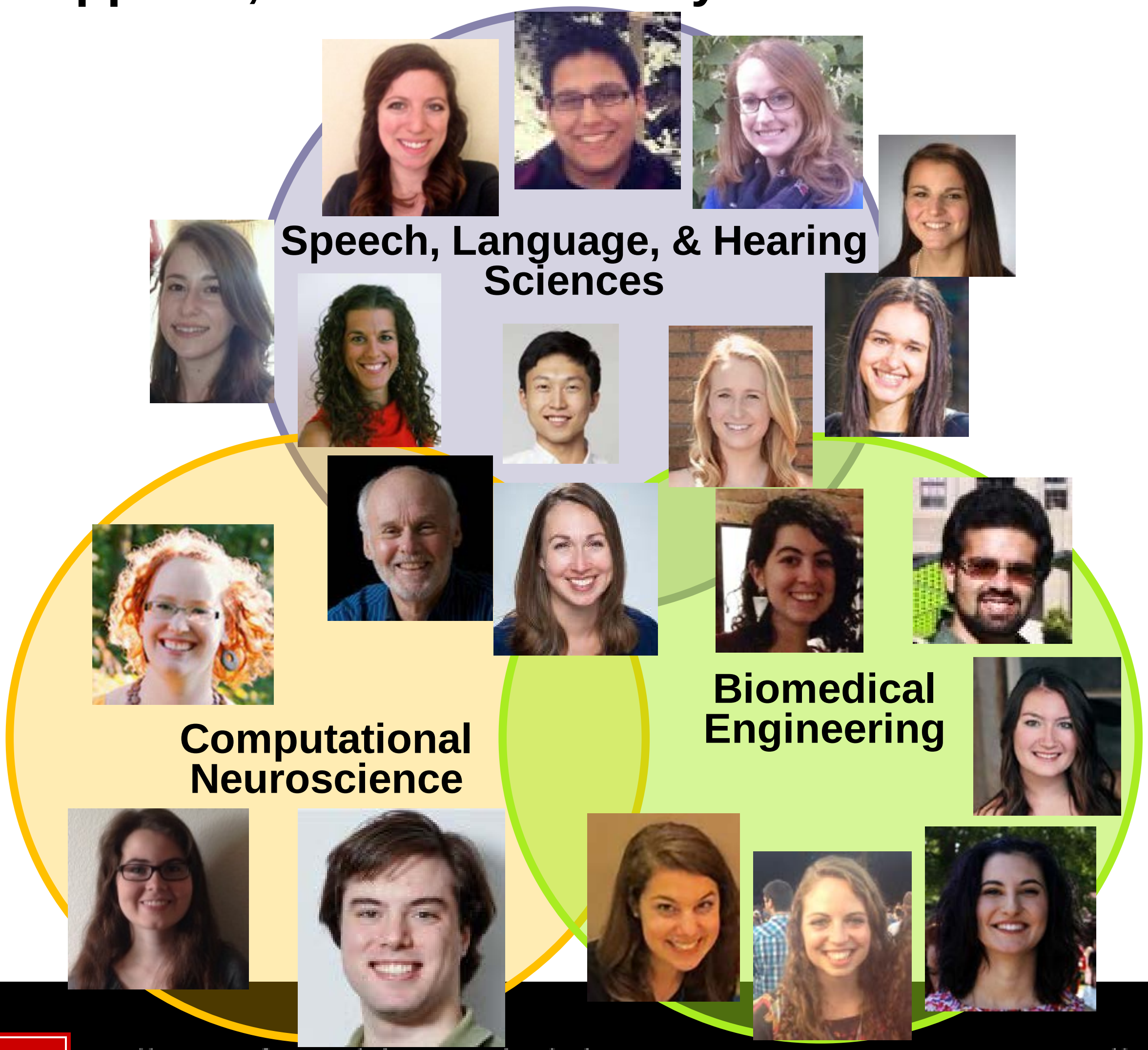
Updates in the assessment of hyperfunctional voice disorders

Cara Stepp
Boston University

Acknowledgements:

Stepp Lab, Boston University:



NIDCD

National Institute on Deafness and Other Communication Disorders

The impact of voice disorders

- U.S. prevalence of voice disorders is 9%[1]
- *Vocal hyperfunction:* 40% of cases[2]
  - “Conditions of abuse and/or misuse of the vocal mechanism due to excessive and/or ‘imbalanced’ muscular forces”[3]
  - Can be the primary cause of voice disorder or secondary to glottal insufficiency
  - Assessment primarily subjective

*[1]Ramig & Verdolini 1998; [2]Roy 2003; [3]Hillman, Holmberg, **Perkell**, Walsh, & Vaughn, 1989*

Motivation

- Individuals with VH are often thought to have increased laryngeal tension
- Direct quantification of tension is … difficult
- Two potential measures:
  - *Kinematic: Stiffness Ratio*
  - *Acoustic: Relative Fundamental Frequency*

Kinematic Stiffness Ratios

- *Kinematic estimates of stiffness* were first developed in the exercise physiology literature[1-4]
- Maximum Velocity / Movement Extent
- Adopted to characterize articulatory gestures[5-9]

[1]Cooke, 1980; [2]Cooke, 1982; [3]Feldman, 1980; [4]Kelso & Holt, 1980; [5]Hertrich & Ackermann, 2000; [6]Kelso, et al., 1985; [7]Ostry, et al., 1987; [8]Ostry, et al., 1983; [9]Ostry & Munhall, 1985

Laryngeal Kinematics

- Gross vocal fold adductory gestures differ as a function of voicing onset (soft, typical, hard)[1-3]
- Qualifying Exam 2007:
  - Model the effects of increased laryngeal stiffness on computed kinematic estimates of stiffness
  - Test predictions on individuals with and without VH

