Local Time-warping in Auditory Feedback Alters Articulatory Timing in Connected Multisyllabic Speech Containing Vowels, Fricatives, and Stops

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Experimental Method: Feedback Perturbation

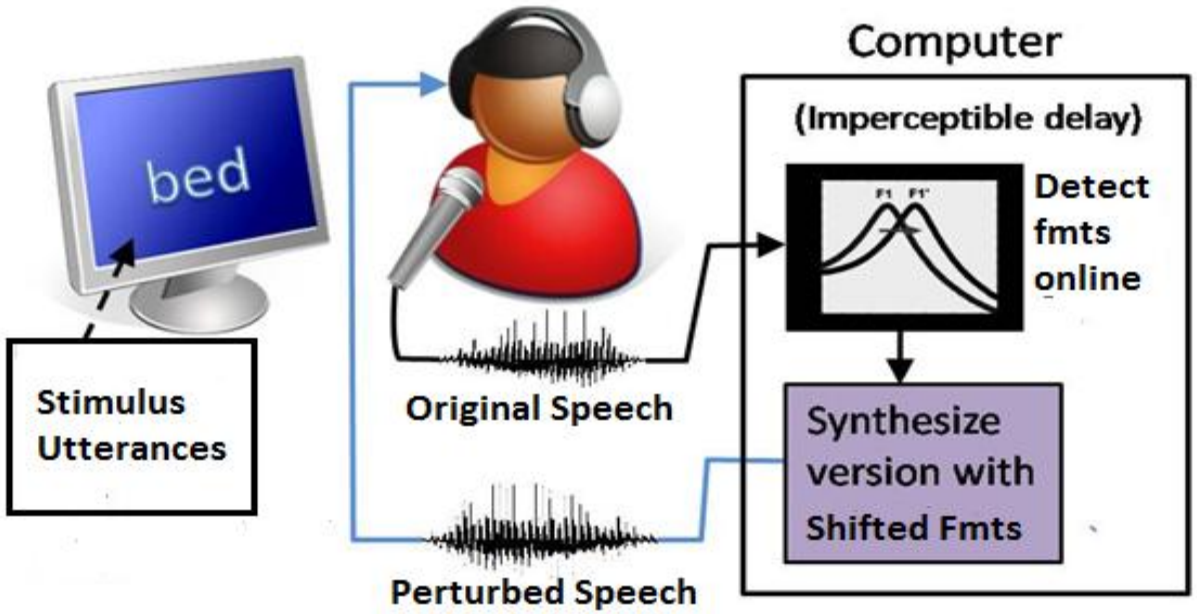
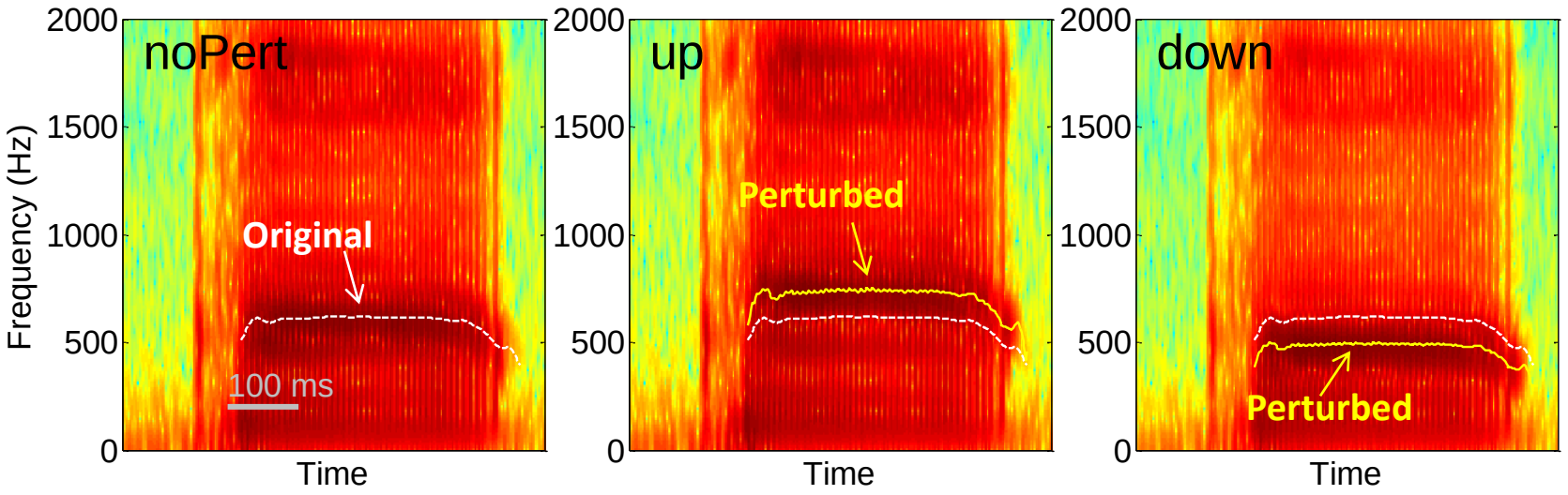


Figure from Ghosh et al. 2006

Auditory feedback and speech motor control

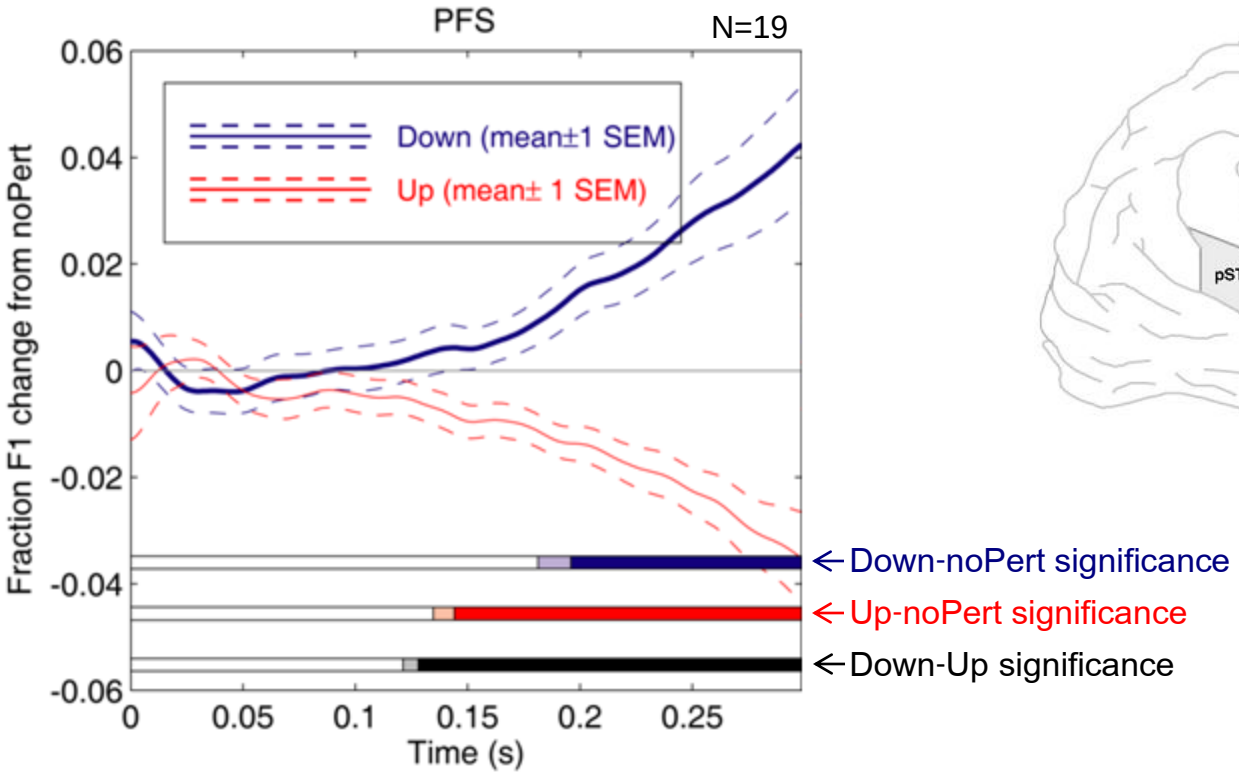
Online Feedback-based Control of the Vowel [ɛ]
(Quasi-static articulatory gestures)



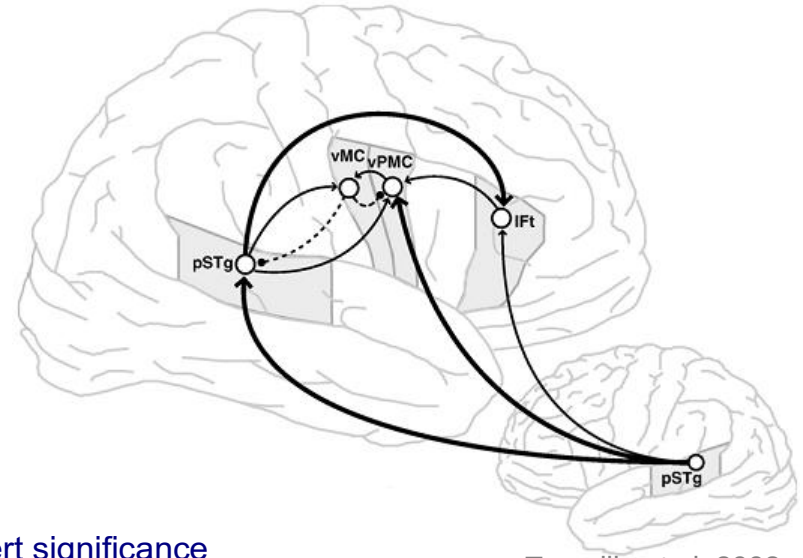
The randomized experiment design

Main							
Block 1	noPert	**F1Down**	noPert	**F1Up**	noPert	noPert	Filler 1
Block 2	**F1Up**	noPert	noPert	noPert	**F1Down**	noPert	Filler 2
Block 3	noPert	noPert	**F1Down**	noPert	**F1Up**	noPert	Filler 3
	⋮	⋮	⋮			⋮	⋮
Block 20	noPert	noPert	noPert	**F1Down**	noPert	**F1Up**	Filler 20

