Synthesis of running speech for studying the mechanisms of speech production : the case of fricatives

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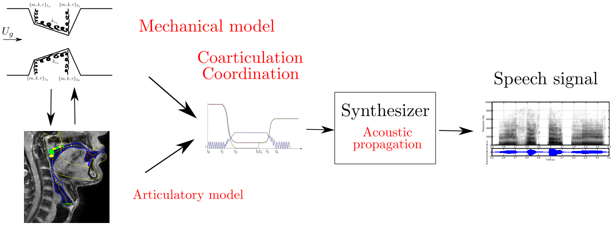
December, 2017

Speech synthesis (utterances), **complete** and **realistic**, based on purely acoustical model

Example of an articulatory synthesizer

Phonatory source



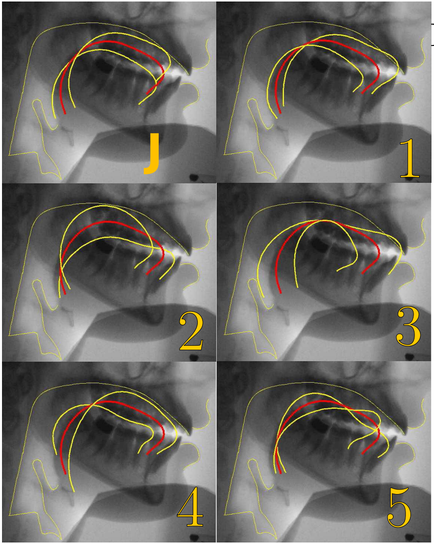
- Realistic acoustics
- Articulatory control

Vocal tract deformation

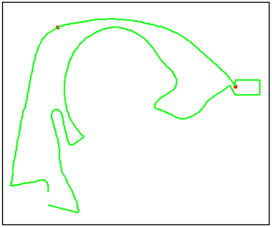
Applications: Medicine, audiovisual, language learning, text-to-speech...

Plan

Tongue modes

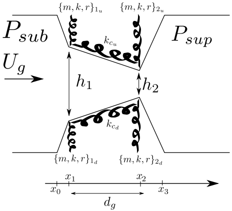


First mandible mode
and
5 first tongue modes



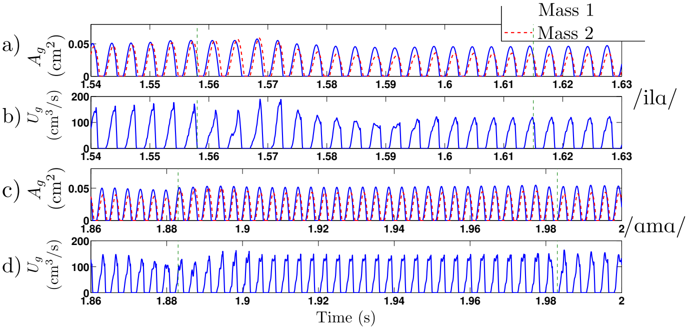
Complete model

Self-oscillating model of the vocal folds



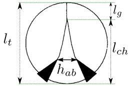
Lous *et al.* (1998)

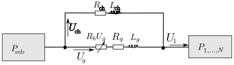
$$\mathbf{M\ddot{y}} + \mathbf{R\dot{y}} + \mathbf{Ky} = f(P_{sup}, P_{sub}, \theta_{geom})$$



Modified glottis model

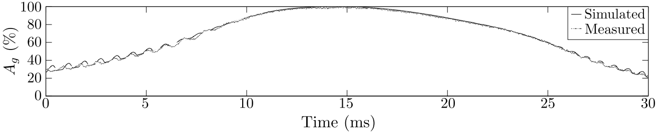
Partial glottal closure

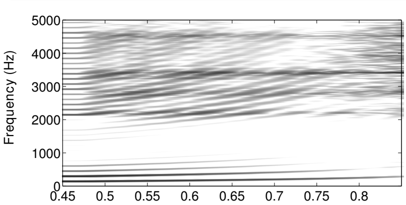


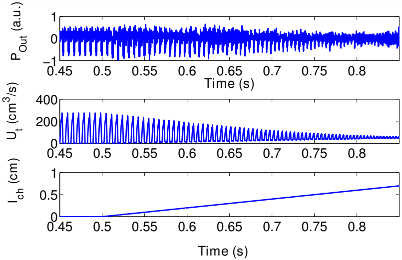


$$P_{sub} - P_1 = \Delta P_{close} + \frac{\partial}{\partial t}\left(L_1 U_{ch} + R_1 U_{ch}\right)$$

cf. Birkholz *et al.*, Interspeech 2011 or Elie and Laprie, ICASSP 2016

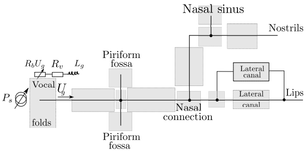






Waveguide network paradigm for speech synthesis

Modeling the vocal tract as a waveguide network[1]



$$\begin{bmatrix} \mathbf{f}^{(1)} \\ \mathbf{f}^{(2)} \\ \vdots \\ \mathbf{f}^{(\mathcal{N})} \end{bmatrix} = \begin{bmatrix} \mathbf{Z}^{(1)} & \mathbf{C}^T_{(1,2)} & \cdots & \mathbf{C}^T_{(1,\mathcal{N})} \\ \mathbf{C}_{(1,2)} & \mathbf{Z}^{(2)} & & \\ \vdots & & \ddots & \\ \mathbf{C}_{(1,\mathcal{N})} & & & \mathbf{Z}^{(\mathcal{N})} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{u}^{(1)} \\ \mathbf{u}^{(2)} \\ \vdots \\ \mathbf{u}^{(\mathcal{N})} \end{bmatrix}$$

