Non linear dynamics of the glottic signal : perspectives

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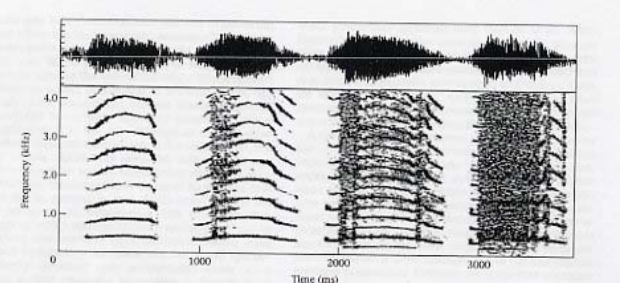
Non-linearities of the vocal signal

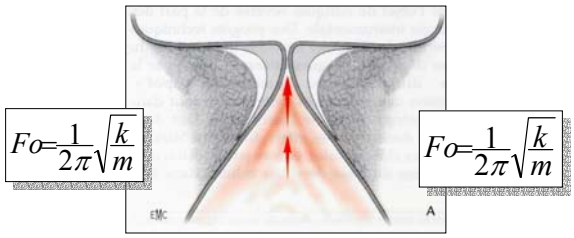
- Pathologic vocal signal (dysphonia)
- Infant cry
- Monkey calls (« coo »)
- Birdsongs
  - Biphonations
  - Subharmonics
  - Chaos



Fitch WT, Neubauert J, Herzel HP. *Calls out of chaos: the adaptative significance of nonlinear phenomena in mammalian vocal production*. Animal Behaviour, 2002;83:407-418

Clinical evidence of nonlinearity : synchronization of the vocal folds

- Normal vocal folds
- Paralytic dysphonia Adduction position (« medial »)

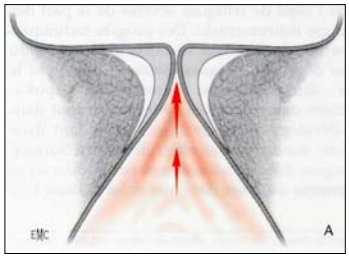


Synchronization is a highly nonlinear phenomenon
due to contact between the vocal folds and to the Bernouilli's effect

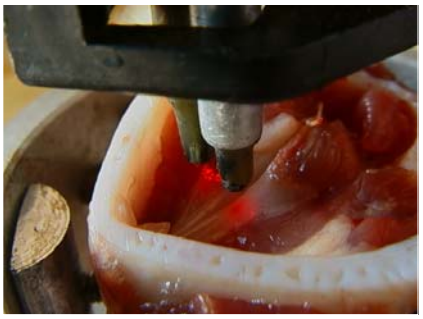
Theoretical physiological mechanism

- Trend to desynchronization
  - Degrees of freedom
    - degree of assymetry between left and right
    - Presence of a mass (polyp, nodule)
  - Subharmonics, noise and chaos

