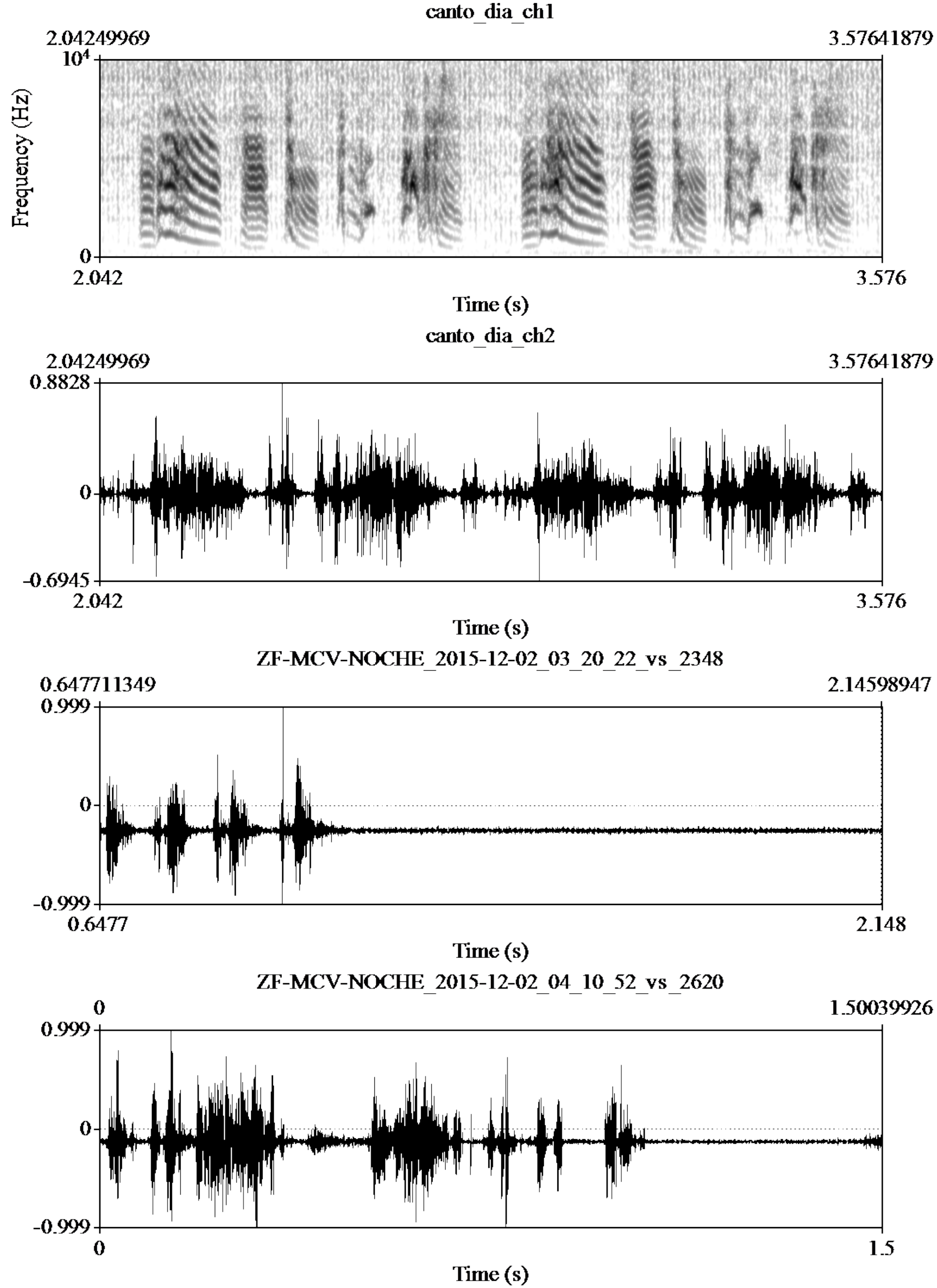
Time evolution of the
Highly correlated patterns