Frication noise generation

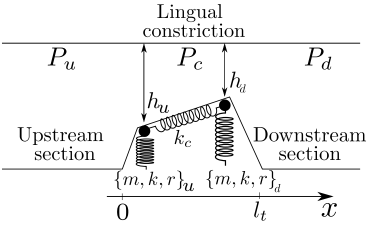
Pressure source is activated when the Reynolds number Re is above the threshold Re_c:

$$P_{n_i} = \max \left\{ 0, \xi w \left(Re^2 - Re_c^2 \right) \frac{U_{DC}^3}{a_{i-1}^{3/2}} \right\}, \quad Re \propto \frac{U_{DC}}{a_c}$$

[1] Elie and Laprie, *Speech Comm.*, 2016

Other oscillator: the alveolar trill

Self-oscillation model of the tongue tip[2]



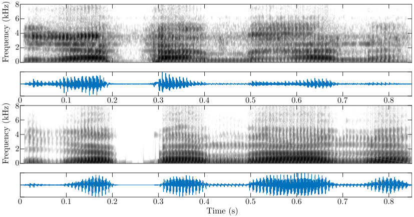
Alveolar trills

- Two-mass model, similar to the VF
- Included in the waveguide network, can be used with realistic VT geometries
- Possibility to consider the incomplete occlusion during contacts

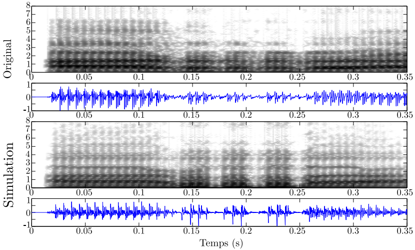
[2] Elie and Laprie, JASA, nov. 2017

A few examples

Il a pas mal (/i.la.pa.ma.lə/)



"ara" (/ara/)

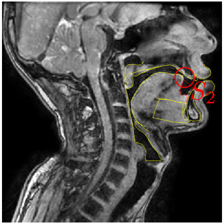


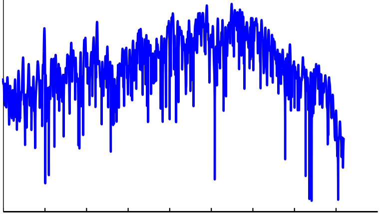
- Reproduction of acoustic features
- Access to quantities not accessible experimentally
- Control of the input articulatory/phonatory parameters

Plan

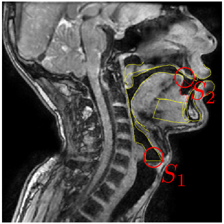
Different sources

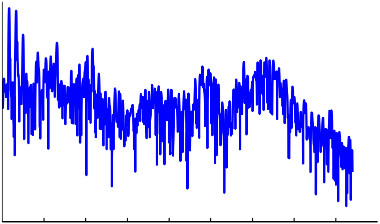
Voiceless Fricative



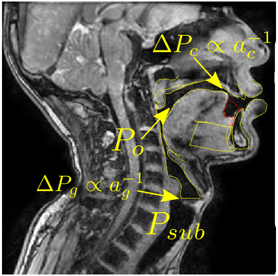


Voiced Fricative





Condition of noise source generation



$$P_{sub} \simeq \Delta P_g + \Delta P_c$$

$$P_o \simeq P_{sub} - \Delta P_g$$

At the glottal level

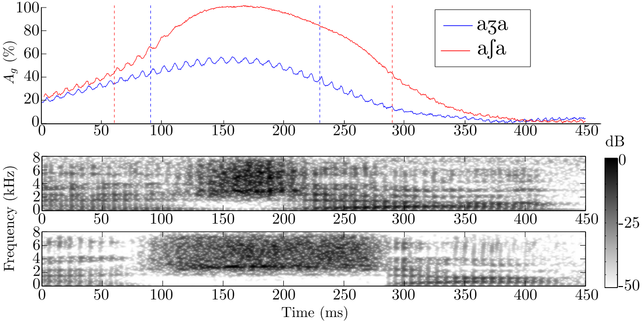
- sufficiently high airflow $\rightarrow$ the glottis should be open
- if voiced fricatives, glottis not totally abducted

At the supraglottal level

- narrow constriction
- high ΔP_c $\rightarrow$ high P_o $\rightarrow$ open glottis

Continuous coordination

Glottal opening in a VFV sequence

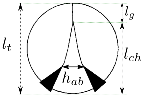


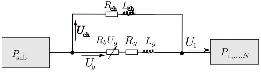
- a low-frequency component (partial abduction of the glottis)
- a high-frequency component (oscillation of the vocal folds)

→ What is the acoustic impact of the partial abduction of the vocal folds ?