- Trend to synchronization
  - Contact during closure
  - Subglottic pressure

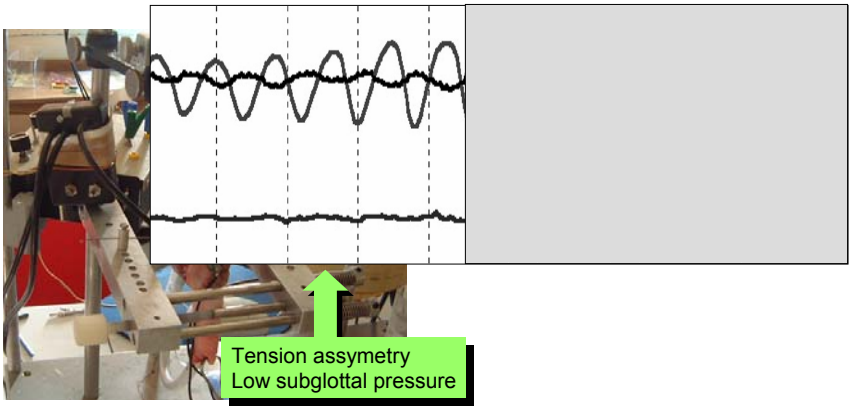


Experimental bench with laser-reflectometers

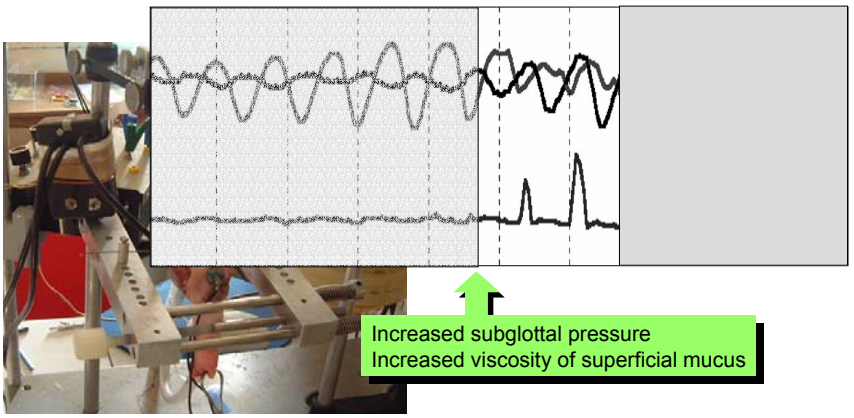


Ouaknine M, Garrel R, Giovanni A. *Separate detection of the vibration of the two vocal fold by optoreflectometry*. Folia Phoniatr Logop 2003

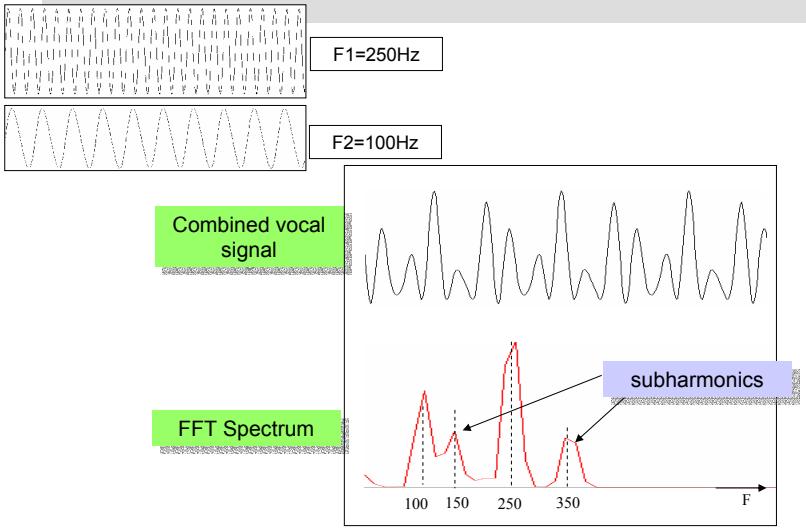
Experimental data in case of assymetry
1- no interaction



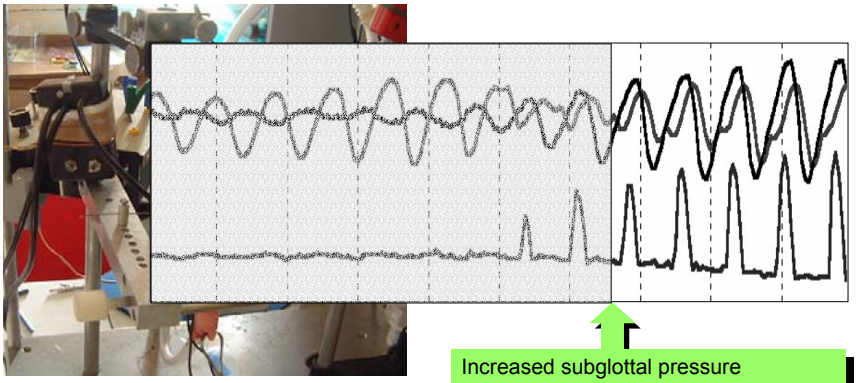
Experimental data in case of assymetry
2- interaction but no synchronization