[1]Ostry & Munhall, 1985; [2]Cooke et al.,1997; [3]Munhall & Ostry, 1983

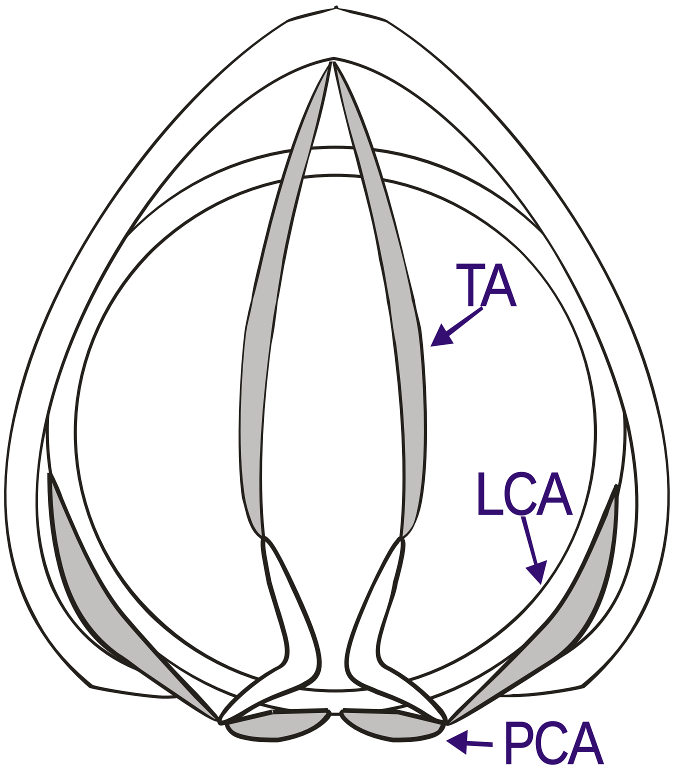
Modeling Hypothesis

Explicitly increasing stiffness in a mechanical model of laryngeal kinematics will increase a ‘stiffness’ parameter based on kinematics

Stepp, Hillman, & Heaton 2010

Model Methods

- 1 df: arytenoid cartilage rotation in 2D
  - No arytenoid translation
  - No arytenoid rotation in the sagittal plane
- Virtual trajectory model; trajectory defined using minimum square jerk
- Muscles = simple springs with parallel stiffness and damping



Modeling Results & Conclusions

- Increasing model stiffness parameters increased the kinematic stiffness ratios

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- Experimental hypothesis:
  - Increasing gesture rate corresponds to an increase in the overall system stiffness
  - If individuals with vocal hyperfunction already have high intrinsic stiffness, **the effects of increasing gesture rates will be mitigated**