Online control of articulatory movements and its neural correlates

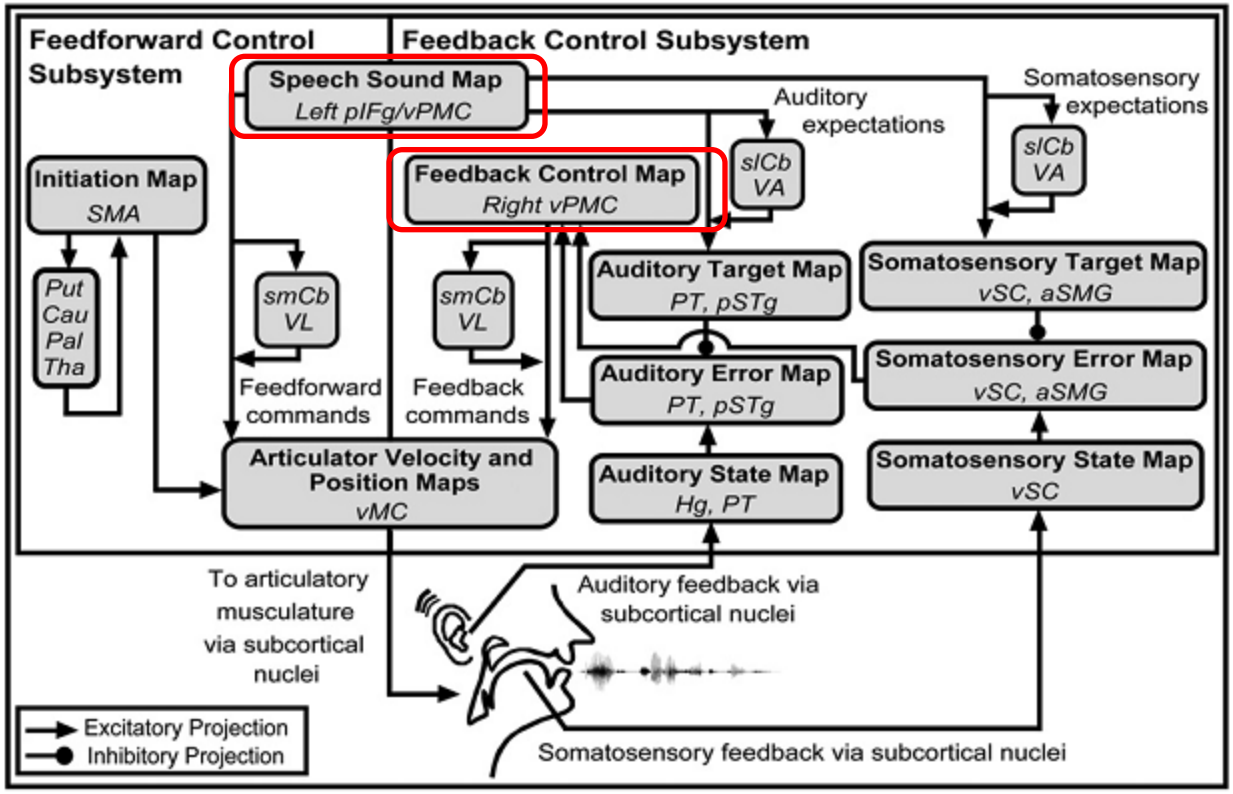


Cai et al. (2012, PLoS ONE)



Tourville et al. 2008
Niziolek & Guenther et al. 2013

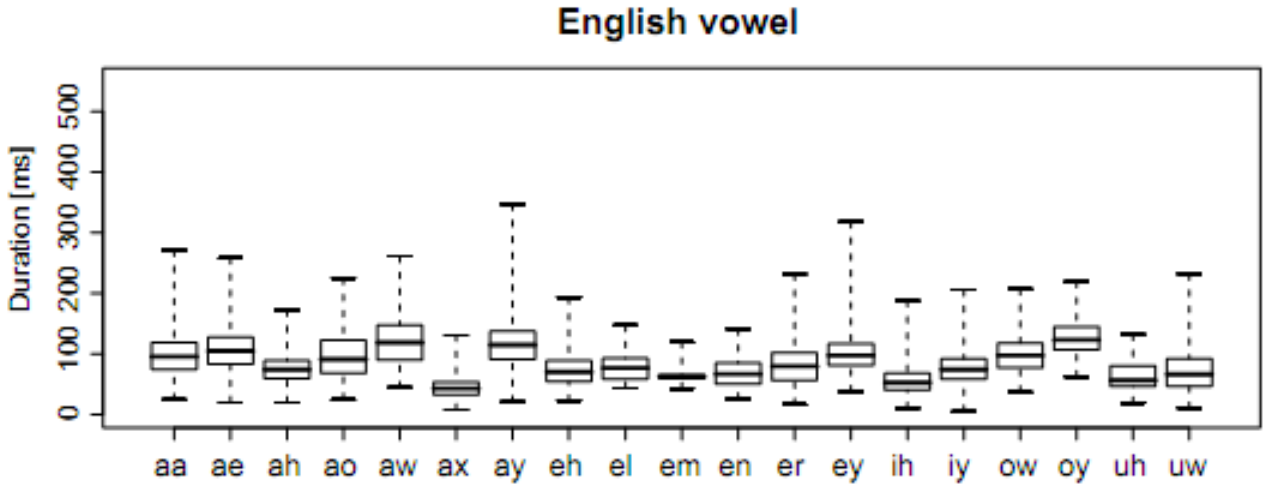
Online feedback-based control in the DIVA model



Golfinopoulos et al. (2009)

Auditory feedback and speech motor control

- The 100-150 ms latency is about equal to the duration of individual speech sounds in running speech.

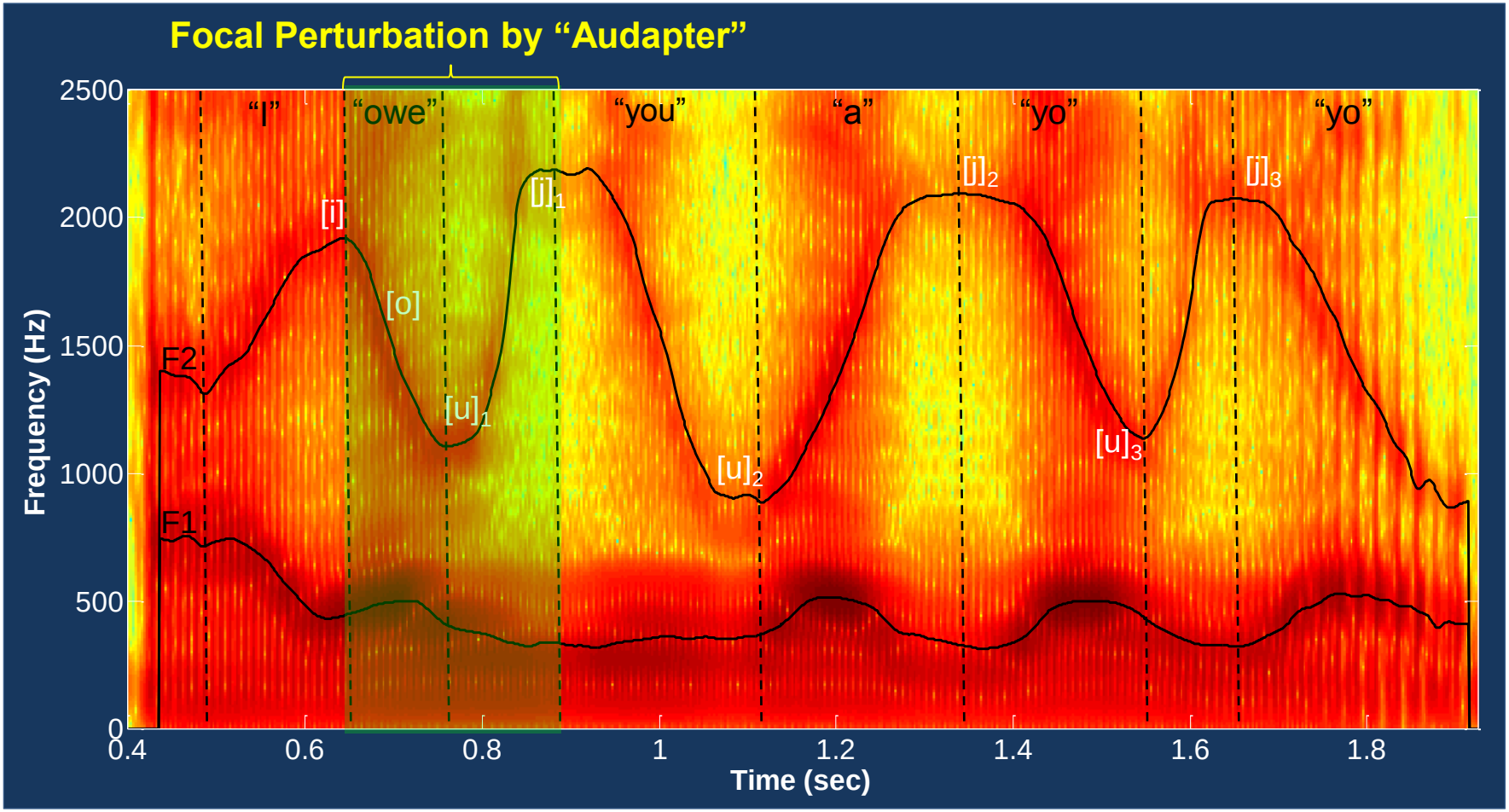


Yamagishi et al. (2008, JASA)

- Question: Is online adjustment relevant for the production of multisyllabic running speech?

