SimpleDIVA: A 3-Parameter Model for Examining Adaptation in Speech and Voice Production

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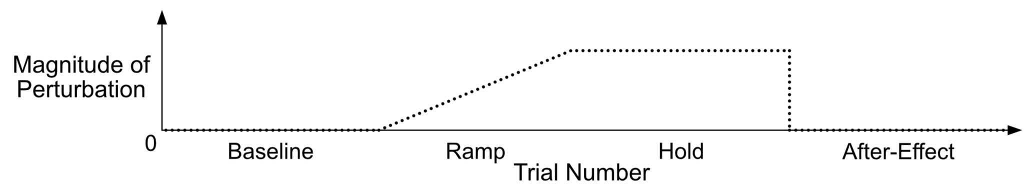
Introduction

- **Sensorimotor adaptation paradigms** — important experimental technique in examining neural mechanisms of motor control, including speech and voice production
- Typical experiment:
  - Participants produce speech while **auditory feedback is perturbed**
  - When perturbations **sustained** over many trials, participants gradually **learn to adjust** their movements to **compensate** for the perturbation (i.e., adaptation occurs)



- This process relies on an interplay between **feedback control** (in detecting and correcting errors within a trial) and **feedforward control** (in updating the motor command for the following trial)
- Challenging to determine contribution of each system from behavioral data alone
- Current speech models (including the **DIVA model**[1,2]) has too many free parameters to quantitatively fit experimental datasets in an unambiguous way
- **Aim: Describe and test a simple 3-parameter computational model that estimates contribution of feedback and feedforward control mechanisms to sensorimotor adaptation**

Methods

Model equations[3]

- Three equations that solve for **gains** in (auditory feedback control (α_A), somatosensory feedback control (α_S), and feedforward control/learning rate (λ_{FF})
- Equations shown for a first formant (**F1**) **adaptation experiment** but applicable to other auditory parameters (e.g., fundamental frequency, f0)
- F1 in a given trial (*n*) is a combination of a feedforward command and a sensory feedback-based correction (if an error is detected)

$$F1_{produced}(n) = F1_{FF}(n) + \Delta F1_{FB}(n) \qquad \text{(EQ 1)}$$

- The sensory feedback-based correction is approximated by the size of the auditory and somatosensory errors detected at the beginning of the production, scaled by the gain parameters

$$\Delta F1_{FB}(n) = \alpha_A * (F1_T - F1_{AF}(n)) + \alpha_S * (F1_T - F1_{SF}(n)) \qquad \text{(EQ 2)}$$

- The feedforward command is updated by adding a scaled version of the sensory feedback-based corrective command

$$F1_{FF}(n+1) = F1_{FF}(n) + \lambda_{FF} * \Delta F1_{FB}(n) \qquad \text{(EQ 3)}$$

Optimization procedure

- Model parameters optimized using a particle swarm algorithm that provides lowest RMSE fit

Testing the SimpleDIVA model with existing datasets

- Simulations performed in MATLAB 2018a
- All datasets from cohorts of young healthy adults
  - A. **F1 upward** perturbation[4]
  - B. **f0 upward and downward** perturbation[5]
  - C. F1 upward perturbation with **noise-masked trials**[6]
  - D. f0 upward and downward f0 perturbation, **measured early and late** in production[7]
  - E. F1 upward perturbation **parameters fit to a different perturbation protocol**

Key References

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Results

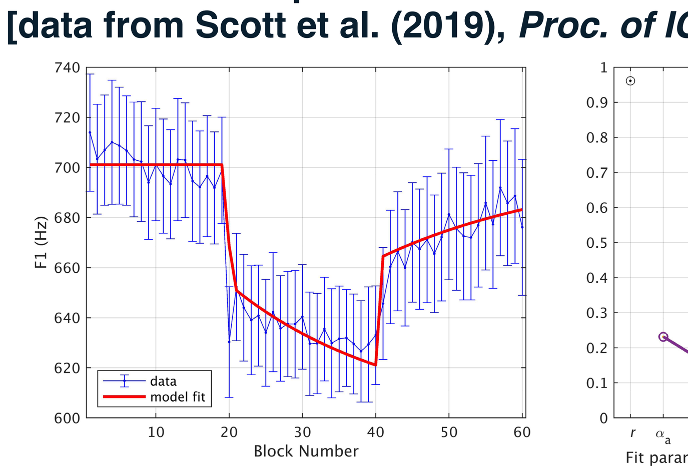
Results of model simulations fit to existing datasets are shown below. Each figure follows the same format. In the **left panel**, the mean and standard error of the **experimental data** are show in **blue** and the **model fits** are shown in **red**. In the **right panel**, a Pearson's correlation coefficient (**r**) describes the relationship between the data and model fits and estimates are given for α_A, α_S, and λ_{FF}.

Gray shading indicates **noise-masked trials** (simulation C).