Acoustic model of fricative production

Incomplete closure of the glottis

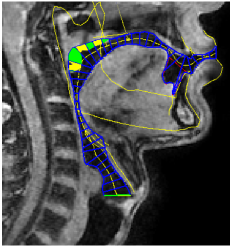


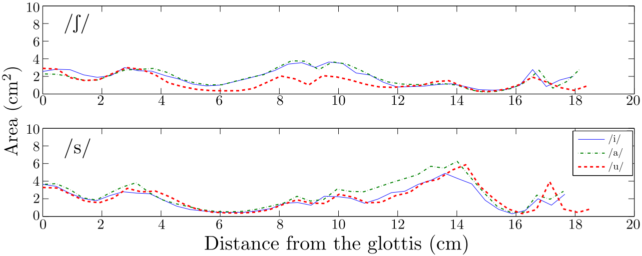


$$P_{sub} - P_1 = \Delta P_{close} + \frac{\partial}{\partial t}\left(L_1 U_{ch} + R_1 U_{ch}\right)$$

cf. Birkholz *et al.*, Interspeech 2011 or Elie and Laprie, ICASSP 2016

A set of area functions extracted from static MRI





→ Simulation of fricatives for different degrees of glottal abduction D_{ab}

Acoustic features

Voicing quotient (VQ)

Quantify the amount of voicing

$$VQ = \frac{\text{Energy of the periodic component}}{\text{Energy of the mix signal}}$$

$VQ = 0 \rightarrow$ voiceless signal, $VQ = 100\% \rightarrow$ purely voiced signal

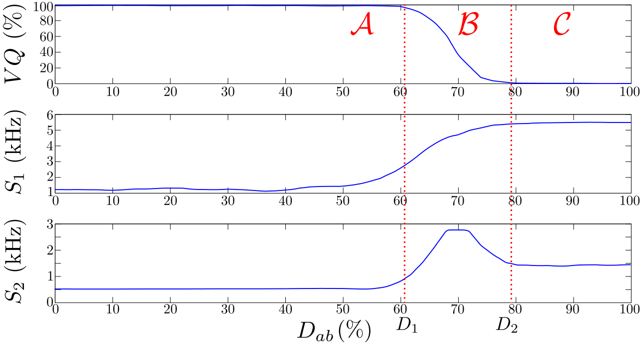
Spectral centroid (S_1)

Balance between low and high frequency components
low $S_1 \rightarrow$ mainly low frequency, high $S_2 \rightarrow$ mainly high frequency

Spectral spread (S_2)

Variance of the spectral distribution
low $S_2 \rightarrow$ narrow band spectrum, high $S_2 \rightarrow$ broad band spectrum

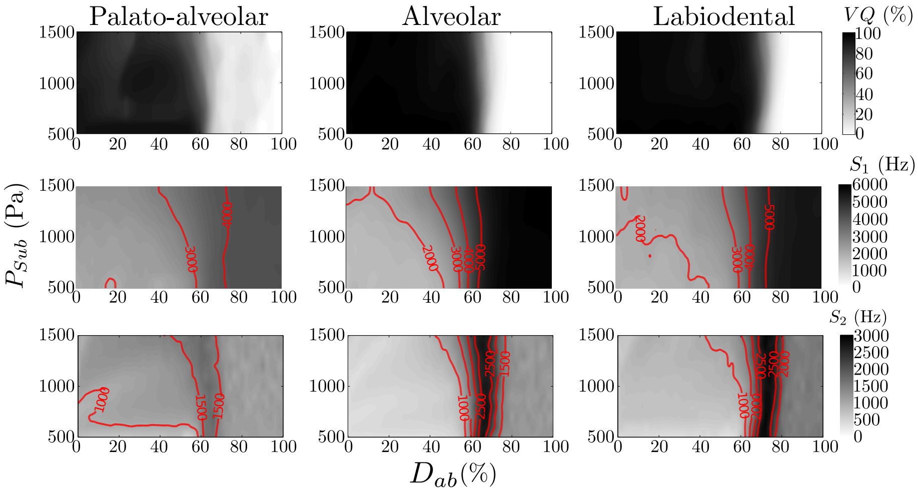
Typical examples



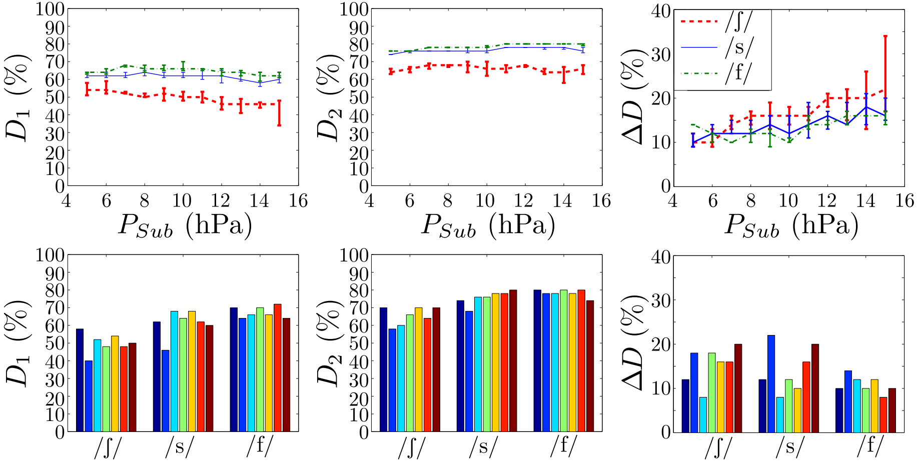
3 regimes of production:

- $\mathcal{A}$ ($D_{ab} < D_1$): low frication noise
- $\mathcal{B}$ ($D_1 < D_{ab} < D_2$): frication noise and voice have similar energy
- $\mathcal{C}$ ($D_{ab} > D_2$): voiceless signal

Acoustic features as a function of P_{sub} (vowel context: /a/)