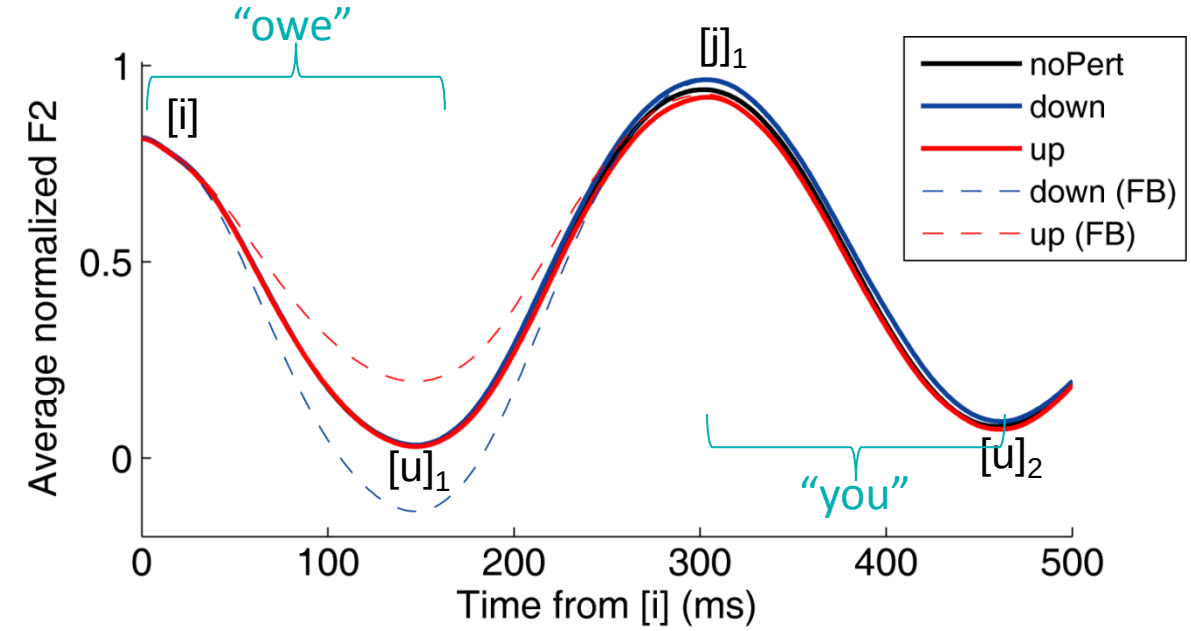
Previous study on auditory-motor interaction during connected speech

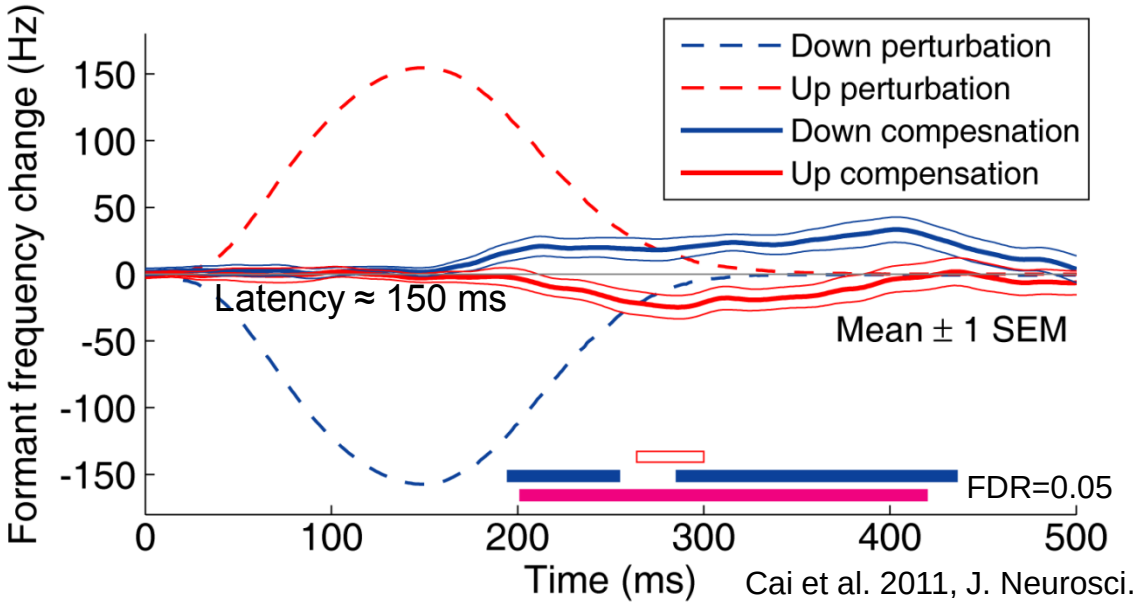
Utterance: "*I owe you a yo-yo*"



Results of the Up/Down (Spatial) Perturbations

N=36

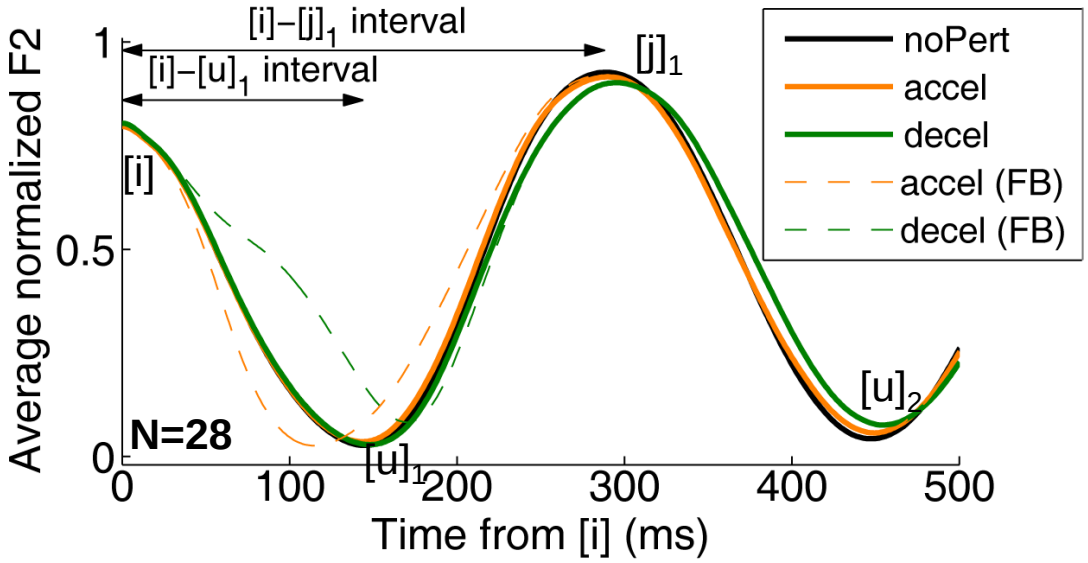




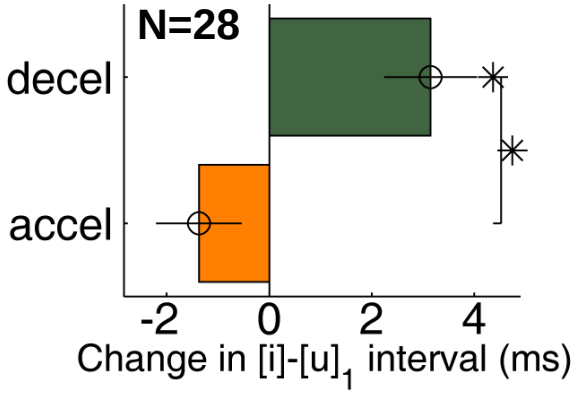
Cai et al. 2011, J. Neurosci.

Magnitude of correction ≈ **16%** of pert.

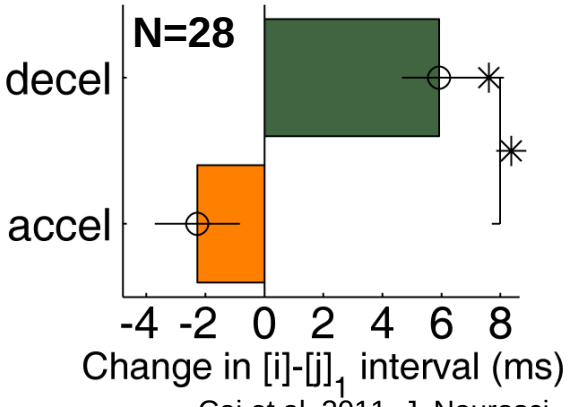
Responses to the Temporal Perturbations



Change in [i]-[u]$_1$ Interval (ms)
(Intra-syllabic)



Change in [i]-[j]$_1$ Interval (ms)
(Inter-syllabic)



Error bars:
±1 SEM

Asterisks:
p<0.05 (*post hoc* Tukey)

Cai et al. 2011, J. Neurosci.

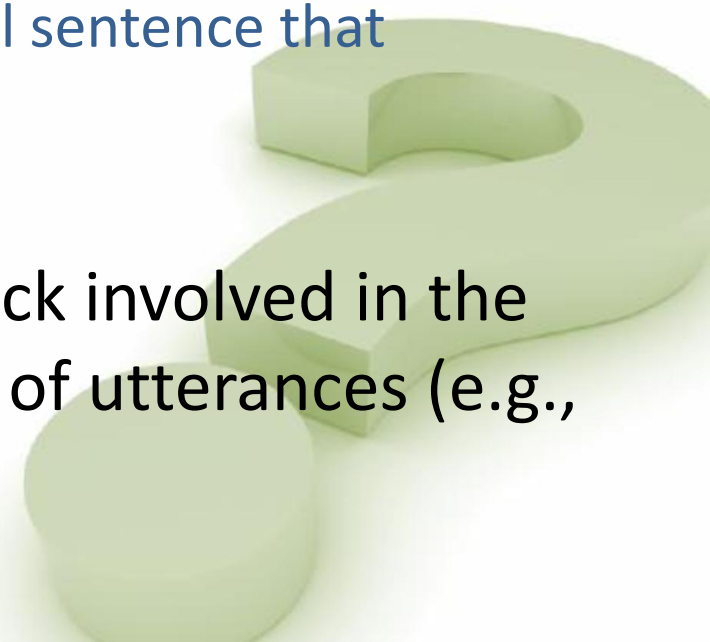
Auditory feedback and speech motor control

- Question: Is online feedback-based control relevant for the production of multisyllabic running speech?