Bilateral crazyness

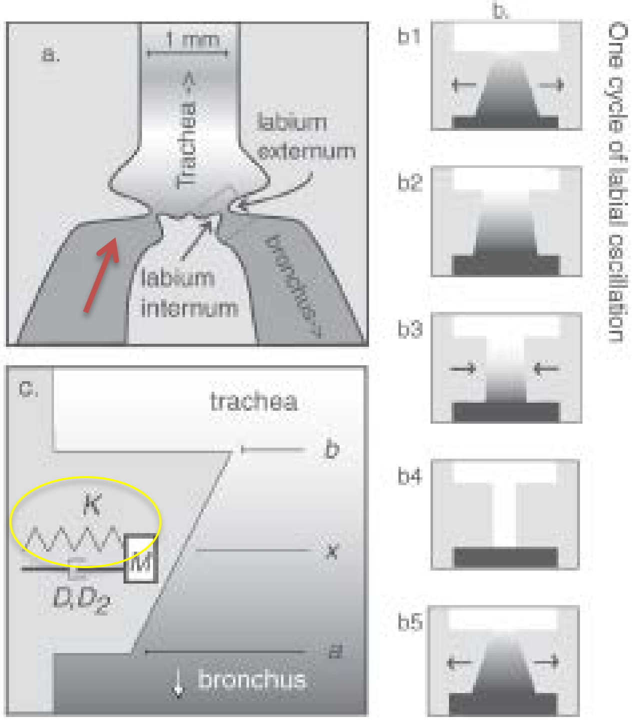






With Juan Doppler
And Agustin Sanchez

A technical issue before listening to dreams...