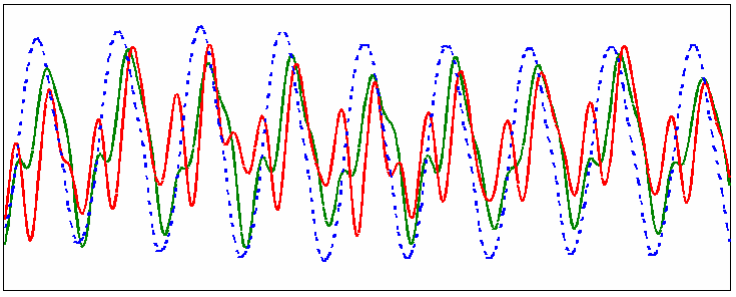
Interactions : non-linear combination



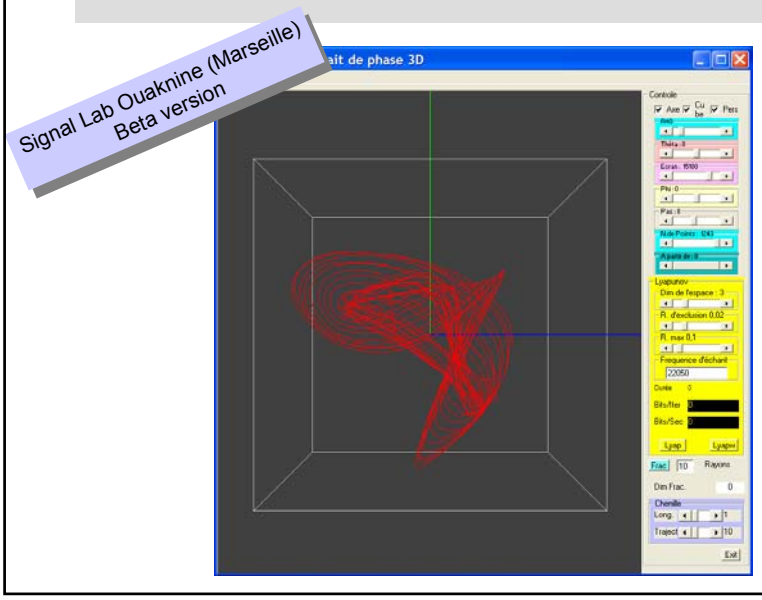
Experimental data in case of assymetry
3- interaction and synchronization 1/1



Strong interactions :
« blind » non-linear combination

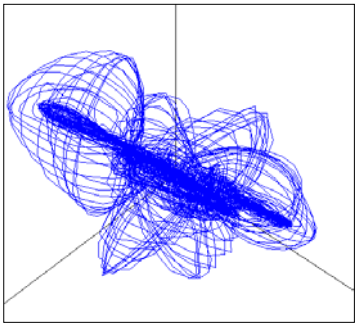


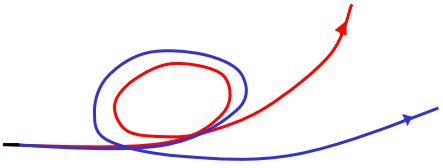
Principles of a Phase Portrait



Quantification of a Phase Portrait

- Fractal dimensions
  - Number of degrees of freedom
- Lyapunov Exponent
  - Divergence of initially close trajectories





Determination of Lyapunov exponent

After n iterations, error amplification factor would be:

$$\left|\frac{E_n}{E_0}\right| = \left|\frac{E_n}{E_{n-1}}\right|\left|\frac{E_{n-1}}{E_{n-2}}\right| \ldots \left|\frac{E_1}{E_0}\right|$$

