Contributions of Auditory and Somatosensory Feedback to Vocal Motor Control

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Introduction

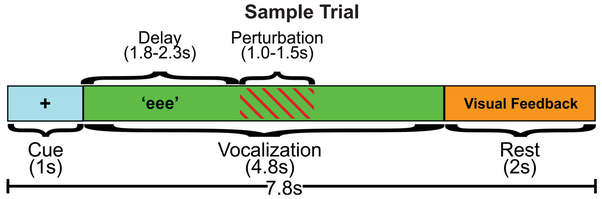
- Current **models of speech motor control** divide processes into distinct control sub-systems
  - Feedforward, auditory feedback, and somatosensory feedback control
  - Perturbation studies — probe role of **feedback** during vocalization
- **Aim of current study: Dissociate roles of somatosensory and auditory feedback control systems in vocal motor control**
  - Unexpectedly perturb a speaker's sensory feedback in both auditory (i.e., pitch-shift reflex) or somatosensory domain (i.e., laryngeal perturbation)

Methods

Participants
- 18 native speakers of North American English (11F, 7M; 18-34 years)
- f_o **acuity** estimated using a 2-down, 1-up adaptive AXB just-noticeable-difference (JND) task

Task
- **Sustained vowel** production, /i/
- Set of 40 trials per condition
- Perturbations applied pseudo-randomly on 25% of trials

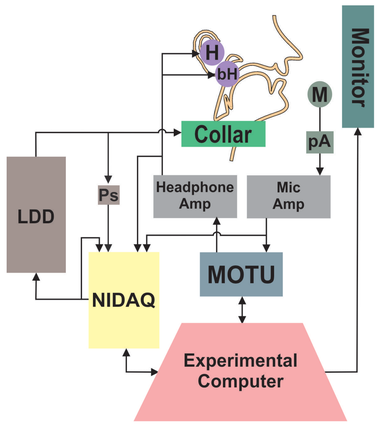
Sample Trial



Experiment 1: Laryngeal Perturbations
- **Physical displacement of the larynx** using a laryngeal displacement device (inflatable balloon placed over the laryngeal prominence)
- Two conditions (x2 sets each):
  - *Without auditory feedback masking*
  - *With auditory feedback masking* (90dB speech-shaped masking noise)

Experiment 2: Auditory Perturbations
- **100 cent downward shift in f_o** heard in earphones, implemented using Audapter
- One condition (x2 sets): Normal auditory feedback

Experimental Setup



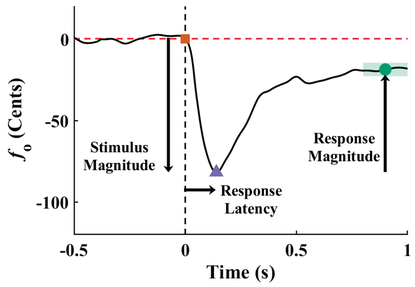
bH = Bone-conduction headphones; **H** = Insert headphones; **LDD** = Laryngeal displacement device; **M** = Microphone; **MOTU** = Soundcard; **NIDAQ** = National Instruments Data Acquisition device; **pA** = Preamplifier; **Ps** = Pressure sensor.

Methods

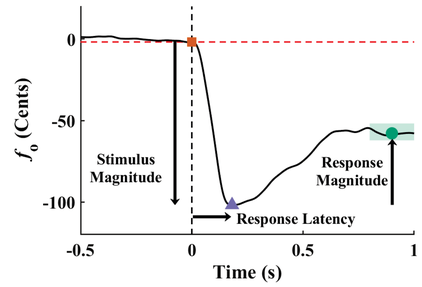
Acoustic Analysis
- f_o(Hz) trace extracted for each trial using Praat, converted to cents
  - Laryngeal perturbation - trace from microphone signal
  - Auditory perturbation - trace from earphone signal
- Four measures captured
  - Initial effect of perturbation (**Stimulus Magnitude**)
  - Participant's compensatory response, in terms of timing (**Response Latency**), magnitude (**Response Magnitude**) and normalized magnitude (**Response Percentage**)

$$Response\ Percentage = \frac{Response\ Magnitude}{Stimulus\ Magnitude} \times 100\%$$