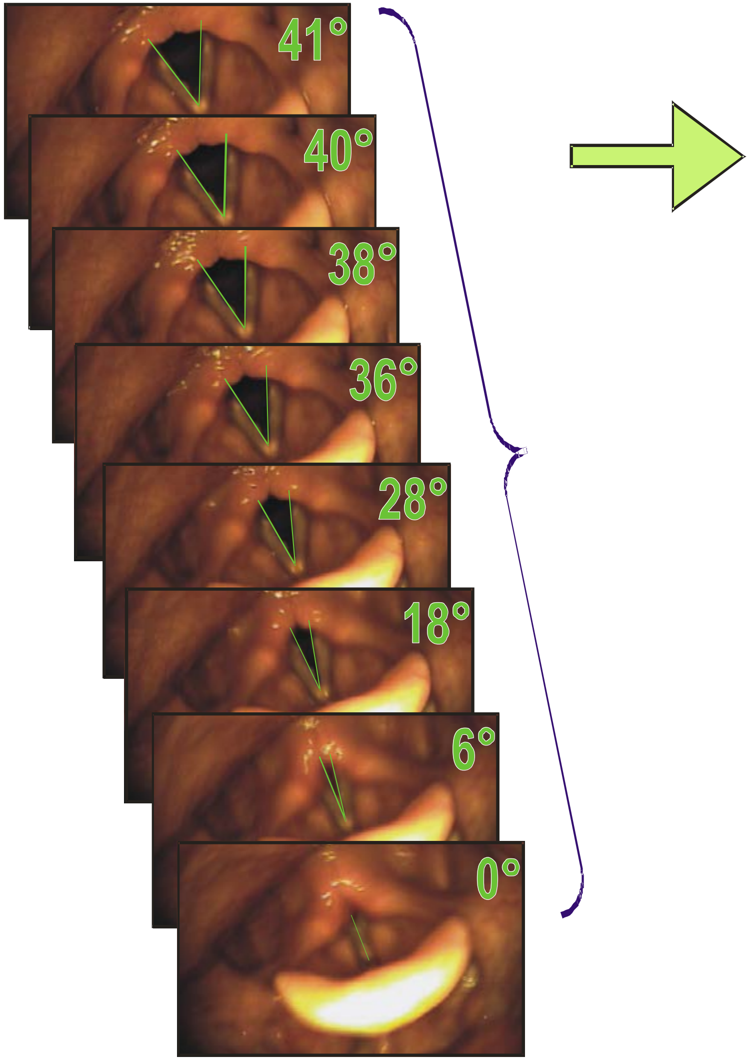
Stepp, Hillman, & Heaton 2010

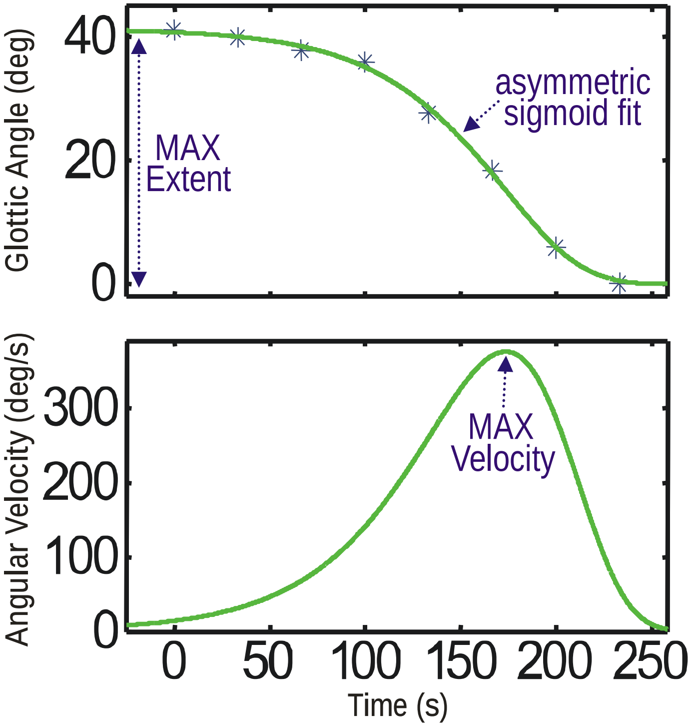
Experimental Methods

- Female Participants:
  - Healthy Normal Voice (N=10)
  - MTD (N=10)
- "sniff-eee" maneuver 3-5 times at 72 (medium) and 104 (fast) gestures/min during transnasal endoscopy

Stepp, Hillman, & Heaton 2010

Experimental Methods

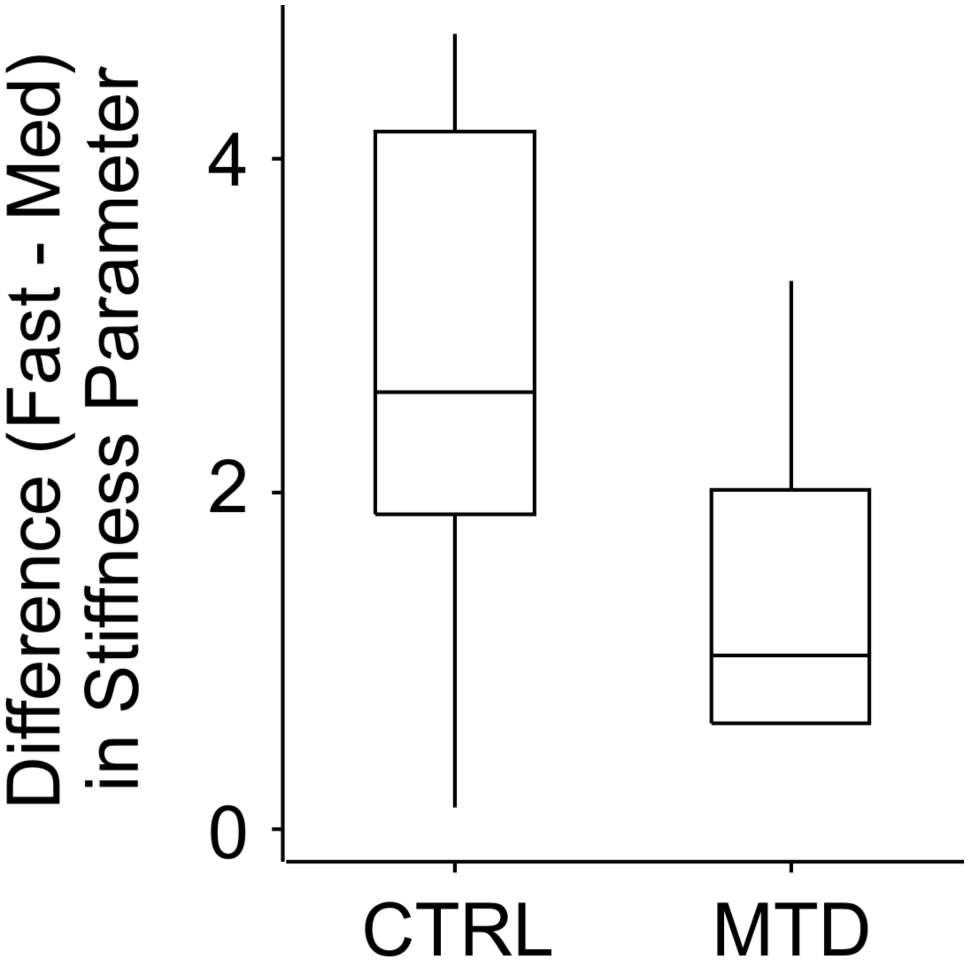




$$\text{Stiffness Ratio} = \frac{\varpi_{MAX}}{\theta_{MAX}}$$

Stepp, Hillman, & Heaton 2010

Results



p* = 0.03

Stepp, Hillman, & Heaton 2010

*(One-tailed Mann-Whitney Test)

Kinematic Stiffness Ratios

- Show differences between controls and VH subjects
- Are not feasible for clinical use!
  - Invasive
  - Time-commitment

Acoustic estimate of laryngeal tension

- Primary symptoms of VH detected via auditory perception
- Can the information be identified quantitatively in the acoustic signal?