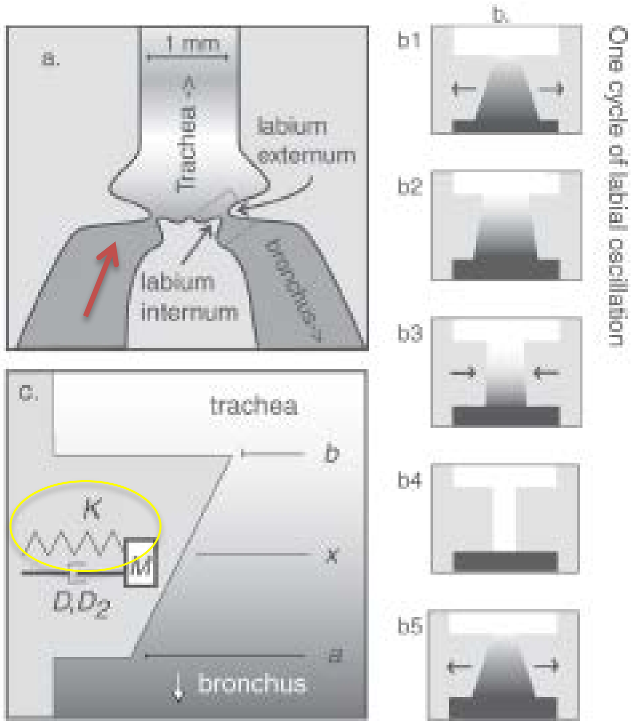


$$\frac{dx}{dt} = y,$$

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

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

A technical issue before listening to dreams…

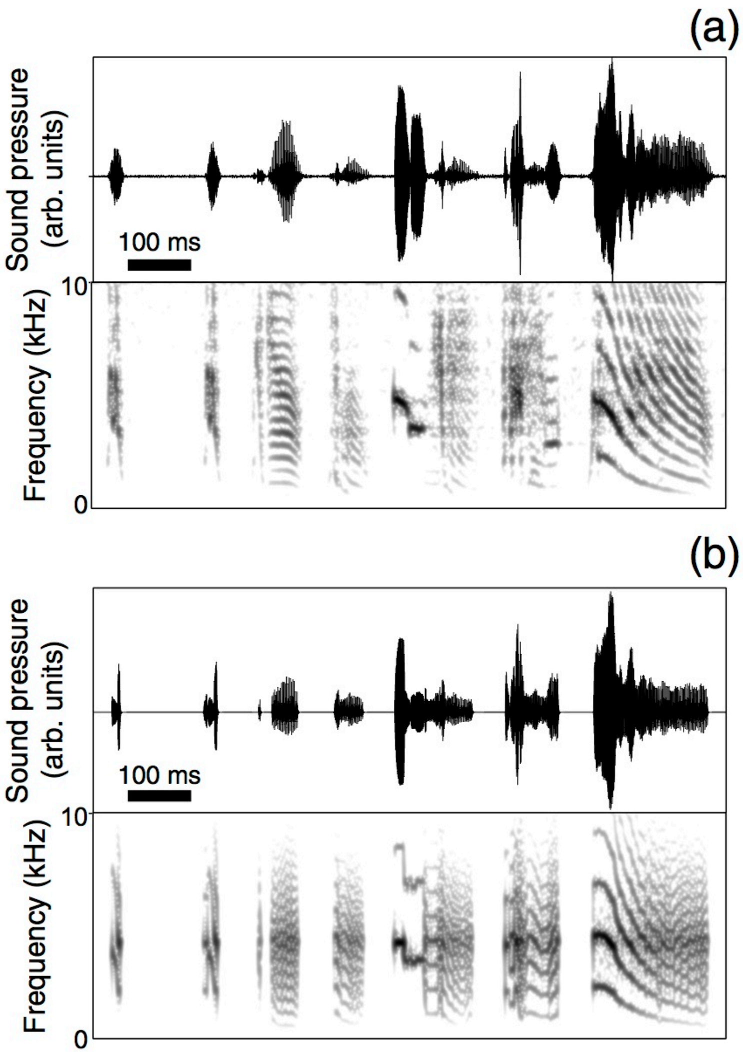


$$\frac{dx}{dt} = y,$$

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

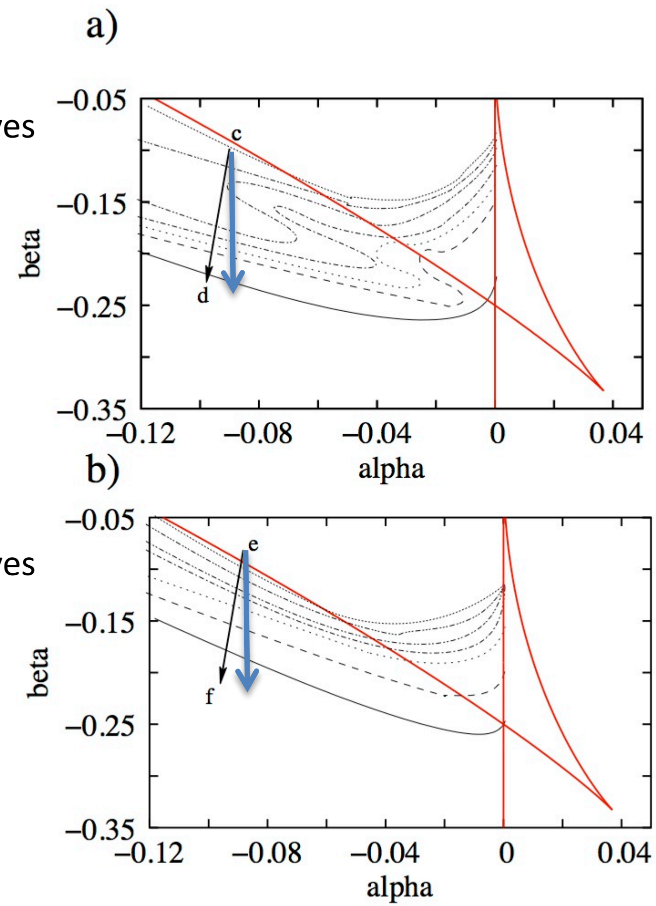
Only one parameter participates of the replay: the tension.

Is it a problem?