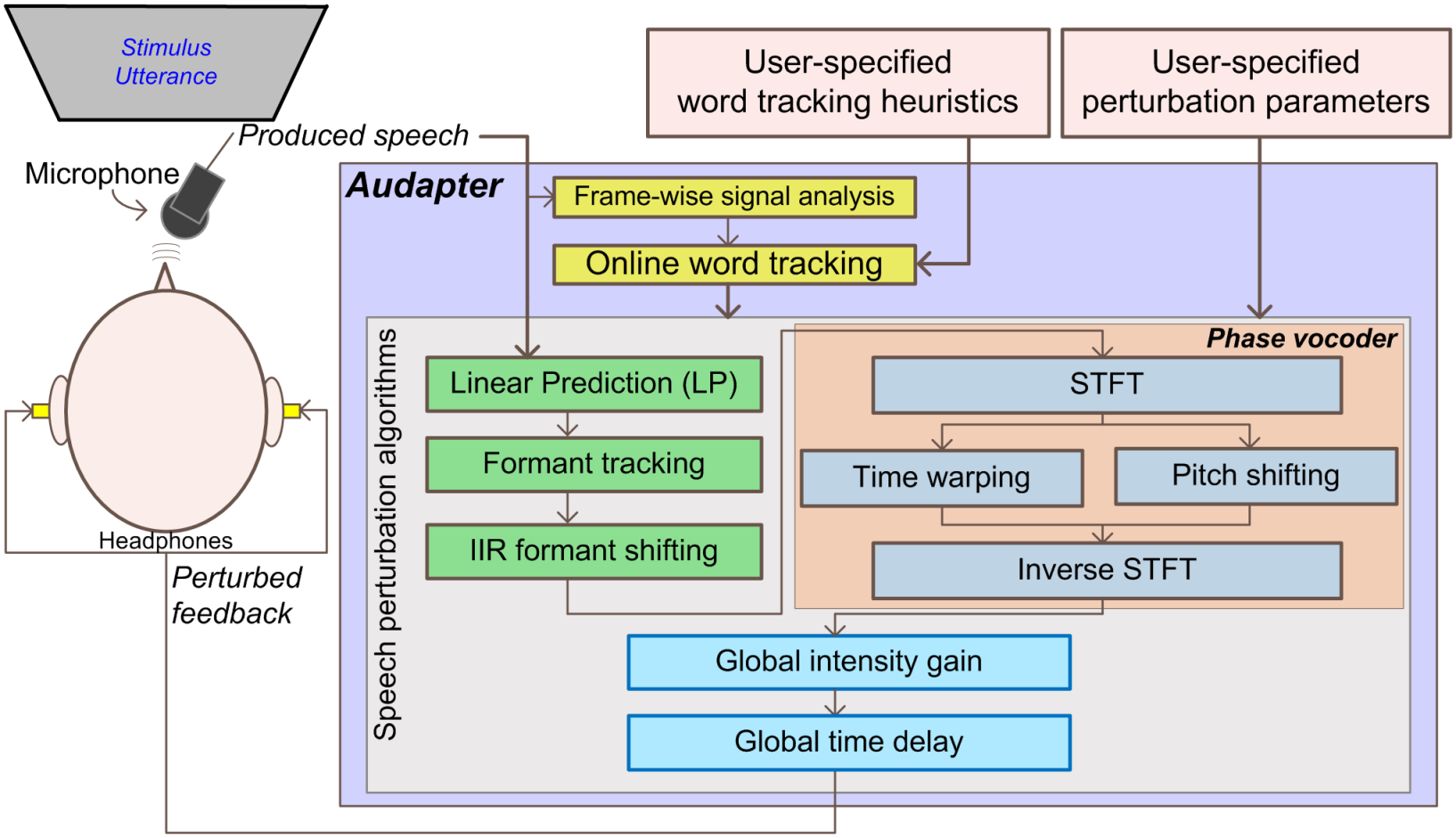
- Answer: Yes. We found evidence for the role of auditory feedback in the online control of articulation position and timing during a multisyllabic utterance.

- But the utterance we used was a special sentence that consisted of vowels and semi-vowels.

- **New Question**: Is auditory feedback involved in the production of more general types of utterances (e.g., stops, fricatives)?



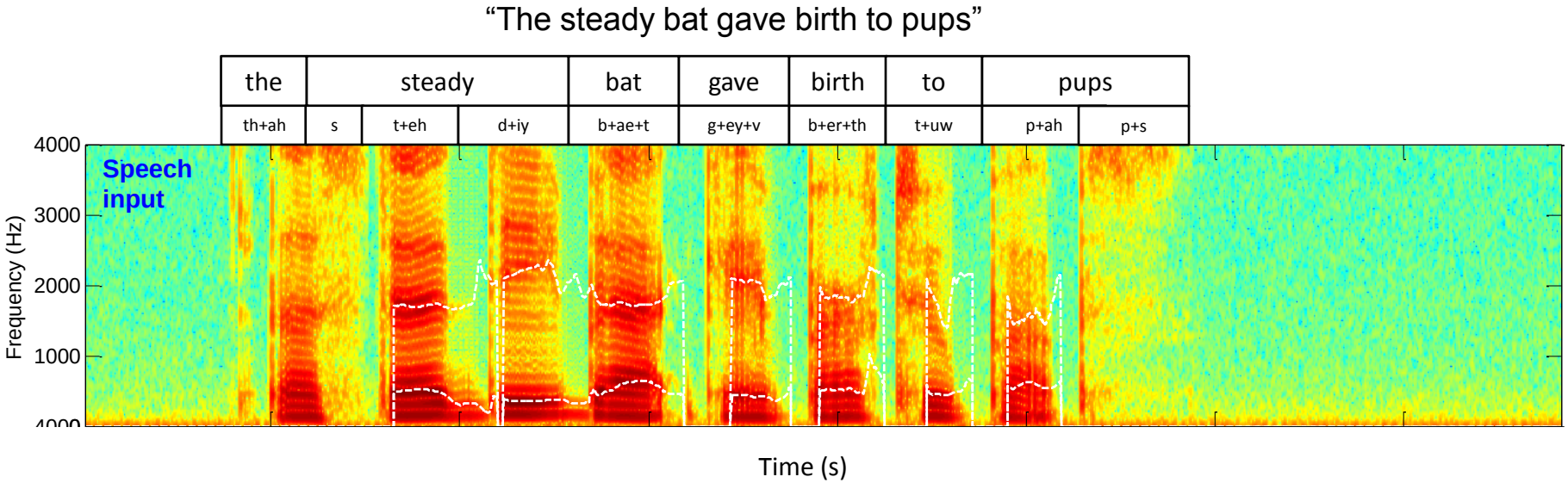
"Audapter": a system for auditory feedback manipulation



Feedback latency: depends on perturbation type: 12 – 32 ms.