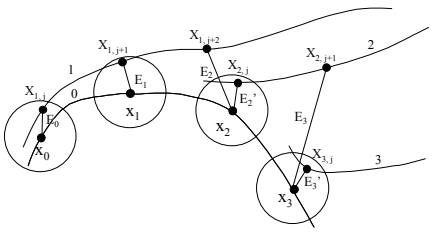
Lyapunov coefficient characterizes the logarithm of increase in relative error during iteration

$$\lambda = \frac{1}{n}\sum_{k=1}^{n} \log\left|\frac{E_k}{E_{k-1}}\right| \quad for \quad n \to \infty \quad ; E_0 \to 0$$

Giovanni A, Ouaknine M, Triglia JM. *Determination of largest Lyapunov Exponents of Vocal Signal: application to unilateral laryngeal paralysis.* J Voice, 1999;13:341-354

Problem : accurate determination of parameters

- Measuring Lyapunov exponent is still challenging because of several choices to be made before computing
  - Exclusion radius
  - Inclusion radius
  - Time delay
- Results can be dramatically different if choices are uncorrect



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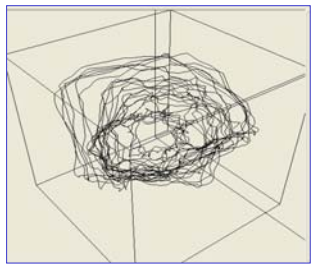
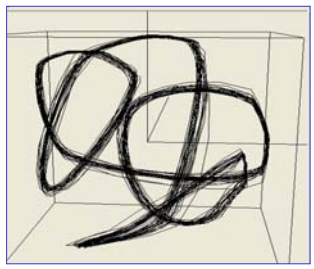
Handling non linear concepts

- Promising avenue for a new classification of dysphonic problems (see *Orlikoff & Baken's « Curing diagnosis »*) :
  - Divergence (Lyapunov exponents)
    - Glottis is made of several moreless coupled oscillators
    - Sensitivity to initial conditions is a way towards chaos
  - Convergence (attractors)
    - Loss of initial conditions (control) is a way towards stability
    - « Control » decreases the degrees of freedom
- Baken's lecture during next Voice Symposium in Boston (June 04)





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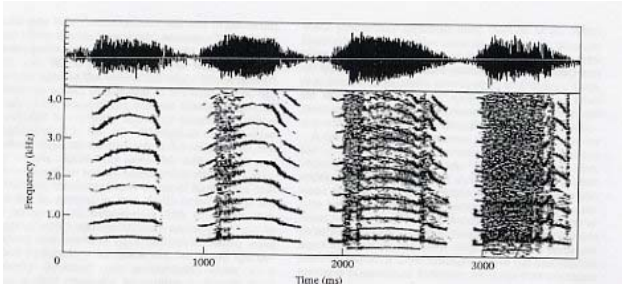