Iso-SCI curves (fixed OEC)

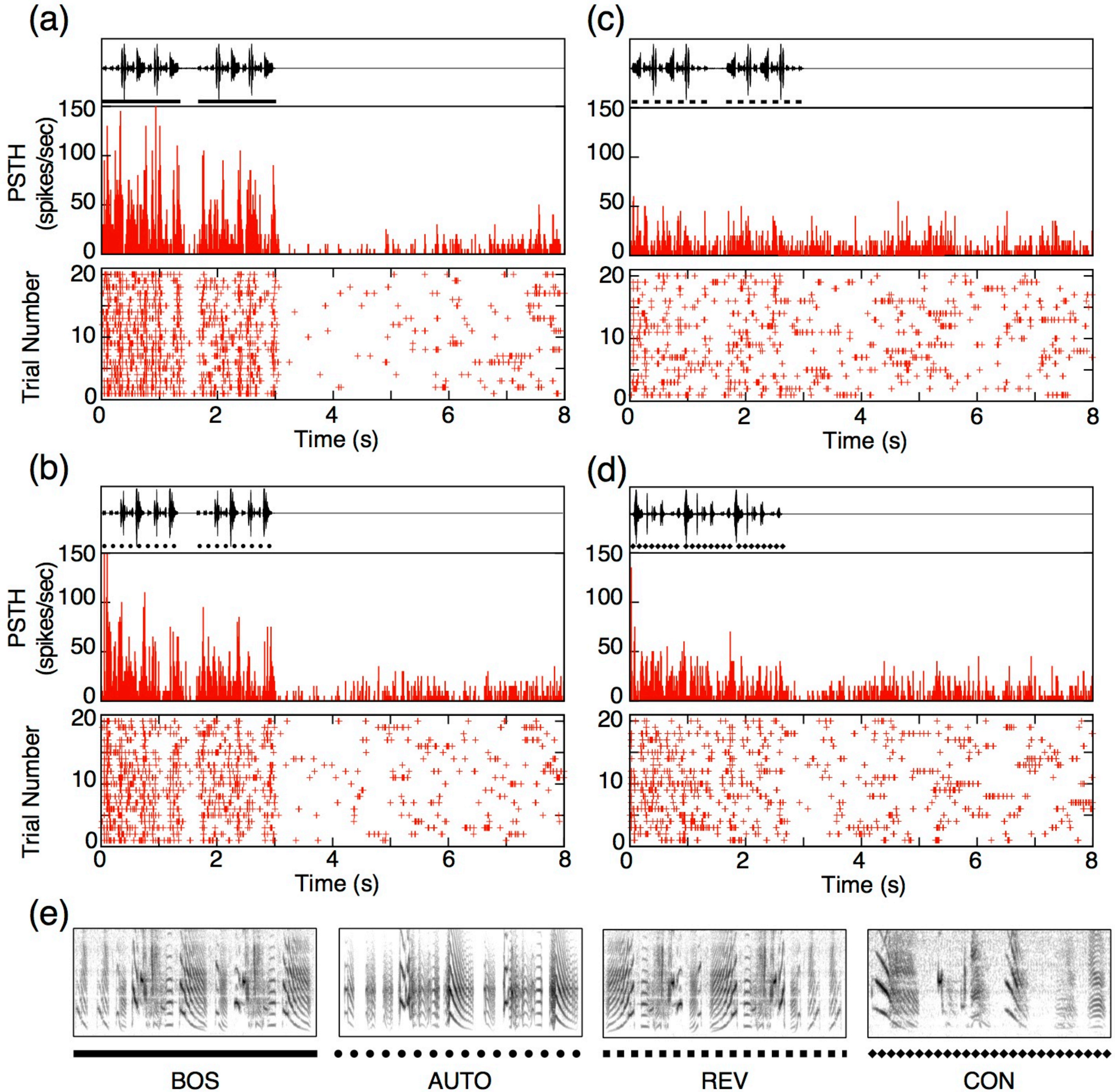
Iso-F curves



Instead of adjusting both parameters,
We can fit only tension and synthesize
Realistic songs