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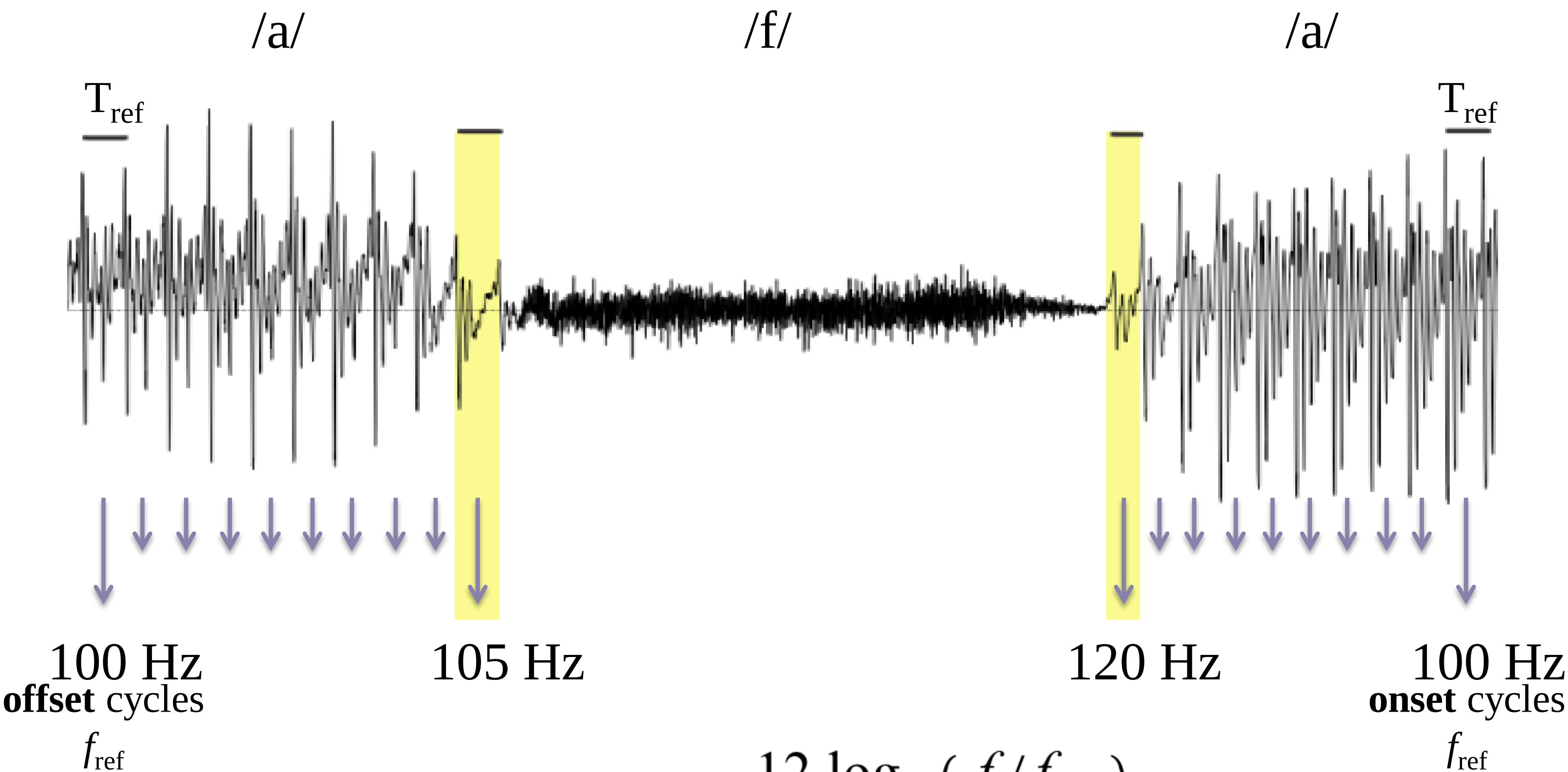
RFF

Relative Fundamental Frequency (RFF)



$$\text{RFF (ST)} = \frac{12 \log_{10}(f/f_{ref})}{\log_{10}(2)}$$

RFF: measure of laryngeal tension?

- Effects of **vocal hyperfunction** on RFF
- Modulation of RFF in individuals with VH:
  - Effects of **surgery**
  - Effects of successful **voice therapy**