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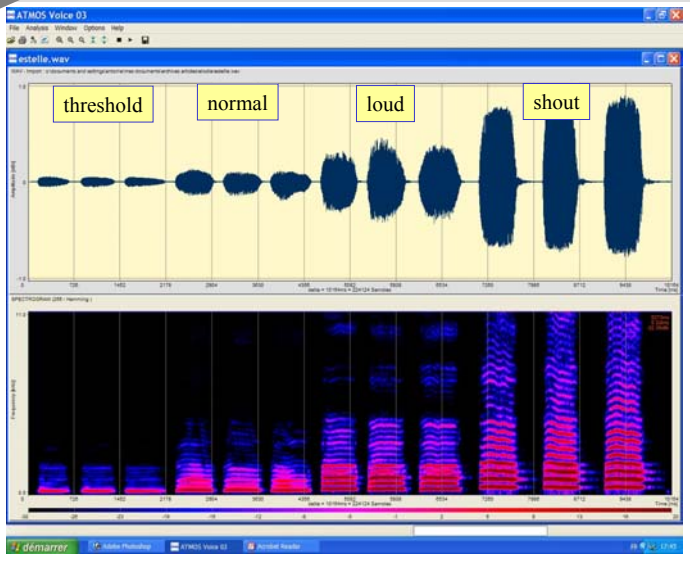
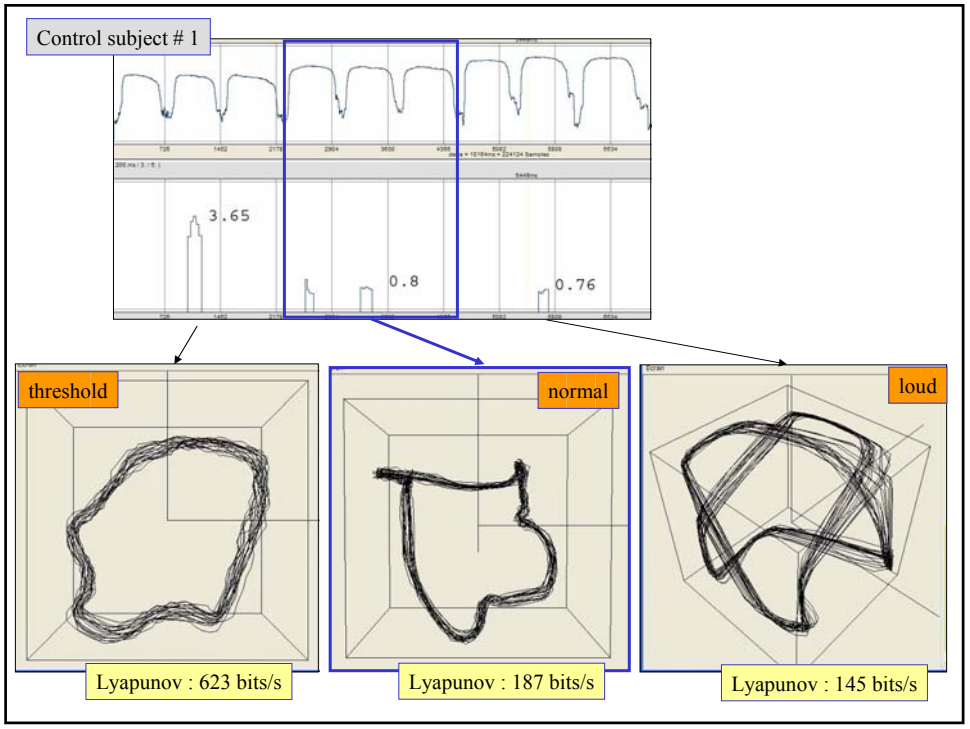
Clinical experiment

- Subject controls
  - Hypothesis : number of degrees of freedom is increased at phonatory threshold because of lack of « control »
  - Phase portrait : instability
  - Lyapunov exponent : increased
- Paralytic dysphonia
  - Hypothesis : number of degrees of freedom is decreased at a « louder » level of voicing if contact is obtained
  - Phase portrait : stability
  - Lyapunov exponent : decreased