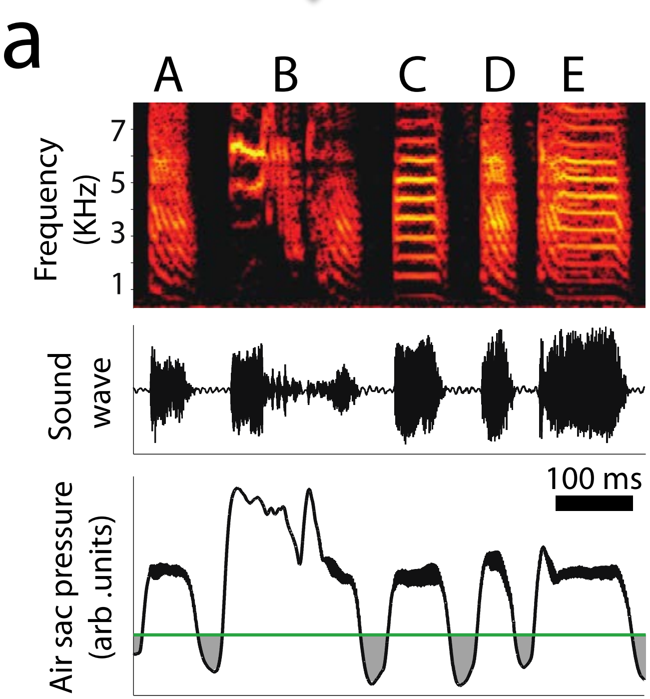
J. Neurophys. Boari et al. 2015

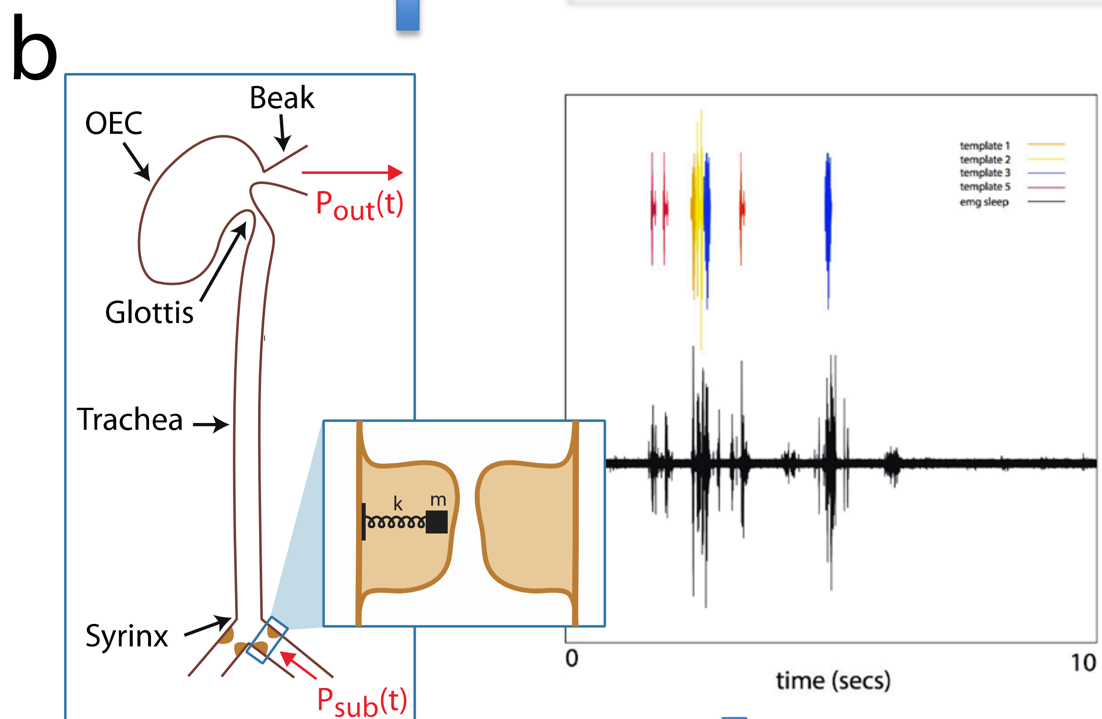
And we can still
Cheat the bird…



In order to listen to the “dreams”…