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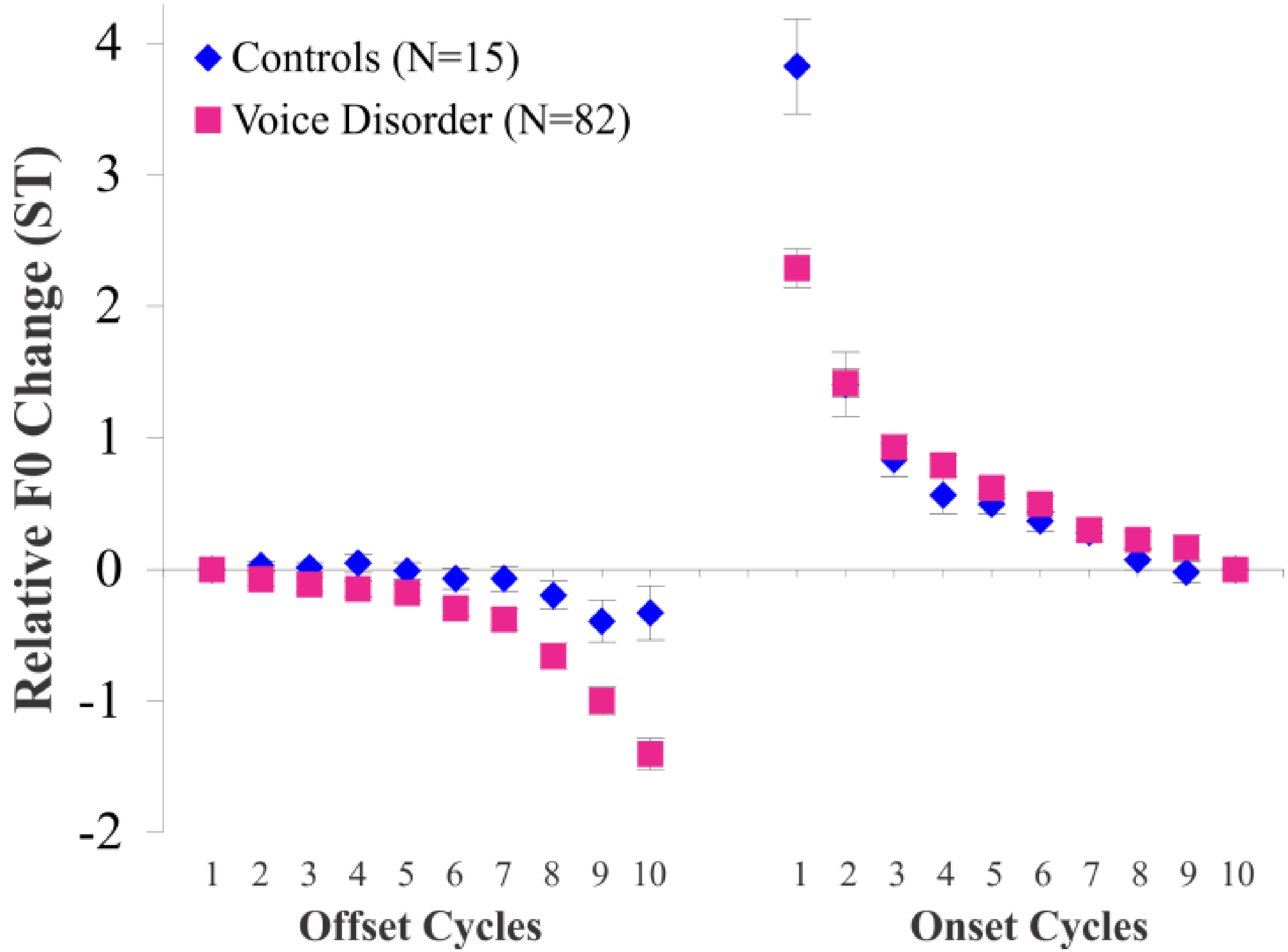
RFF in VH