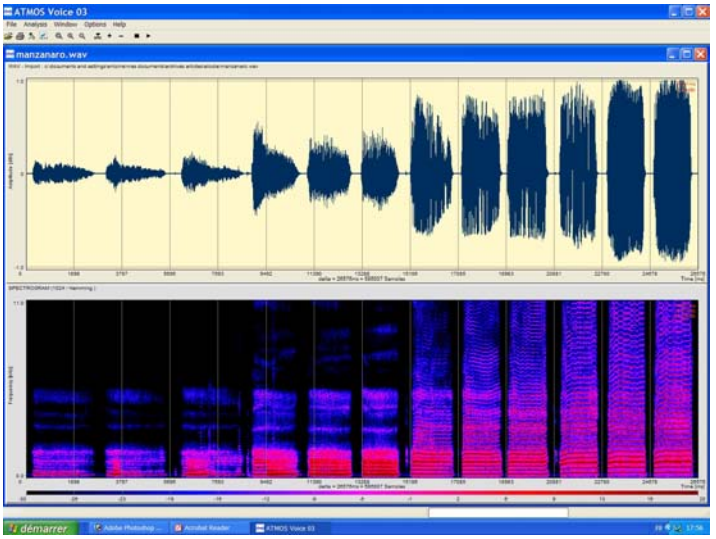
Control subject # 1

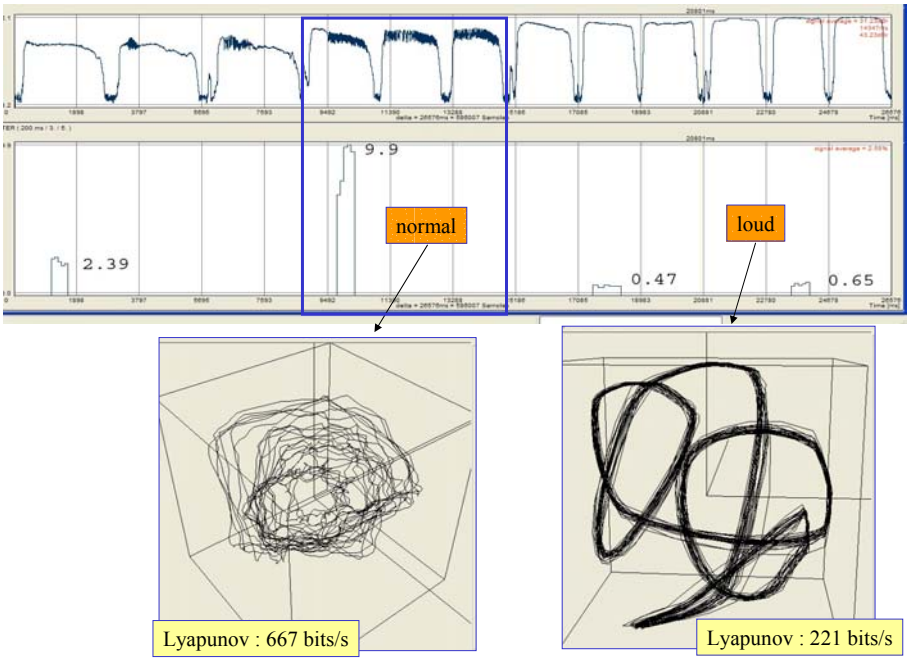
Atmos Voice 03
Beta version





Abduction vocal fold paralysis

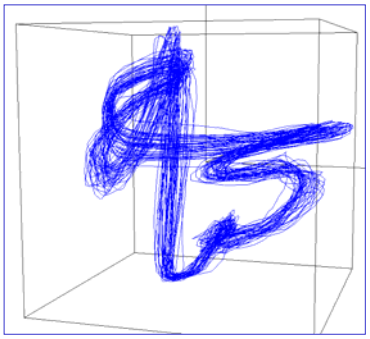




Conclusion
« Curing diagnosis »

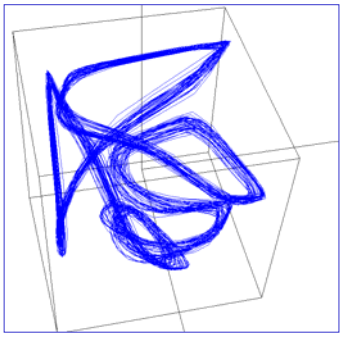
Polyp in a 43 old man
Sustained /a/

Comfortable pitch and intensity



Same patient
Sustained /a/

Comfortable pitch and intensity
during a session of speech therapy



Next Meeting of the

International Conference for

Voice Physiology and Biomechanics

ICVPB

http://icv2004.free.fr

Marseille, 18 – 20 August 2004