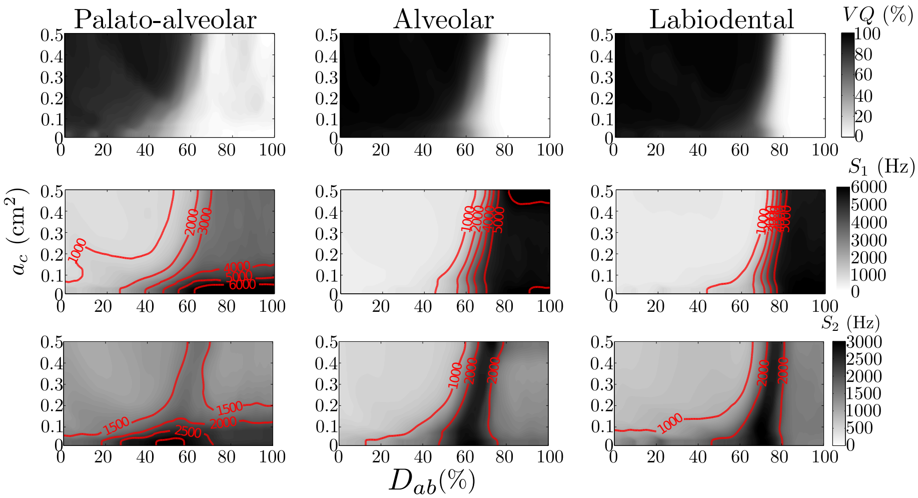


Minimal lengths as a function of P_{sub}

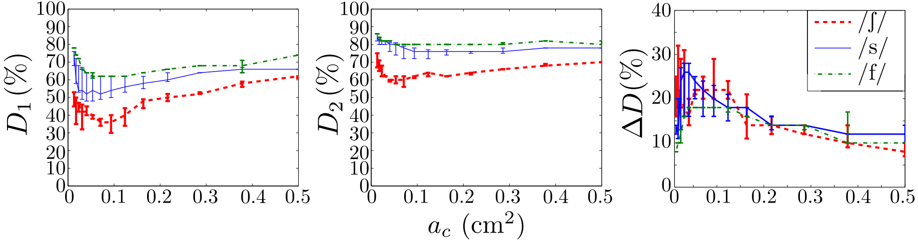


- P_{sub} modifies D_1 and D_2: $D \searrow$ when $P_{sub} \nearrow$
- P_{sub} modifies ΔD: $\Delta D \nearrow$ when $P_{sub} \nearrow$

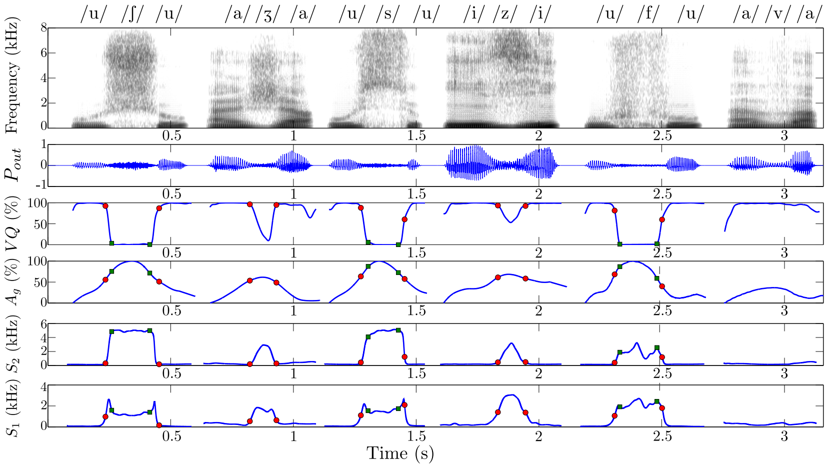
Acoustic features as a function of a_c (vowel context: /a/)



Minimal lengths as a function of a_c



Experiments confirm the observations



Possible strategies for fricative production: hypothesis

Voiceless fricatives

- $\mathcal{A} \rightarrow \mathcal{B} \rightarrow$ sustained $\mathcal{C} \rightarrow \mathcal{B} \rightarrow \mathcal{A}$: easy ($\mathcal{C}$ is stable)

$\rightarrow$ voiceless fricatives are longer to maximize the ratio $\mathcal{C}/\mathcal{B}$

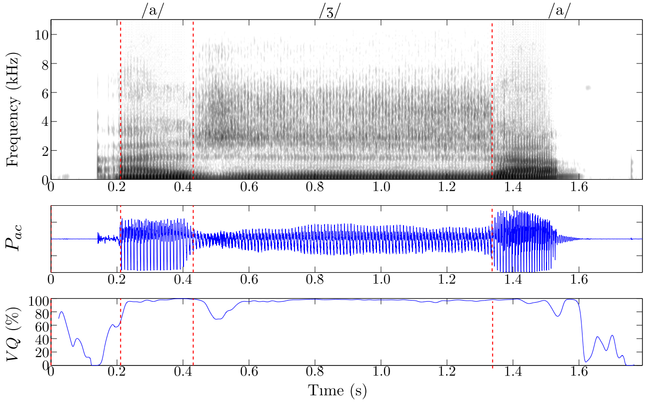
Voiced fricatives

- $\mathcal{A} \rightarrow$ sustained $\mathcal{B} \rightarrow \mathcal{A}$: risky ($\mathcal{B}$ too unstable)
- $\mathcal{A} \rightarrow \mathcal{A}/\mathcal{B}$ boundary $\rightarrow \mathcal{A}$: favors voicing
- Very short $\mathcal{A} \rightarrow \mathcal{B} \rightarrow \mathcal{A}$ or $\mathcal{A} \rightarrow \mathcal{B} \rightarrow \mathcal{C} \rightarrow \mathcal{B} \rightarrow \mathcal{A}$ sequence: maximize proportion of $\mathcal{B}$ over the fricative segment