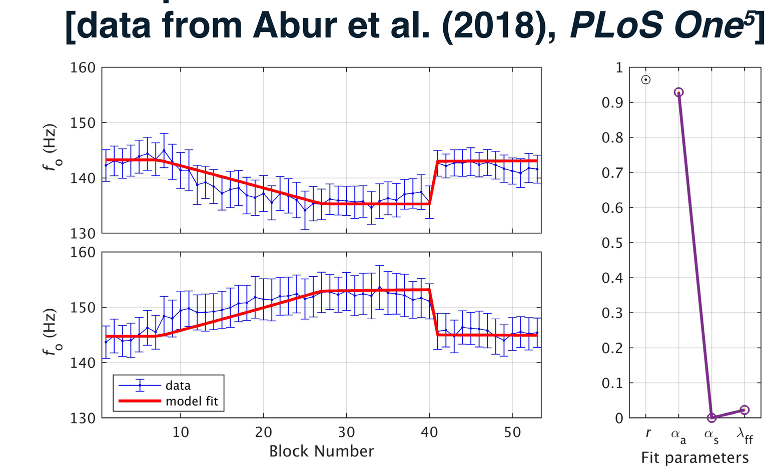
Parameter estimates can be **interpreted** as follows:

- **Higher α_A** leads to a higher compensatory response
- **Higher α_S** leads to a decrease in the compensatory response (somatosensory feedback controller counter-acts compensation)
- **Higher λ_{FF}** leads to a larger amount of the corrective command being added to the feedforward command for the next trial

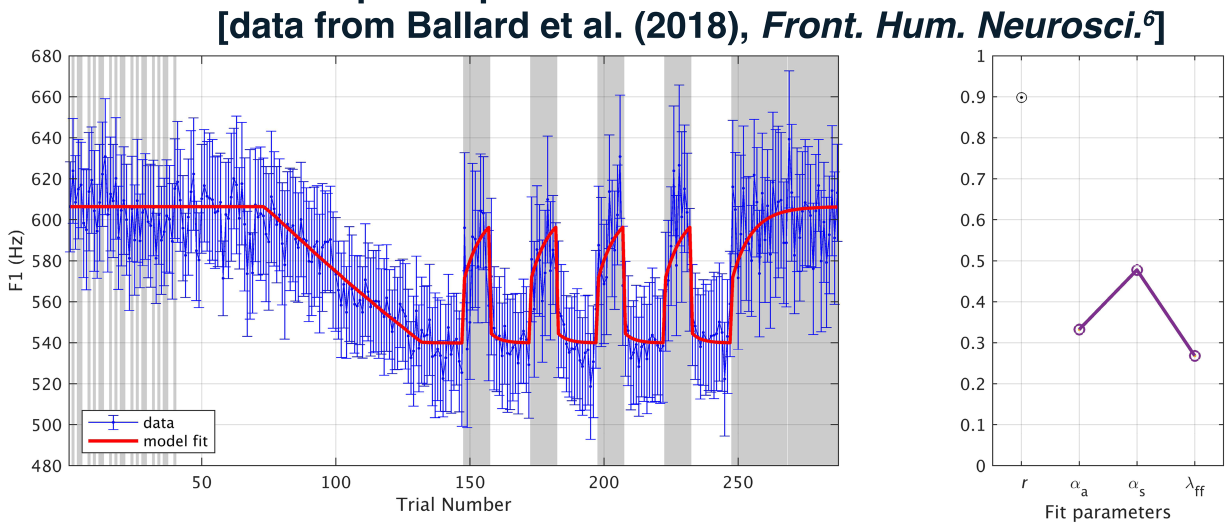
A. F1 Upward Perturbation
[data from Scott et al. (2019), *Proc. of ICPhS*[4]]