Stepp, Hillman, & Heaton 2010

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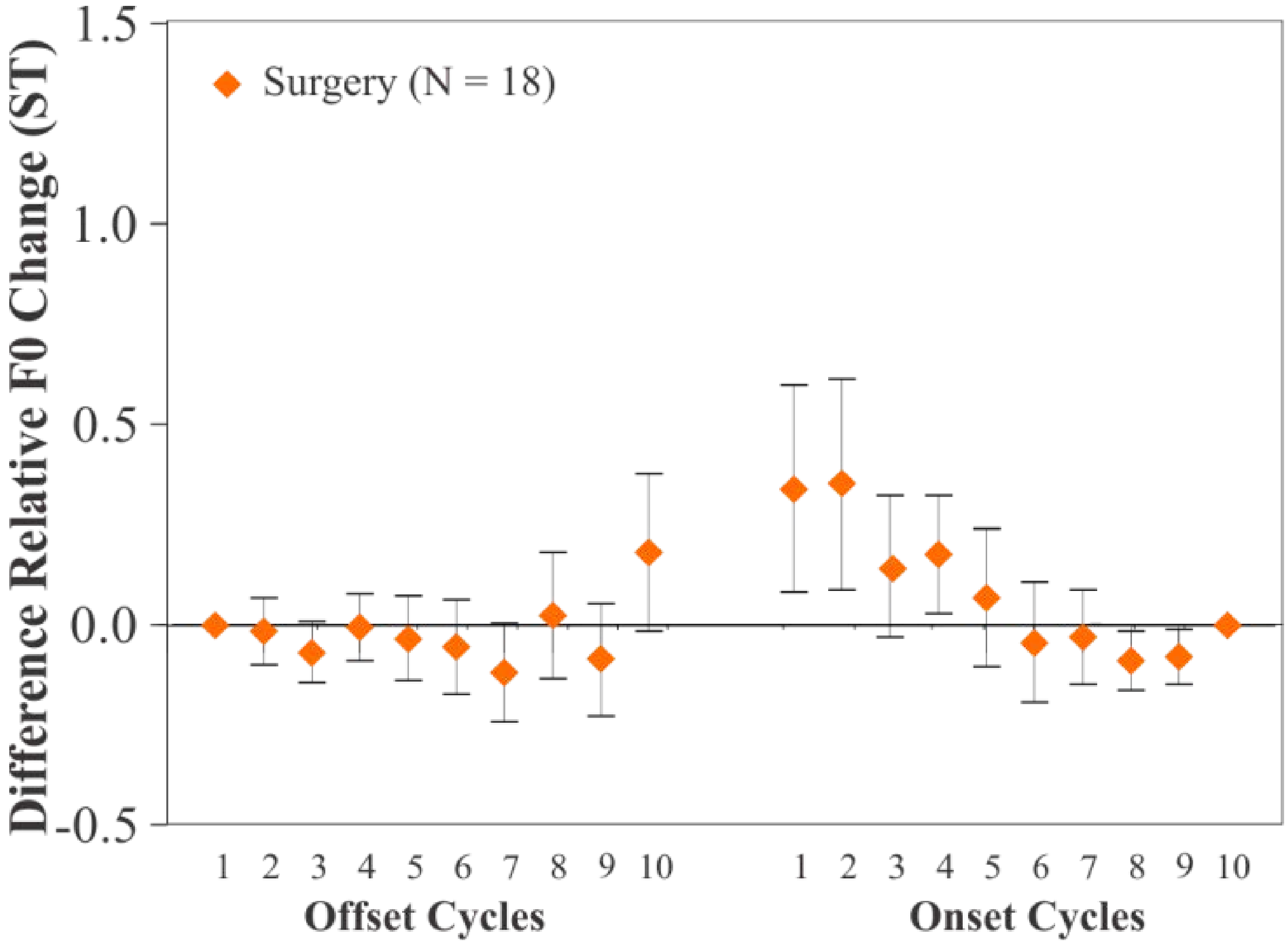
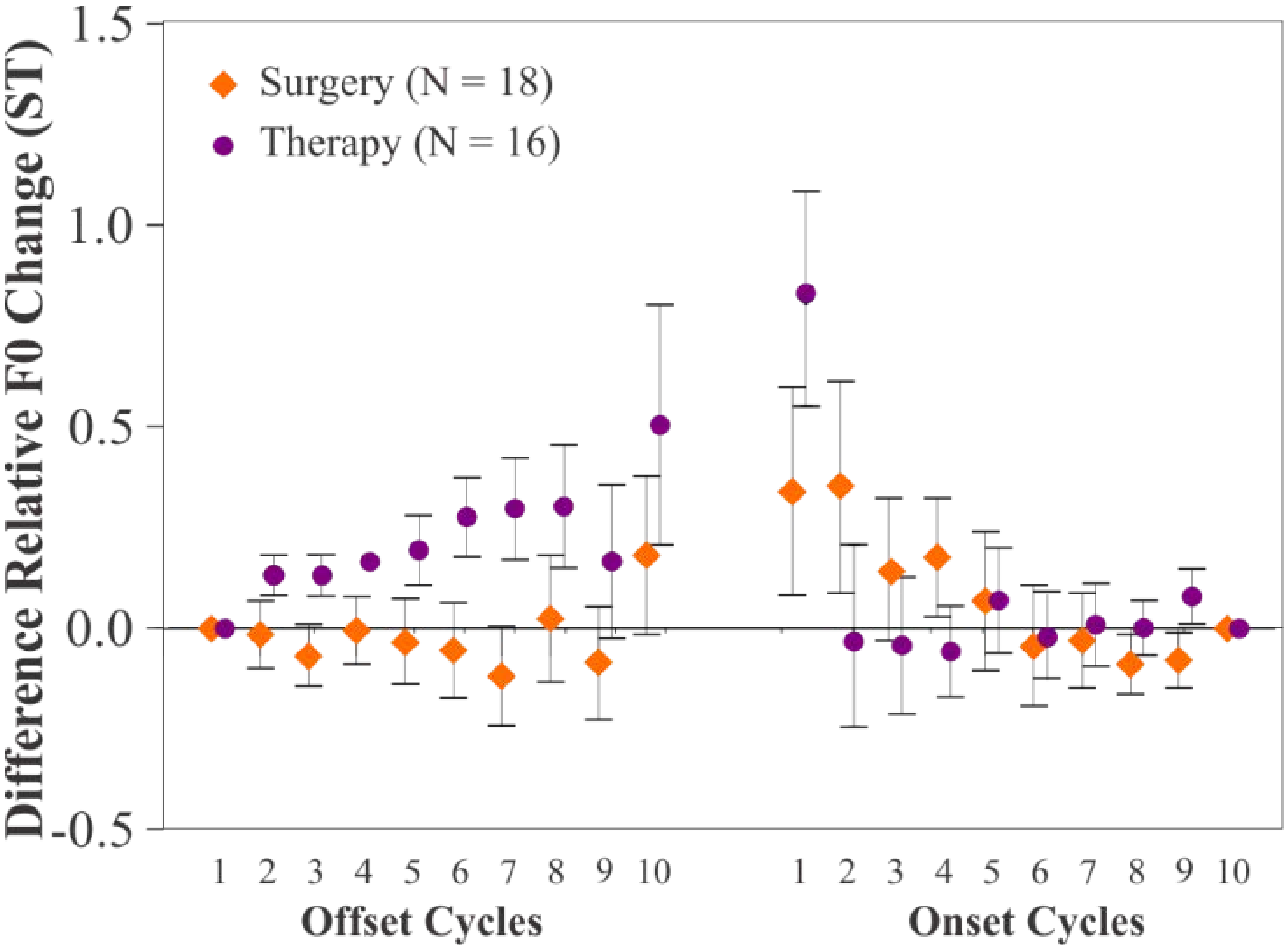
Effects of surgery



Stepp, Hillman, & Heaton 2010

Effects of successful therapy



Stepp, Hillman, & Heaton 2010; Stepp, Merchant, Heaton, & Hillman, 2011

Summary: RFF

- Effects of **VH** ↓ RFF
- Effects of **surgery** in individuals with VH — RFF
- Effects of **voice therapy** in individuals with VH ↑ RFF

RFF: Clinical translation

- Potential clinical applications
  - Treatment outcome
  - VH predictions
- Limitations of manual estimation:
  - Subjectivity
  - Impractical time commitment

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Automation

New Automated Estimates

- Highly correlated with manual estimates
- Discriminate between individuals with voice disorders and those with healthy voices
- Objective
- 20–40 min/speaker → <1 min/speaker!

Lien, Calabrese, Michener, Heller Murray, Van Stan, Mehta, Hillman, Noordzij, & Stepp, In Review.

Current Work

Use automated algorithms to validate RFF as a clinical voice measure!