$\rightarrow$ voiced fricatives are shorter to avoid instability

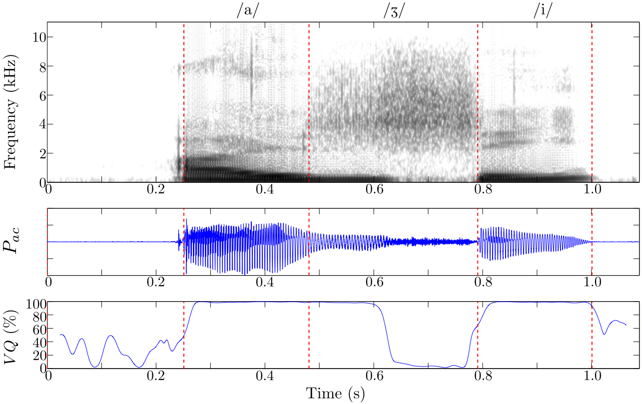
What if voiced fricatives are exaggeratedly longer ?

Speakers usually prefer sustaining regime $\mathcal{A}$ for longer fricatives (Ex. 1)



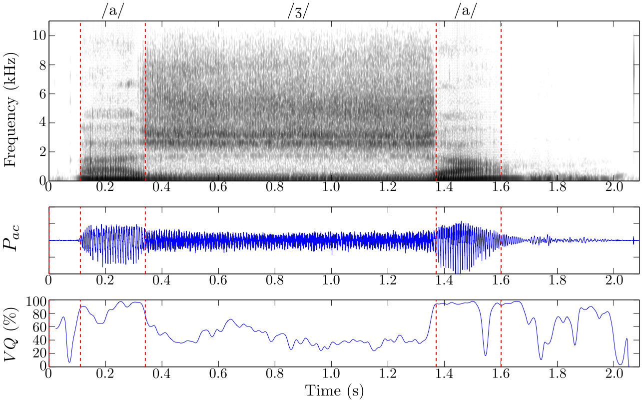
What if voiced fricatives are exaggeratedly longer ?

There may be some "devoicing" incidents (Ex. 2)



What if voiced fricatives are exaggeratedly longer ?

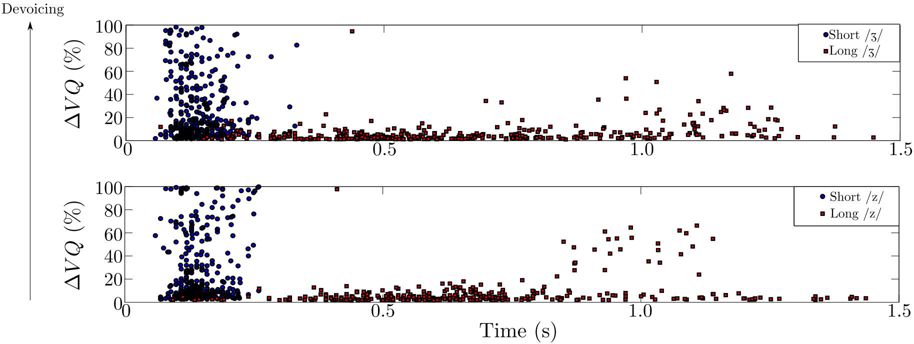
But a (very) few speakers sustains $\mathcal{B}$! (Ex. 3, study in progress)



First results

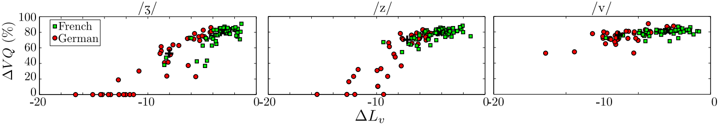
Corpus of 15 speakers (/VFV/ pseudowords)

Short fricatives *vs.* long fricatives

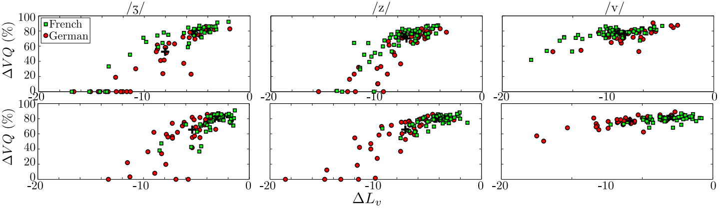


Another investigation in progress: Influence of language

German speakers devoice their fricatives more than French speakers



Learners of both German and French include these differences in the learning process



IFCASL Database: Fauth *et al.* Designing a bilingual speech corpus for French and German language learners: a two-step process. In LREC-9th Language Resources and Evaluation Conference, 2014

Plan

Some conclusions on the production of fricatives

Simulations have evidenced the role of the glottal opening in fricatives

- It controls regimes of production
- The simultaneous presence of noise and voicing is unstable

→ Several articulatory strategies for producing voiced fricatives

Possible reasons for using different strategies

- Only physiological
- Phonological context
- Contextual (sociolinguistic, prosodic. . .)

Future investigations

- Check speaker variability
- Influence of language
- Role in prosody

→ Integration into running speech synthesis

References of our works

Articulatory synthesis

- Elie B., and Laprie Y. "Extension of the single-matrix formulation of the vocal tract: consideration of bilateral channels and connection of self-oscillating models of the vocal folds with a glottal chink". Speech Comm. 82, pp. 85–96 (2016).
- Elie B., and Laprie Y. "Copy-synthesis of phrase-level utterances". EUSIPCO, Budapest, pp 868–872 (2016).
- Elie B., and Laprie Y. "A glottal chink model for the synthesis of voiced fricatives". ICASSP, Shanghai, pp 5240–5244 (2016).