New types of online auditory feedback perturbation

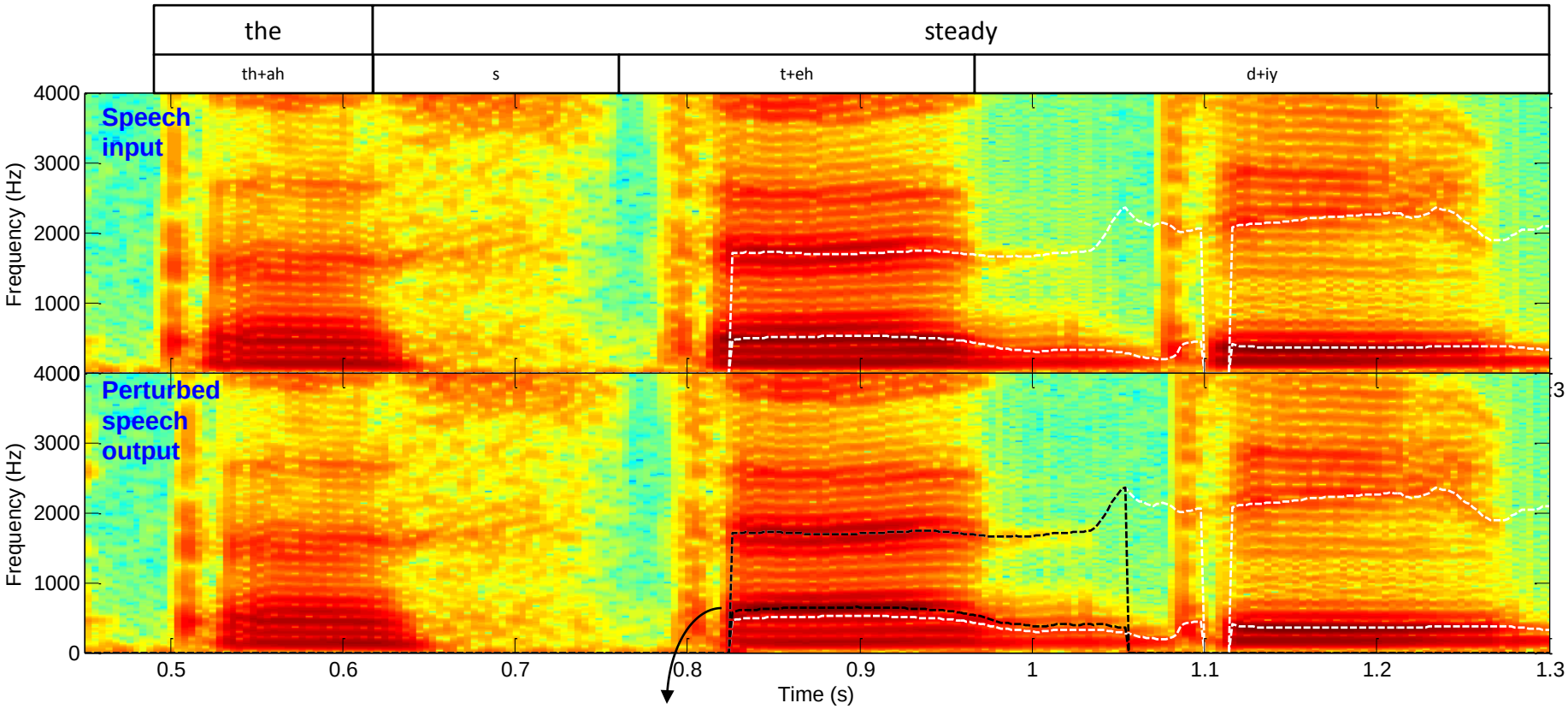
Spatial (“F1Up”) Perturbation



New types of online auditory feedback perturbation

Formant ("F1Up") Perturbation

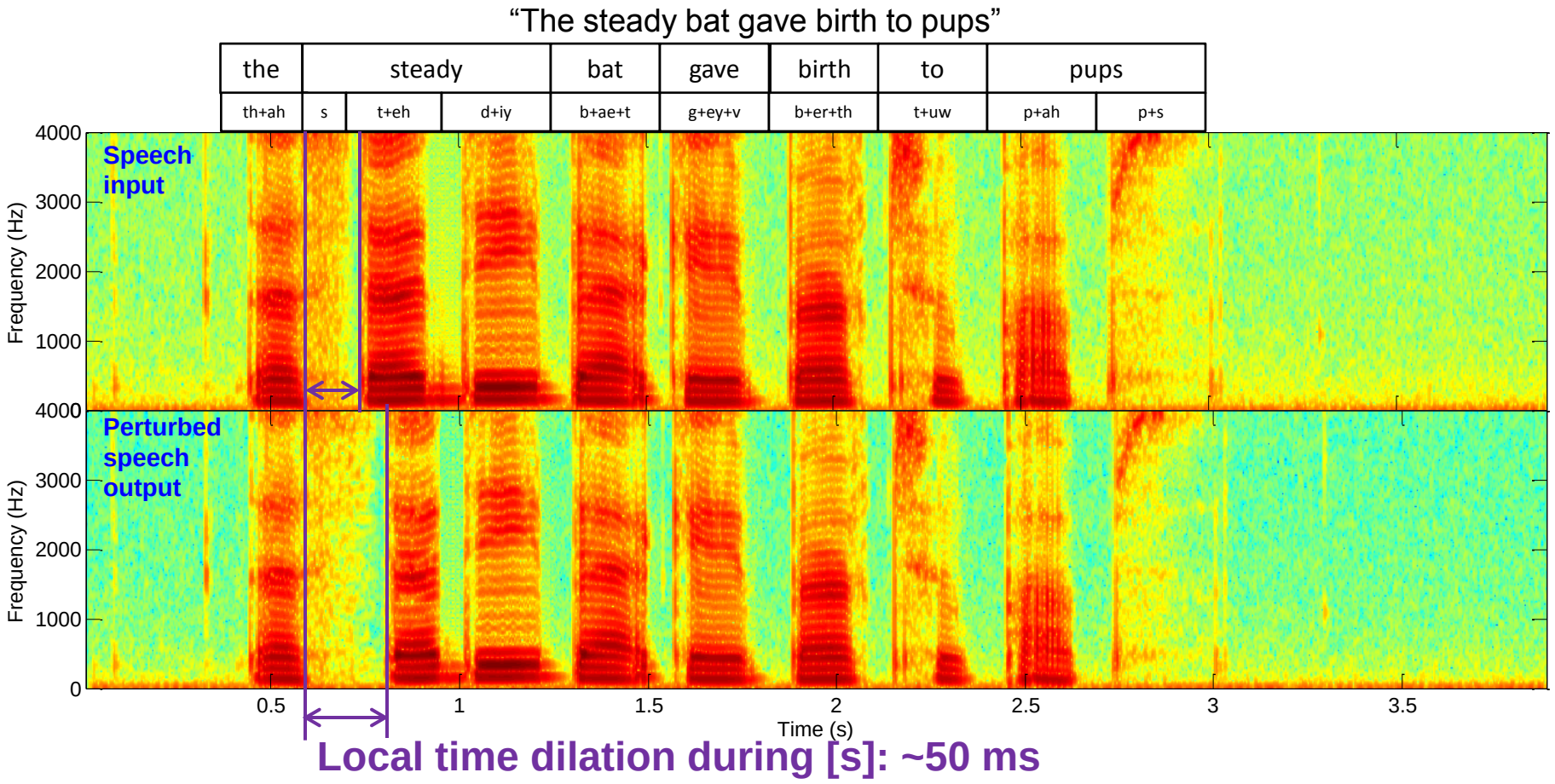
(Zoomed-in view)



Local formant perturbation: 25% F1 up-shift

New types of online auditory feedback perturbation

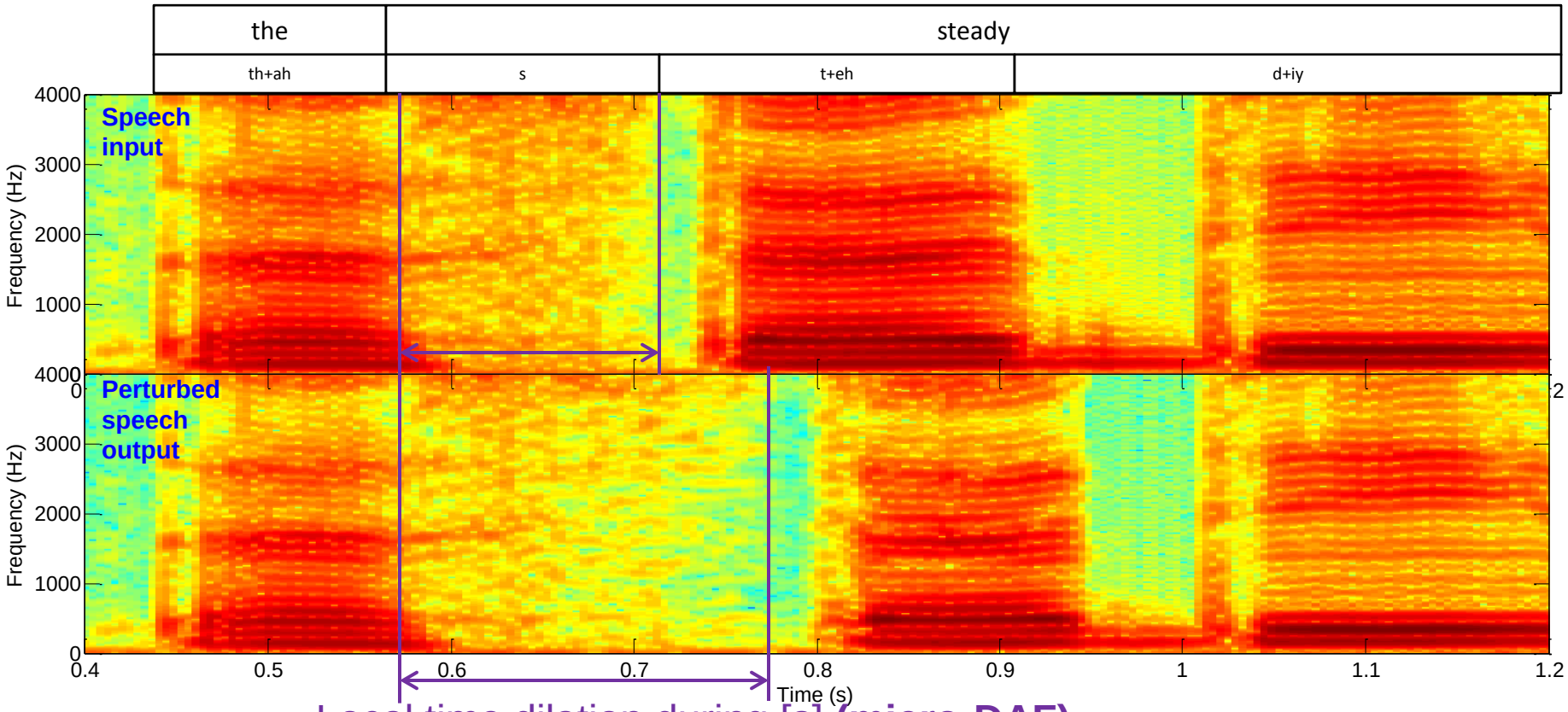
Temporal (“decel”) Perturbation



Local time dilation during [s]: ~50 ms

New types of online auditory feedback perturbation

Temporal (“decel”) Perturbation
(Zoomed-in view)



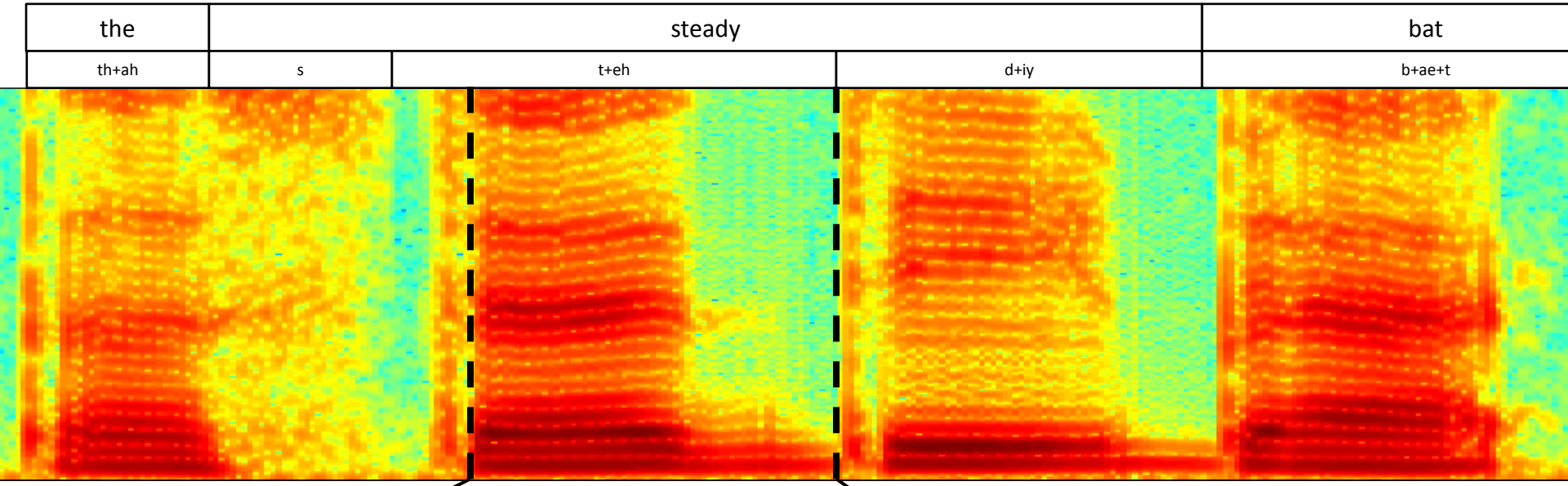
Local time dilation during [s] **(micro-DAF)**