B. f0 Upward and Downward Perturbation
[data from Abur et al. (2018), *PLoS One*[5]]

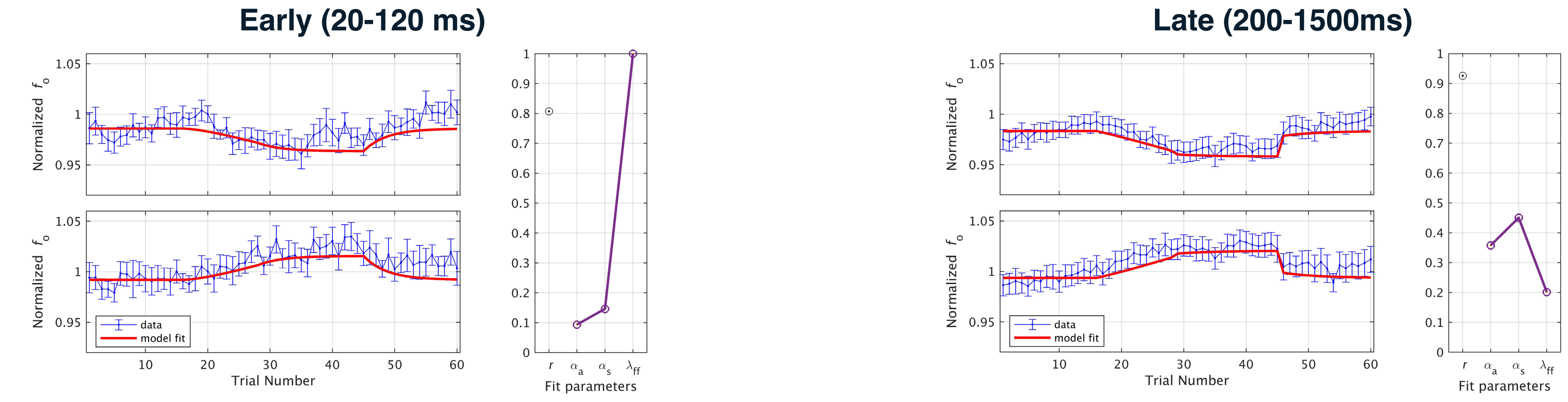


C. F1 upward perturbation with noise-masked trials
[data from Ballard et al. (2018), *Front. Hum. Neurosci.*[6]]



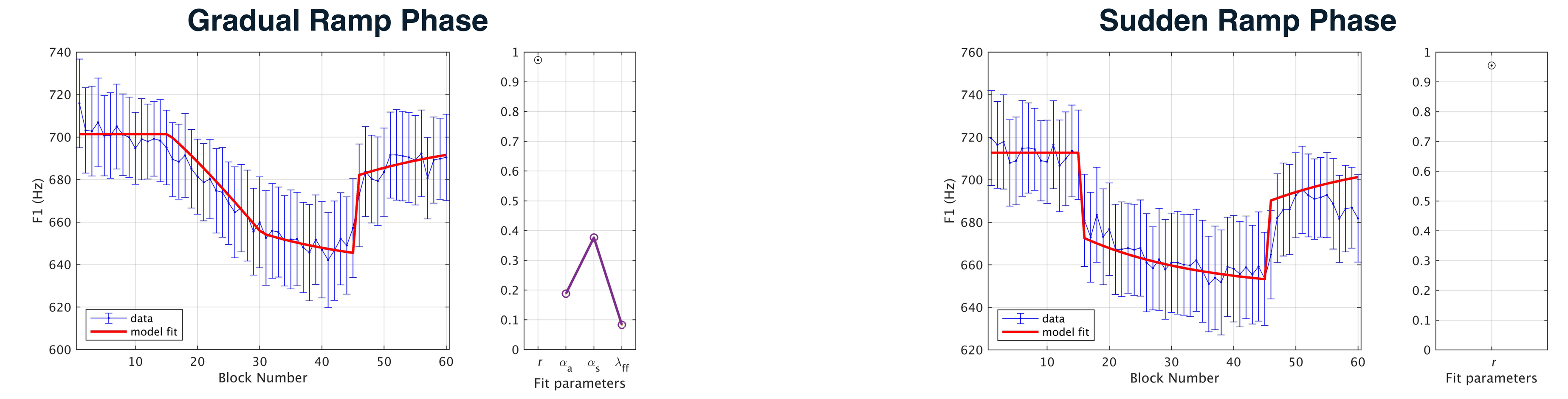
D. f0 upward and downward f0 perturbation, measured early and late in production
[data from Heller-Murray (2019), *doctoral dissertation*[7]]

Early (20-120 ms) **Late (200-1500ms)**



E. F1 upward perturbation model parameters fit to a different perturbation protocol
[data from Chao & Daliri, *unpublished*]

Gradual Ramp Phase **Sudden Ramp Phase**



Discussion

- Overall, SimpleDIVA provides **excellent fits to existing F1 and f0 adaptation datasets** (mean correlation coefficients = .95 +/-.03). The simulations revealed a number of properties of the model:
  - Accounts for perturbations in **single or multiple auditory dimensions** (e.g., upward and downward perturbations)
  - Sensitive to the presence of **masking noise** — somatosensory feedback continues to play a role in the absence of auditory feedback
  - Captures variations in **measurement window** — motor control early in trial is dominated by feedforward control
  - Can **predict** average group responses from one experimental condition to another (within same group of participants)
- SimpleDIVA offers new insights into speech and voice motor control by providing a mechanistic explanation for the behavioral responses to the adaptation paradigm that are not readily interpretable from the behavioral data alone
- Next steps:
  - Use SimpleDIVA to **develop clear, testable hypotheses** that can be evaluated empirically
  - Use SimpleDIVA to understand differences in speech motor processing in individuals with **communication disorders**
  - **Expand functionality** of SimpleDIVA to (1) statistically compare groups, and (2) specify individual perturbation values
- Compiled SimpleDIVA code freely available online as a Windows or Mac **application** — MATLAB license not required

SimpleDIVA App