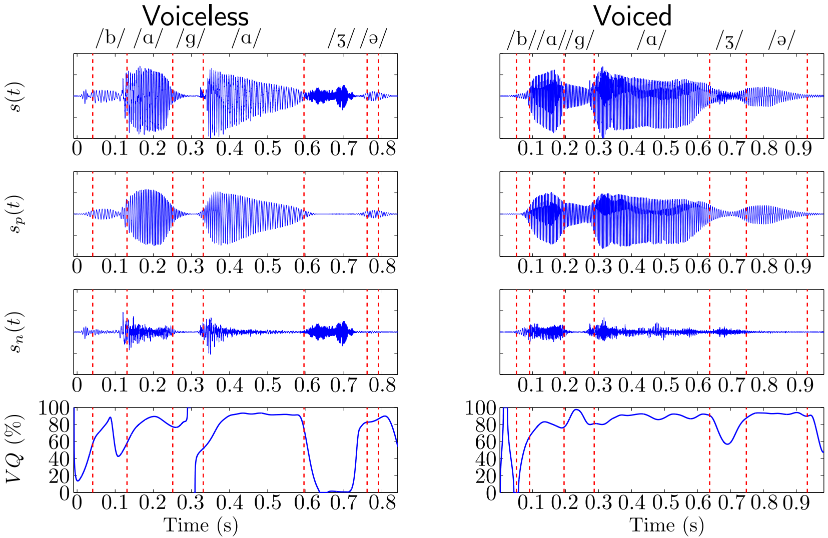
Production of fricatives

- Elie B., and Laprie Y. "Acoustic impact of the gradual glottal abduction degree on the production of fricatives: A numerical study ". J. of the Acoustical Society of America 142(3), pp. 1303–1317 (2017).
- Elie B., and Laprie Y. "Glottal opening and strategies of production of fricatives". Interspeech, Stockholm, pp. 206–209 (2017).
- Ghosh, Sucheta, et al. "L1-L2 Interference: The case of final devoicing of French voiced fricatives in final position by German learners." Interspeech (2016).

Trill production

- Elie B., and Laprie Y. "Simulating alveolar trills using a two-mass model of the tongue tip". J. of the Acoustical Society of America 142(5), pp. 3245–3256 (2017).

Example of French native speakers uttering final voiced fricatives



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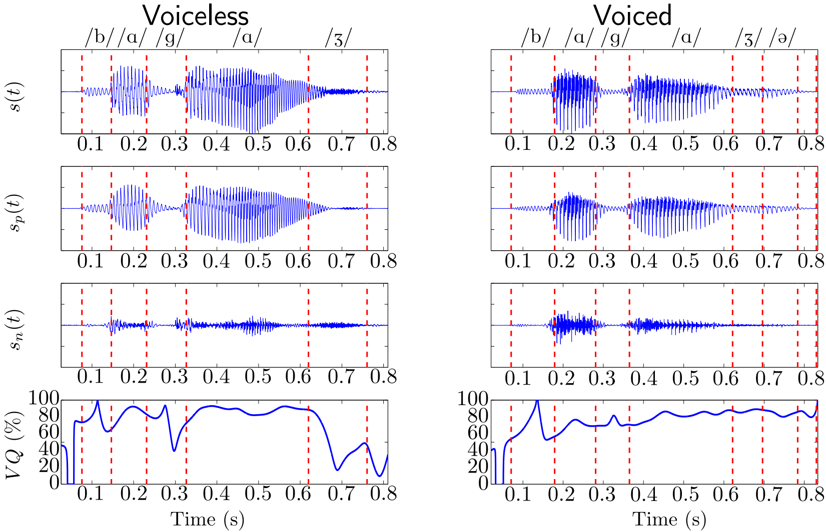
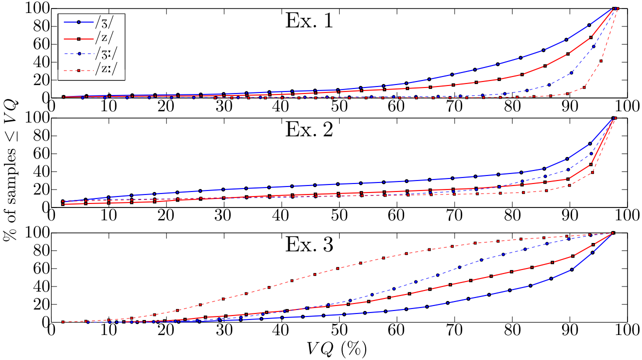


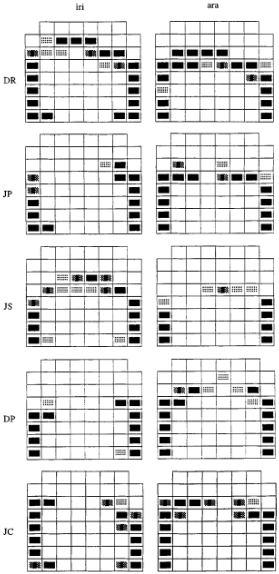
What if voiced fricatives are exaggeratedly longer ?