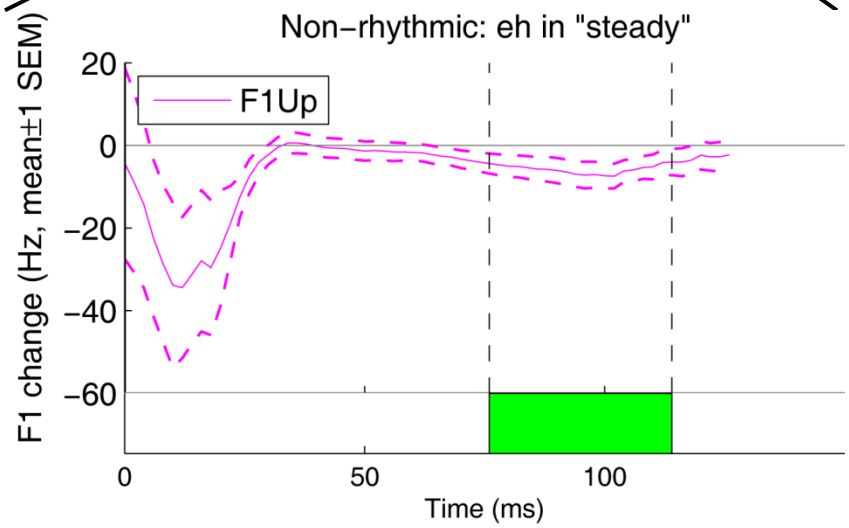
Speech timing patterns: Non-rhythmic and rhythmic

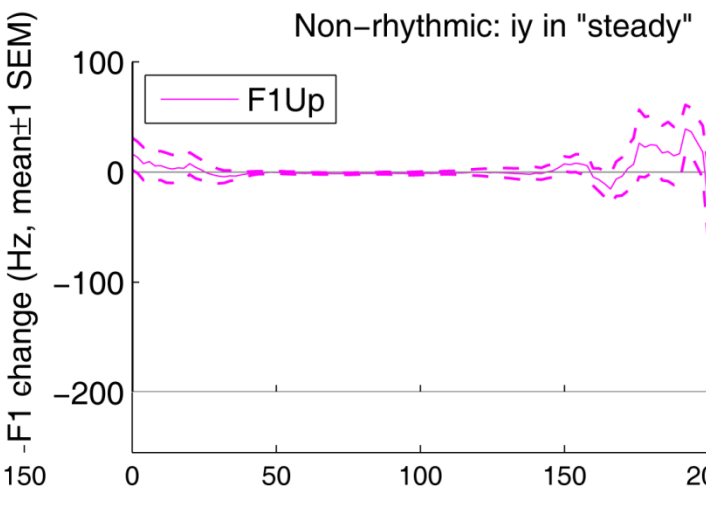
- **Non-rhythmic (normal) timing**

- **Rhythmic timing**:
  Isochronous syllables according to an auditory tone sequence