Laryngeal Perturbation Measures

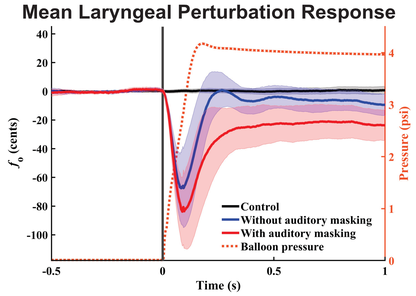


Auditory Perturbation Measures



Results

Mean Laryngeal Perturbation Response



Mean Auditory Perturbation Response

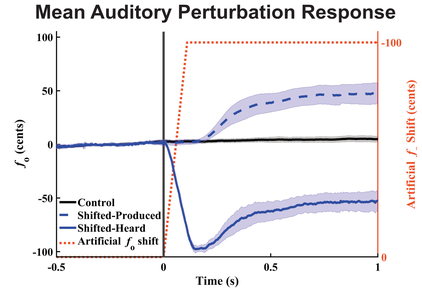


Table 1. Mean (SD) of Measures by Condition

Condition	Stimulus Magnitude (cents)	Response Latency (s)	Response Magnitude (cents)	Response Percentage (%)
Laryngeal perturbation: Without auditory masking	74.91 (51.95)	0.09 (0.02)	67.34 (42.51)	95.34 (19.61)
Laryngeal perturbation: With auditory masking	91.52 (53.31)	0.10 (0.02)	68.79 (37.23)	75.96 (14.94)
Auditory perturbation	101.30 (6.25)	0.17 (0.02)	46.83 (20.65)	46.02 (19.99)

Key References

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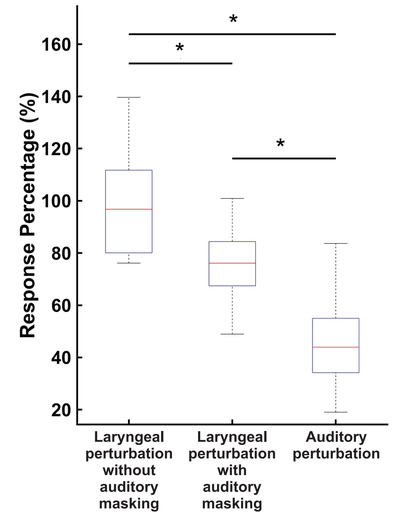
Results

Effect of Condition
- Repeated measures ANOVA: **Significant effect of condition on Response Percentage** ($F(2, 26) = 11.54$, $p < .001$), when controlling for f_o acuity
  - Pairwise comparisons (Tukey's): **all contrasts different** ($p < .01$)
- Repeated measures ANOVA: No significant effect of condition on Stimulus Magnitude, Response Latency, or Response Magnitude, when controlling for f_o acuity

Response Percentage Across Conditions



Correlations

Pearson correlations: No significant relationships between: (1) Response Percentage in laryngeal and auditory perturbation experiments, (2) f_o acuity and Response Percentage in laryngeal and auditory perturbation experiments

α = .01 for all analyses, to account for multiple comparisons

Discussion

- **Greater compensation for laryngeal perturbations when auditory feedback was available** compared to when it was masked
  - Suggests that both auditory and somatosensory feedback control mechanisms contribute to the degree of compensation to a laryngeal perturbation
  - Paradigm effectively dissociated role of somatosensory and auditory feedback control mechanisms — potential for future application to studying voice disorders (e.g., spasmodic dysphonia)
- Degree of **compensation varied as a function of perturbation modality**
  - Laryngeal perturbation without auditory masking (95%) > laryngeal perturbation with auditory masking (76%) > auditory perturbation (46%)
  - Supports hypothesis that, during laryngeal perturbations, somatosensory and auditory feedback controllers work in tandem to compensate for the perturbation, whereas during auditory perturbations, they work in competition
- The degree of **compensation to laryngeal and auditory perturbations were not correlated with each other nor with auditory acuity**

Acknowledgments

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