- Simultaneous measurement of RFF with physiological indicators of laryngeal tension
- Large-scale data collection across multiple clinical sites
  - Across voice disorders
  - As a function of time and treatment phase

Current Work

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RFF vs. Kinematic Stiffness Ratios

Purpose: Investigate the relationship between RFF and a kinematic estimate of laryngeal stiffness during speaker-modulated effort in healthy individuals

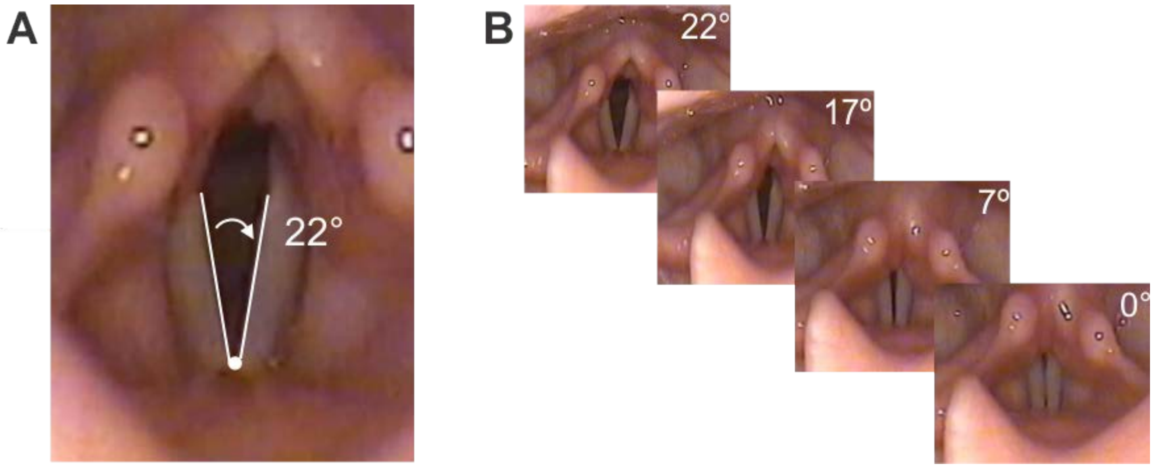
Methods

- Participants
  - Twelve healthy young adults
  - Ages 18 – 31 years (M = 22.7, SD = 4.4; 10 female)
- Protocol: Iterations of /ifi/ while varying vocal effort

	Task	Description
1	Typical Speaking Voice	Typical pitch and loudness of conversational speech
2	Moderate Vocal Strain	Twice the speaker-perceived strain as their typical voice
3	Maximal Vocal Strain	As much speaker-perceived strain as possible
4	Breathy Voice	Allowing extra air to escape while maintaining typical loudness
5	Controlled Speed	Largo (50 words per minute)
6	Hard Glottal Attack	Overemphasize the first sound of each token
7	Push-Pull Exercise	Pull up on the arms of the chair while straining their voice

Methods

- Automated RFF algorithms[1]
- Kinematic Stiffness Ratios:
  - Flexible endoscope (distal chip); Halogen light source
  - Similar methods to previous work



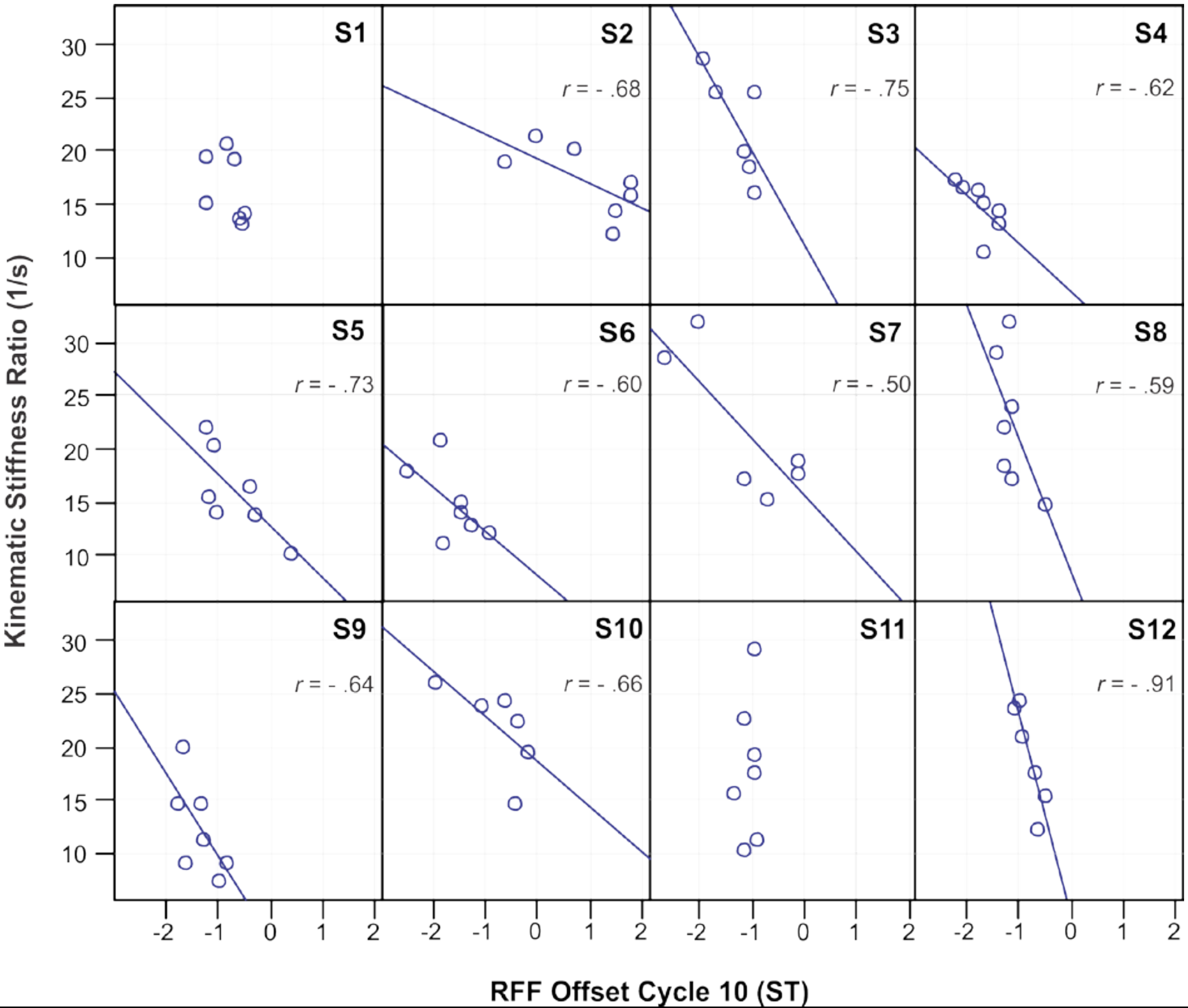
[1]*Lien, Calabrese, Michener, Heller Murray, Van Stan, Mehta, Hillman, Noordzij, & Stepp, In Review.*