Cumulative histograms



Occurrence of LP contacts: some answers

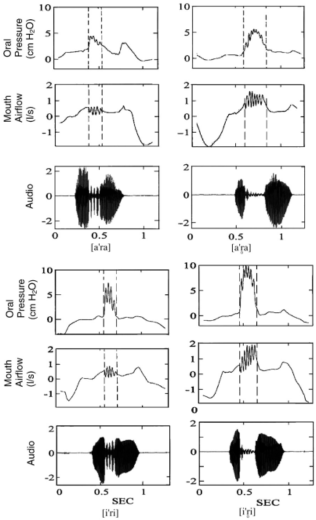
Data from Recasens and Pallarès



- Variability across speakers: some almost never make LP contacts
- Variability intra-speaker

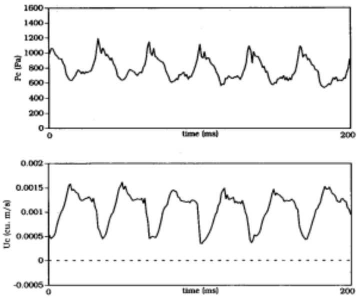
Air flow measurements

Data from Solé and McGowan



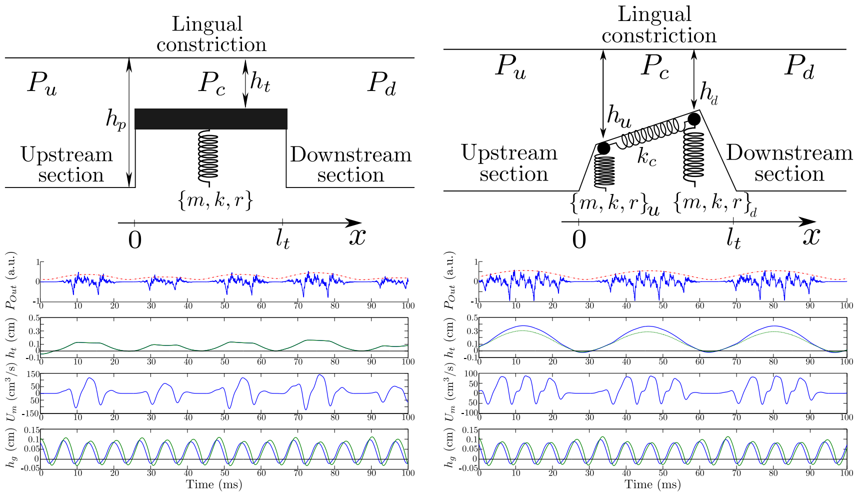
- DC component of the airflow: incomplete closure of the vocal tract ?
- are there LP contacts ?

From McGowan, on voiceless trills:



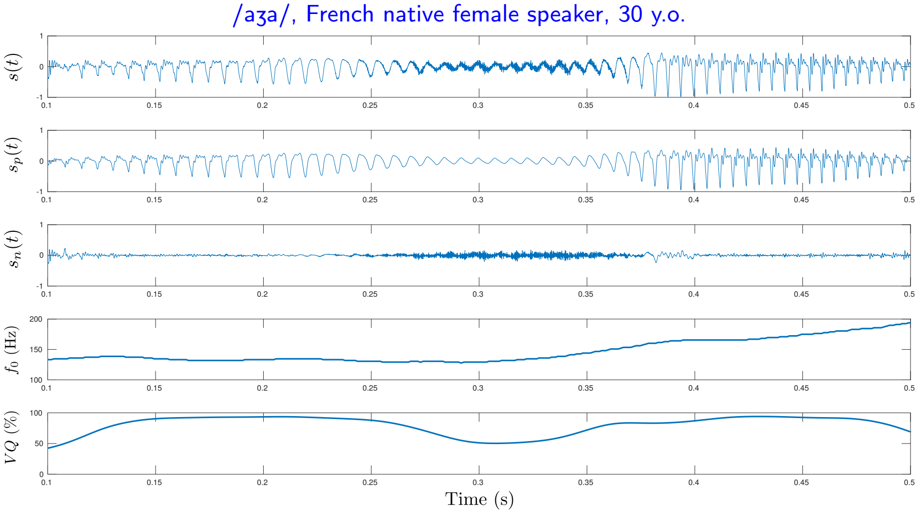
→ Needs more data

Comparison single mass and two-mass models



Effect on perception

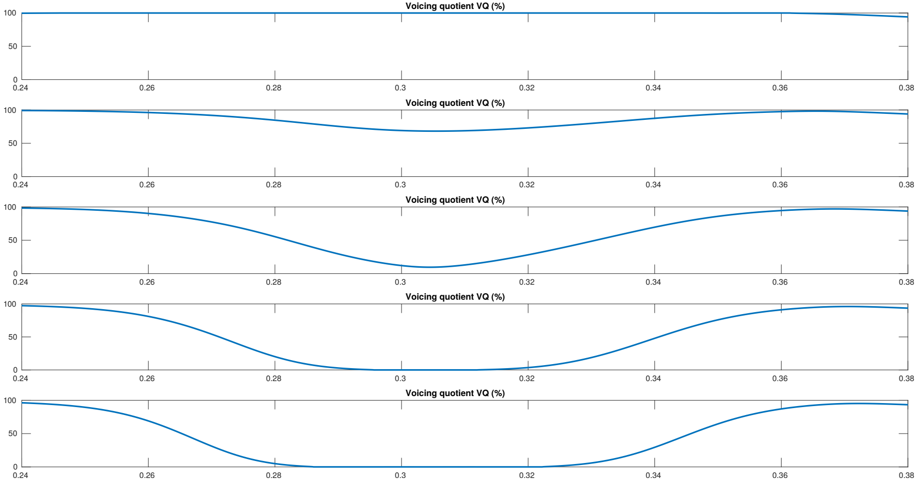
Example of natural utterance



Effect on perception

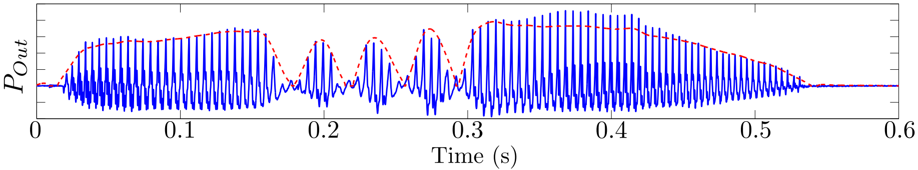
Virtual modification of *VQ*

/aʒa/for decreasing voicing



Example of alveolar trill

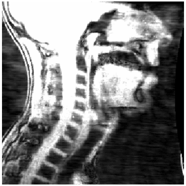
Trills in /ara/ context

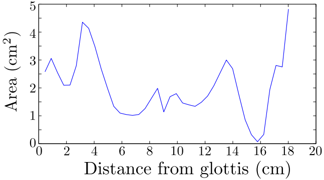


Questions:

- Can we model LP contacts and incomplete closure of the VT ?
- What are the articulatory/phonatory conditions that favor the self-oscillation of the tongue tip ?

Data taken from cineMRI acquisitions

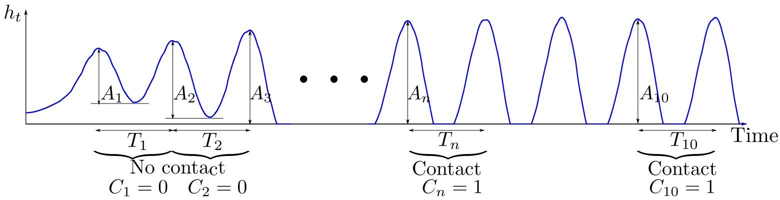




Investigation of the impact of various model parameters

- Mass of the tongue tip m_1
- Equilibrium position h_0
- Lateral ratio r_l $(= \frac{\text{open area during contact}}{\text{initial area at rest}})$
- Glottal abduction degree D_{ab}

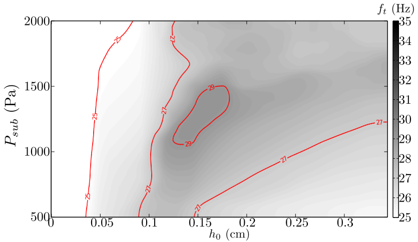
Studied features

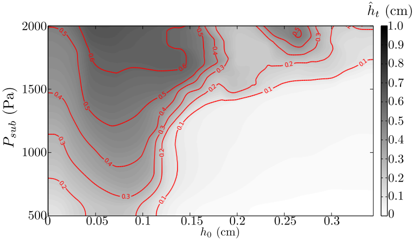


Investigation of the impact of various model parameters

- Trill frequency $f_t = \frac{1}{\hat{T}}$
- Trill amplitude $\hat{h}_t = \hat{A}$
- Contact ratio $C_r = 100 \times \frac{1}{N_{per}} \sum_{n=1}^{N_{per}} C_n$

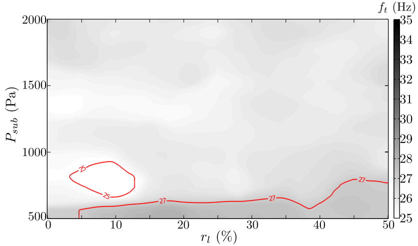
Effect of the equilibrium position

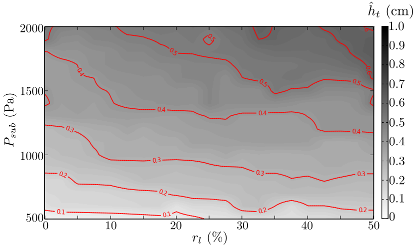




- Max of amplitude for 0.5 mm$<h_0<1$ mm
- No oscillation for $h_0>1.5$ mm, if $P_{sub}<1500$ Pa

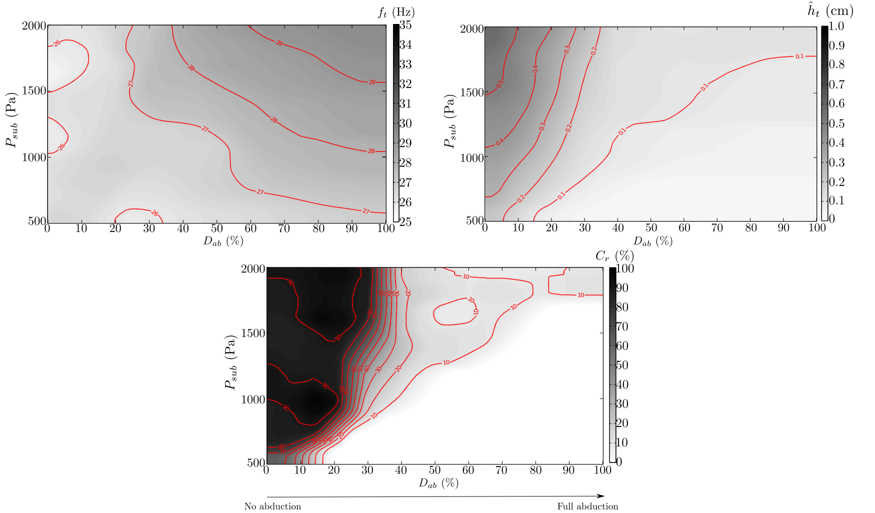
Effect of the lateral ratio





- Slight rise of the trill amplitude with lateralization
- Yet, limited impact of the incomplete closure on the trill properties

Effect of the glottal abduction degree



Glottal abduction decreases the trill amplitude