Formant (F1Up) compensation under F1Up perturbation

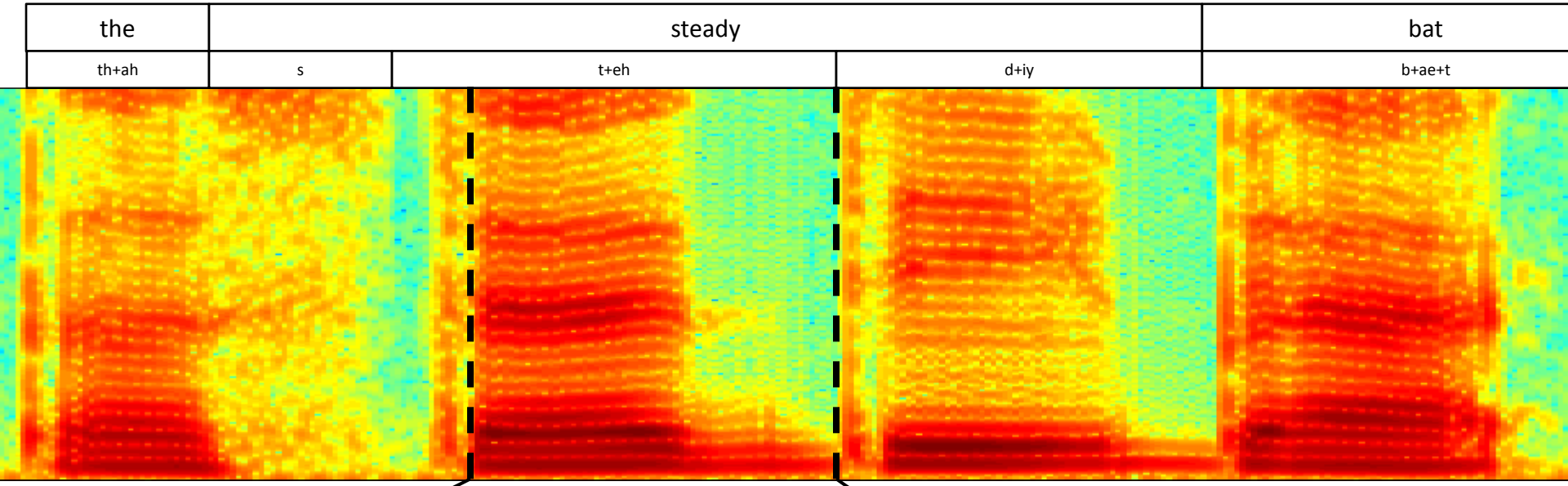


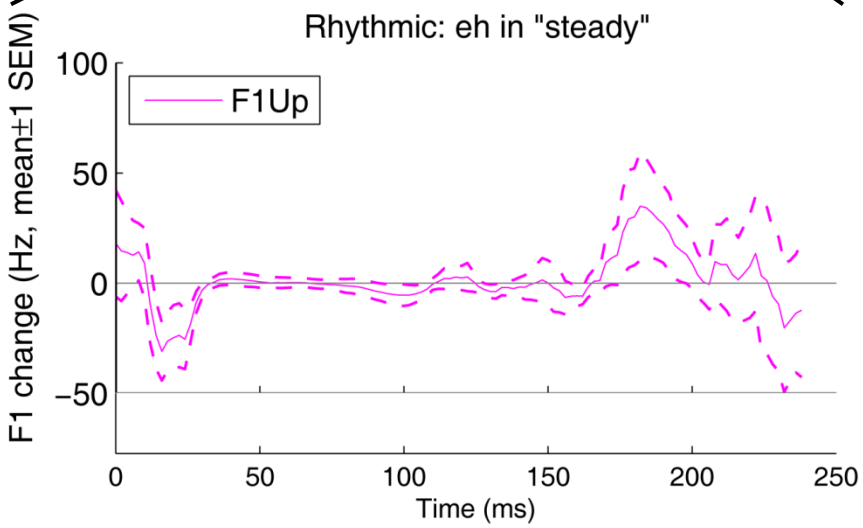


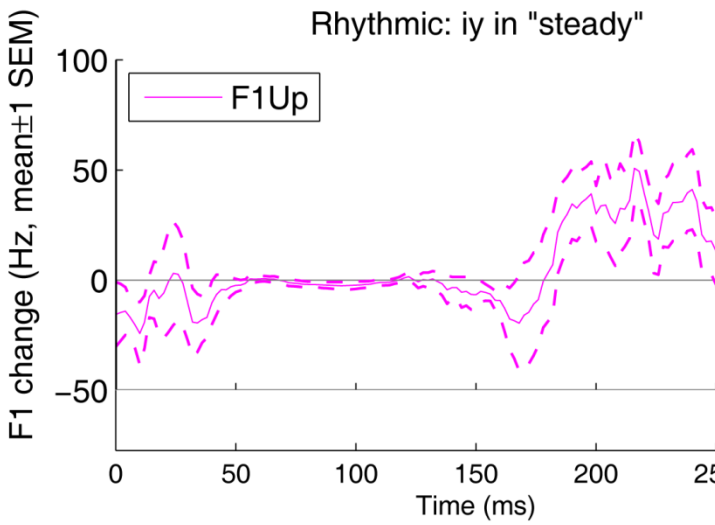


p<0.05: permutation test on lengths of uncorr. p<0.125 intervals

Formant compensation under F1Up perturbation



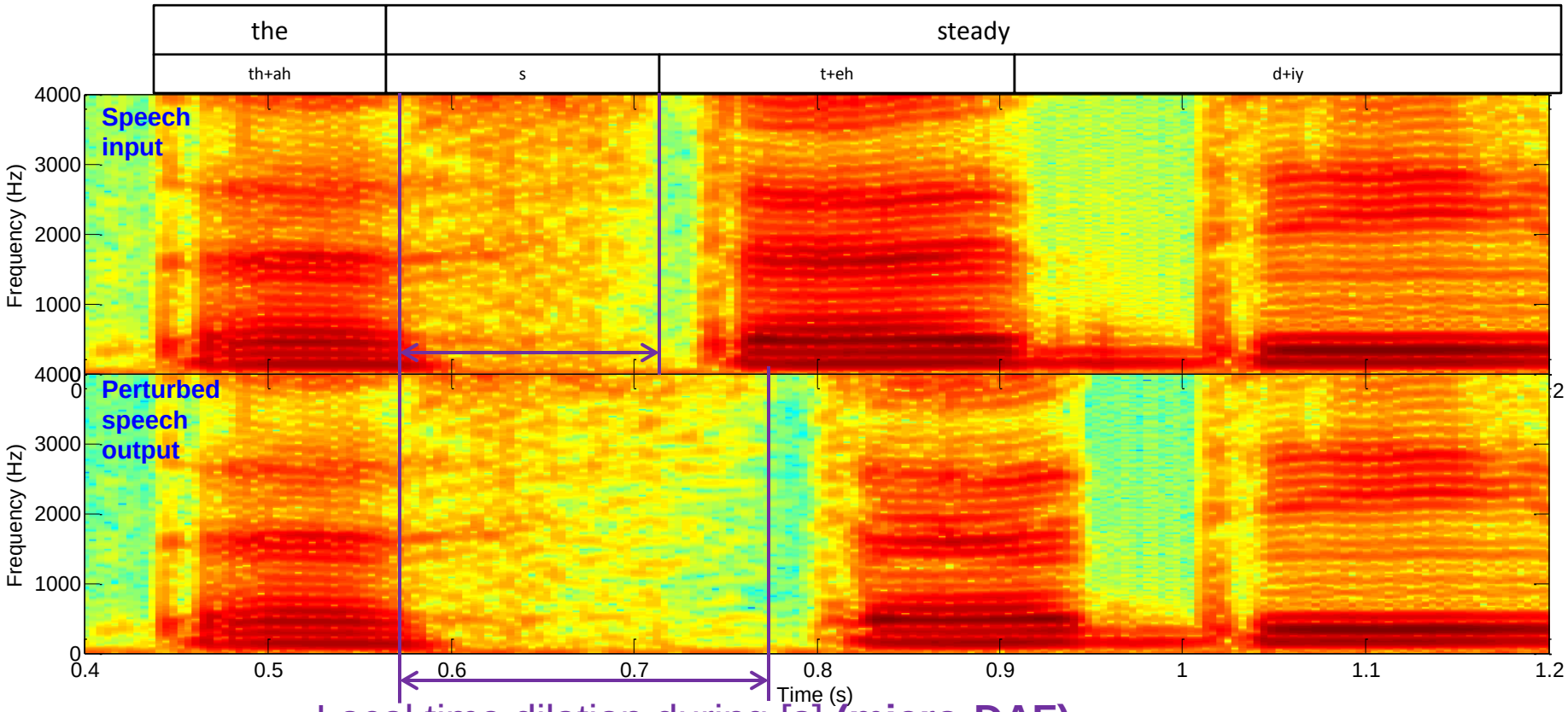




p<0.05: permutation test on lengths of uncorr. p<0.125 intervals

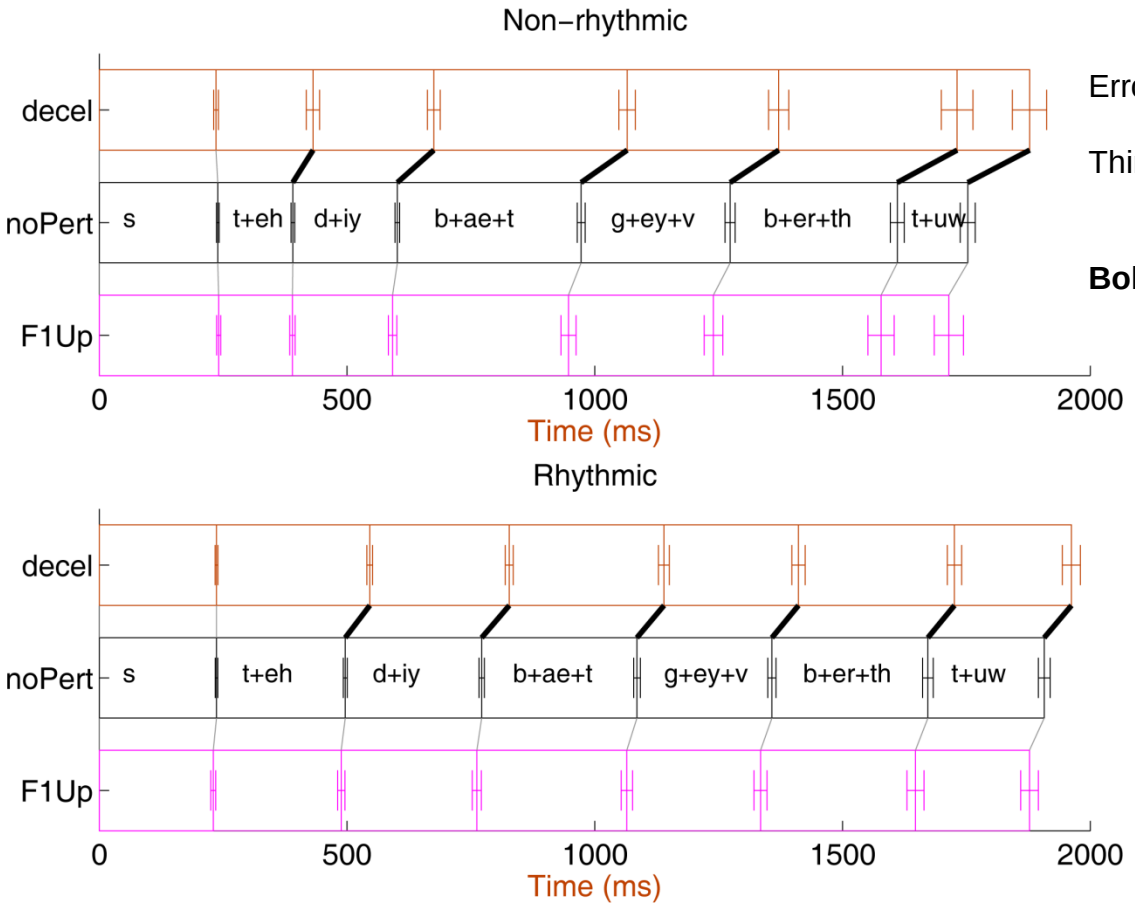
New types of online auditory feedback perturbation

Temporal (“decel”) Perturbation
(Zoomed-in view)