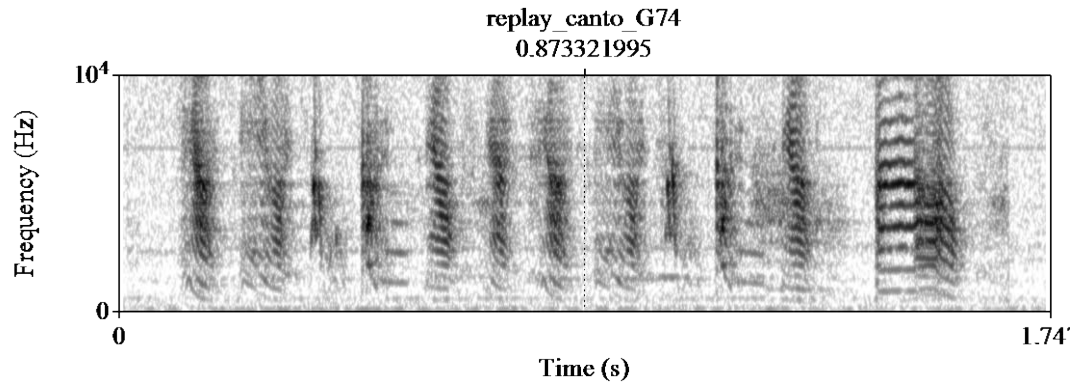
1. We measure tension



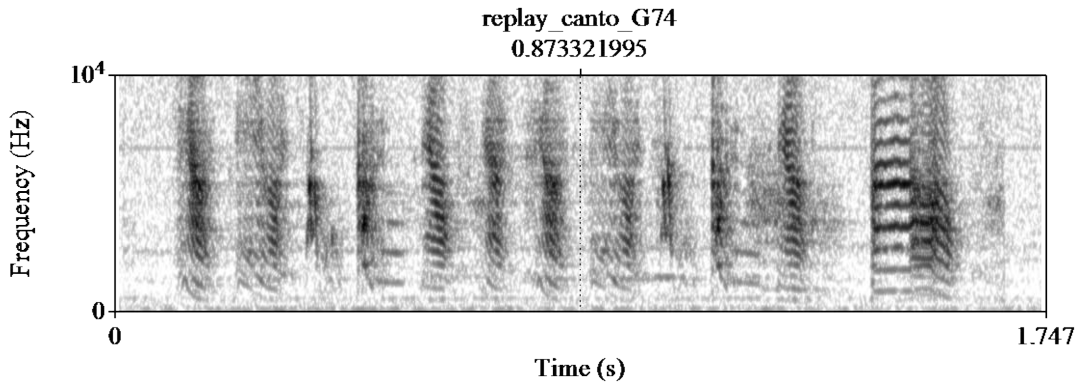


3. We synthesize song…

2. We integrate
The equations of
the model

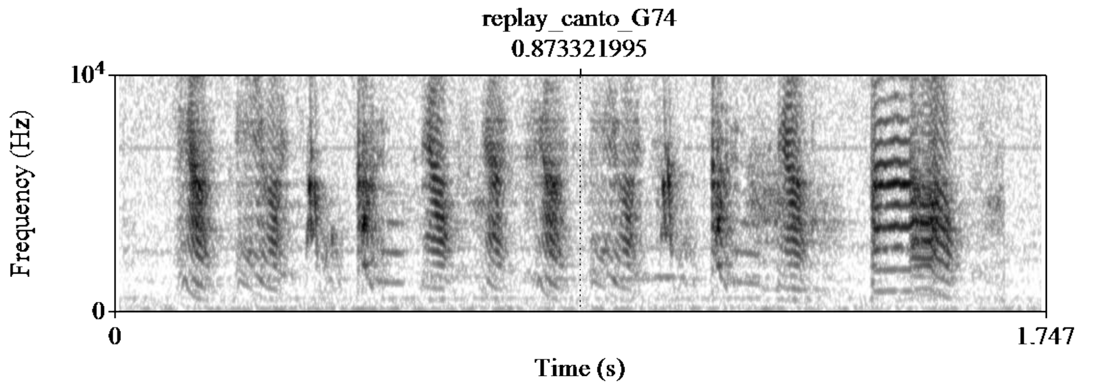


This is how a song sounds

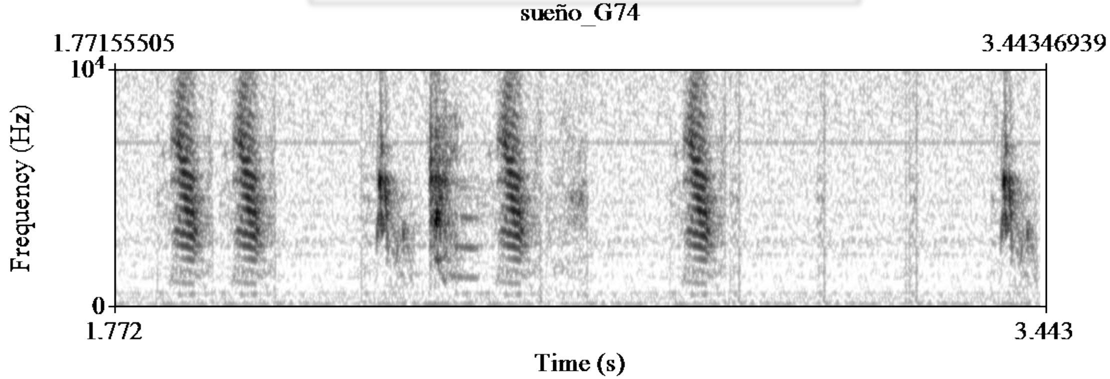


This is how a song sounds

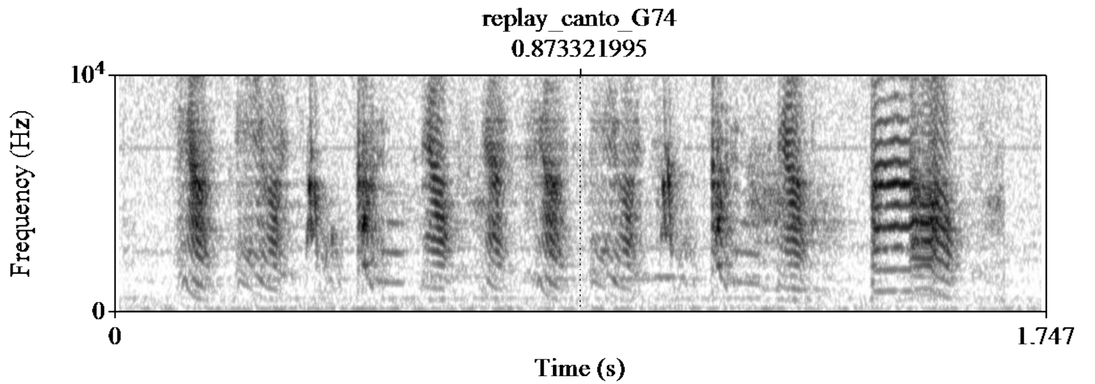
This is how a dream “sounds”