Local time dilation during [s] **(micro-DAF)**

Example timing responses from individual subject

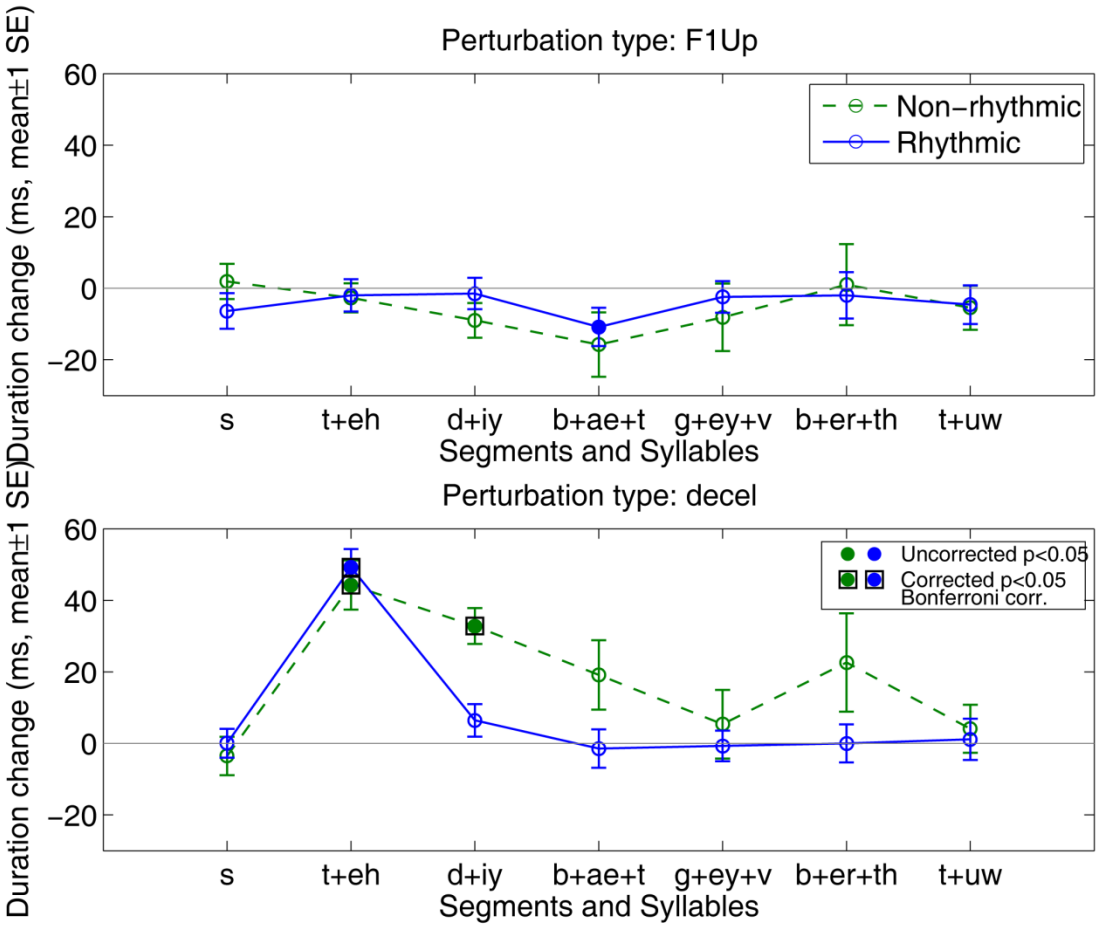


Error bars: ±1 SEM

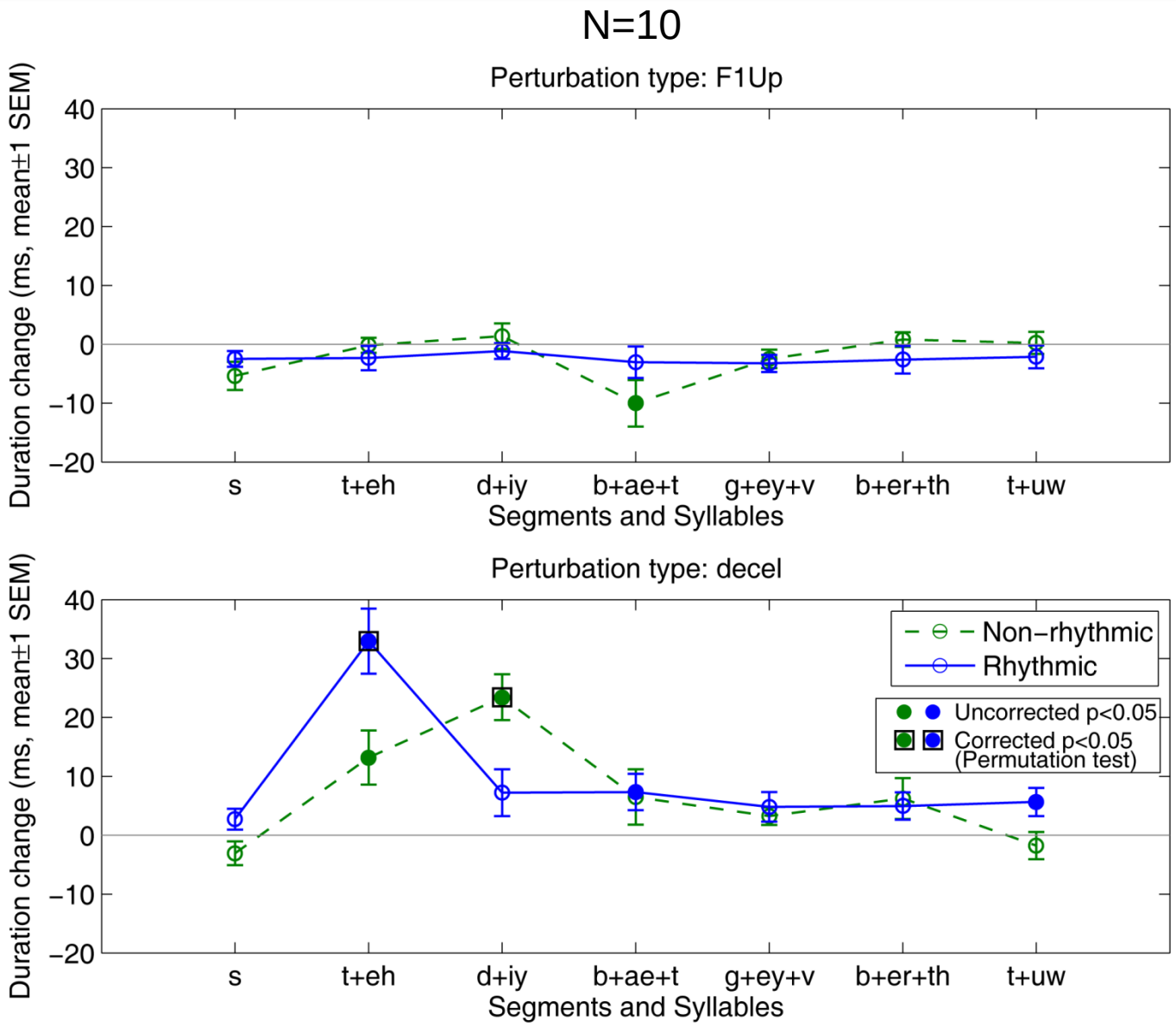
Thin oblique lines:
p≥0.05 (non-significant changes)

Bold oblique lines:
p<0.05 (uncorrected)

Example timing responses from individual subject



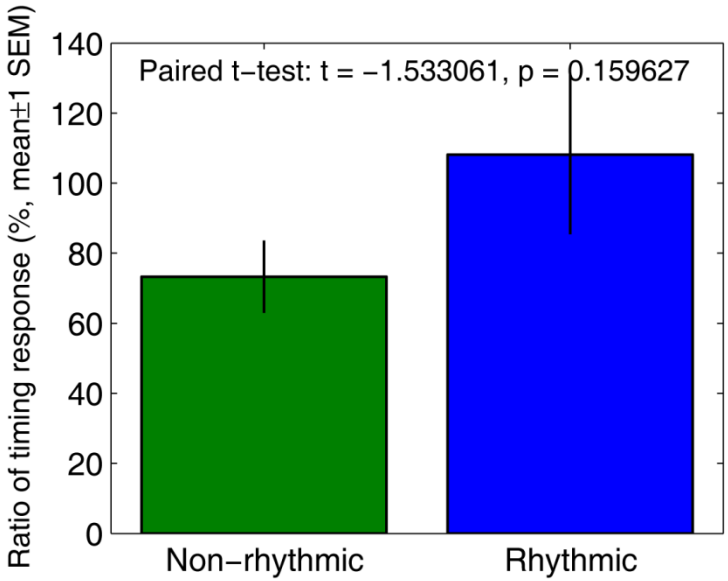
Group-average timing responses



Ratio of timing response

Ratio of timing response under the Decel perturbation is defined as:

$$\%response = \frac{\textit{Change in the produced duration of the word “steady”}}{\textit{Shift in the onset time of [t] in the auditory feedback}}$$



- The ratio was on average **80-100%**, which seems to exceed compensation ratios observed under online formant and pitch perturbations (10% - 30%).
- Timing is more malleable than other articulatory parameters during speech motor execution?

Auditory feedback and speech motor control

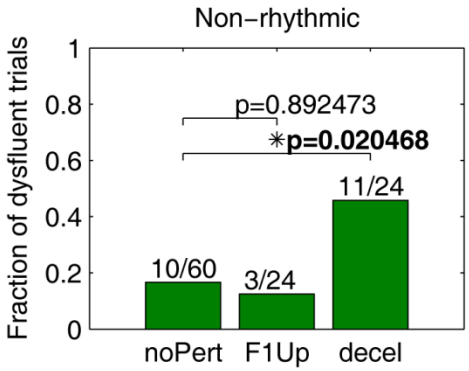
- **Question**: Is auditory feedback involved in the production of more general types of utterances (e.g., stops, fricatives)?

- Answer: Yes.
  - The role in spatial control is weak but detectable under the normal (non-rhythmic) speech timing pattern;
    it appears to be weakened under rhythmic pacing of speech (!)
  - The role in timing is strong in both (!) normal and rhythmic speech

Induced dysfluency in PWS due to Decel perturbation

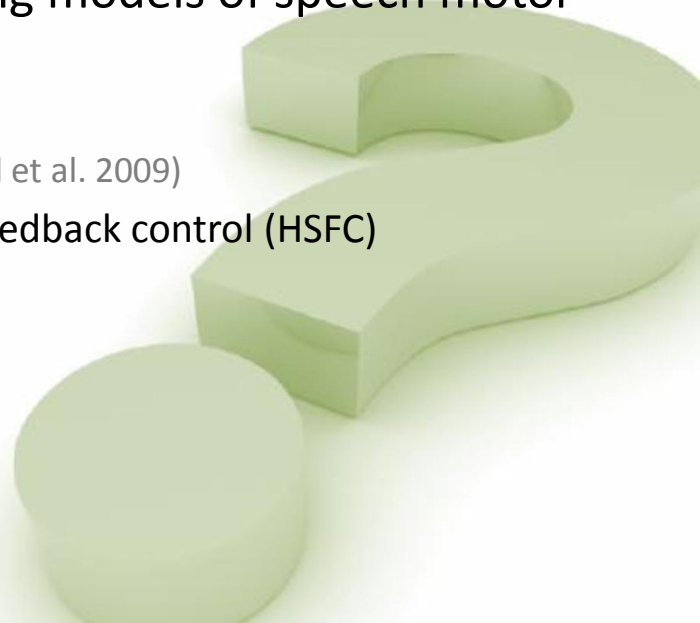
- In two of the five persons who stutter (PWS) examined so far, the Decel perturbation caused increases in the frequency of stuttering without conscious awareness.
- In other PWS, frequency of stuttering was unaltered.

Data from an example PWS



Discussion

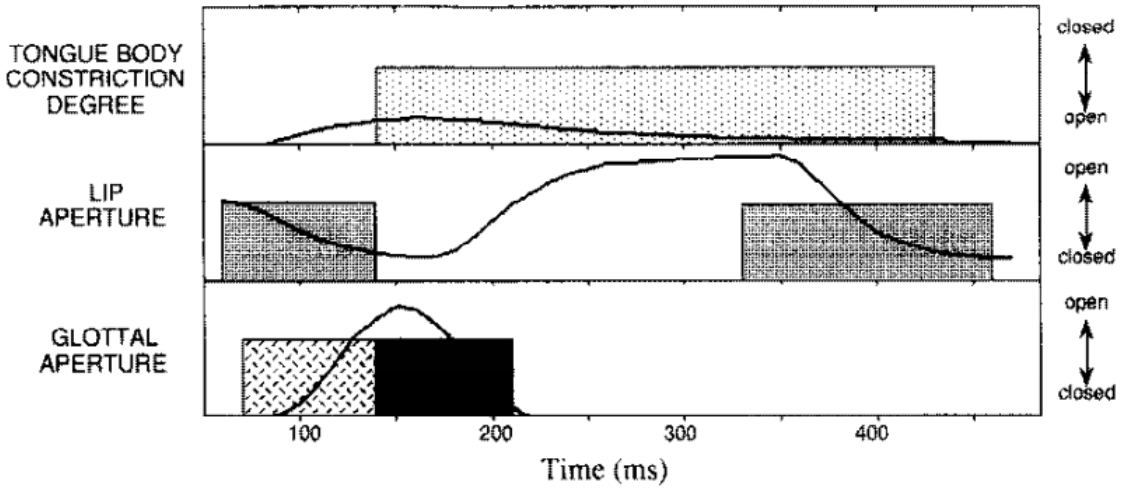
- Questions for future research:
  - If confirmed in more PWS, what can we make of the induced dysfluency by Decel perturbation and the absence of it in normal speakers?
  - What brain regions are involved in the online auditory feedback-based spatial and temporal control during multisyllabic running speech?
  - Can we incorporate these finings into existing models of speech motor control?
    - DIVA / GODIVA
      (Guenther et al. 2006; Golfinopoulos et al. 2009; Bohland et al. 2009)
    - State feedback control (SFC) / Hierarchical state feedback control (HSFC)
      (Hickok et al. 2011; Hickok 2013)



Discussion: A unique challenge for speech production

Task Dynamic Model

(Saltzman and Munhall1989)



- The concept of a “timing score” independent of sensory feedback needs to be revised.

Acknowledgements

- Marc Boucek, Virgilio Villacorta and Satrajit Ghosh for writing the precursor to Audapter
- Kevin Reilly contributed to the coding of the original formant tracking and phase vocoder algorithms
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- Jason Tourville

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