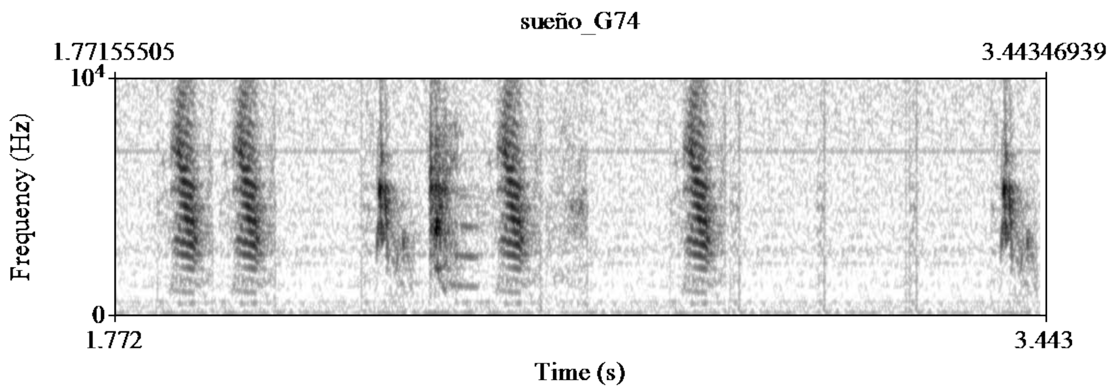


This is how a song sounds

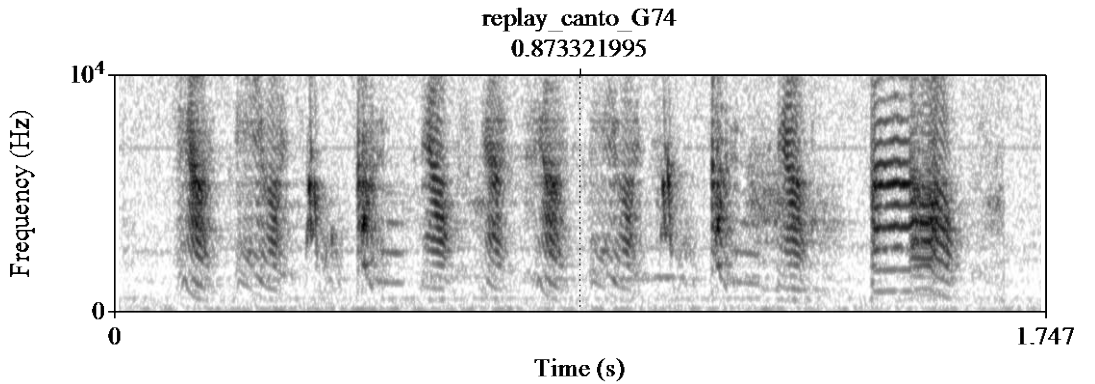


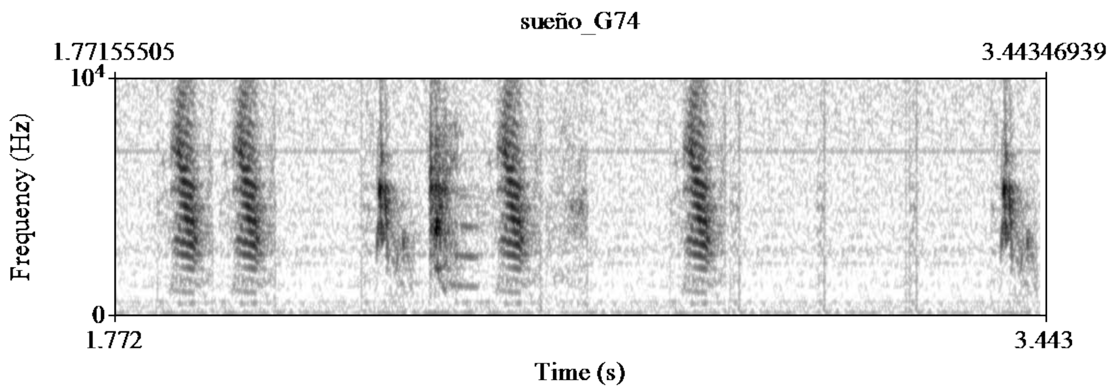
This is how a dream “sounds”





Syllables (or gestures) as natural units, altered order…
And many practices that do not correlate well with patterns used during song production





And how do these non so well correlated sound like? …
Work in progress !

Conclusions

1. Periphery as a tool to unveil what happens At the CNS.

2. Variability questions Replaying as a tool for Consolidation.

3. Existence of minimal Natural units. Gestures?

What are they? What Are they for?