Results

- Linear mixed effect analysis: $R^2 = 0.52$
- RFF offset cycle 10 and onset cycle 1 both significantly predicted the kinematic stiffness ratios

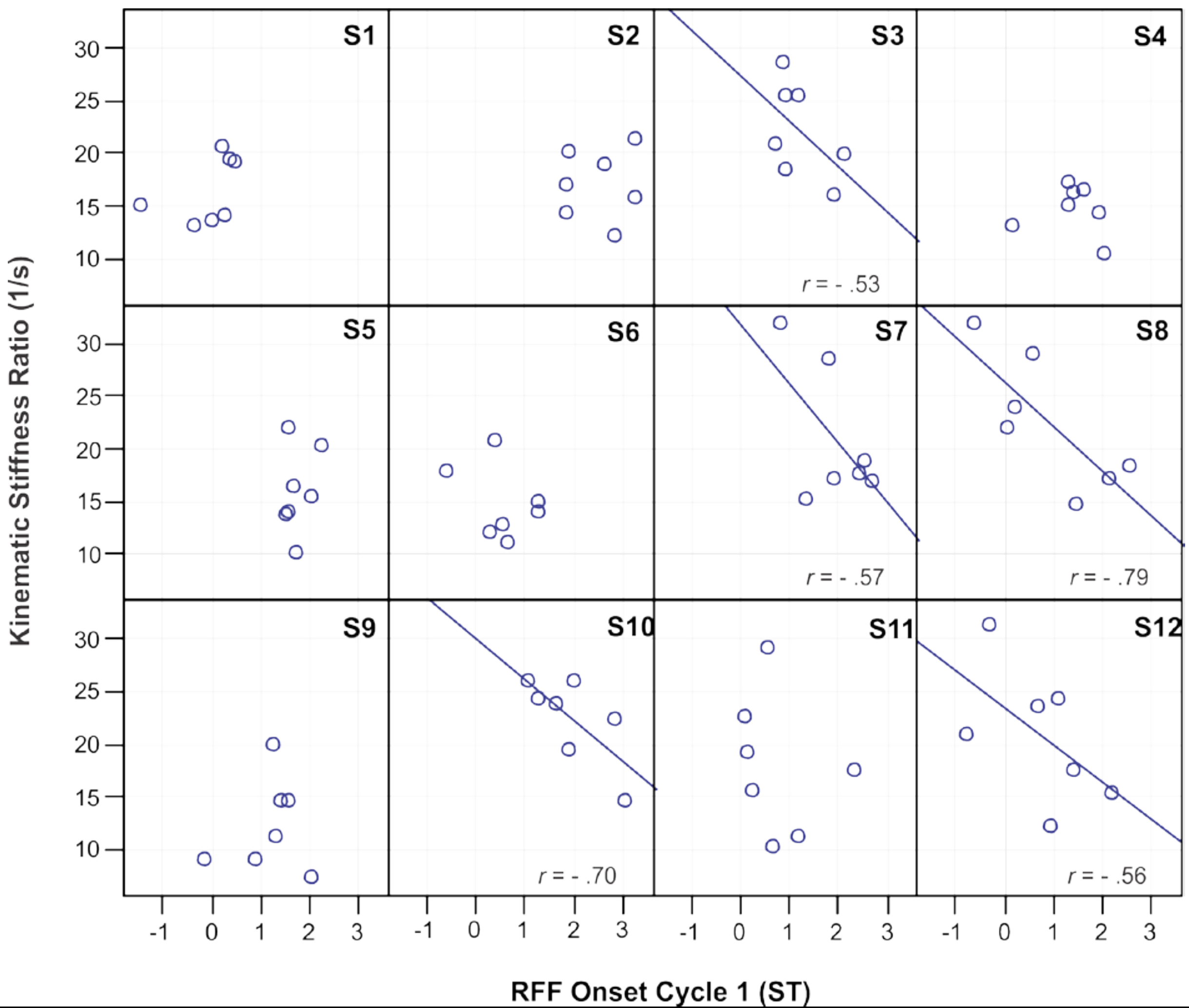
	df	F	p	η_p^2
RFF offset cycle 10	1, 79	27.5	< 0.001	.29
RFF onset cycle 1	1, 79	6.1	0.016	.08

Results: RFF offset cycle 10



- Range:
  r = - 0.9 to 0.2
- 83% exhibited at least a moderate ($r \leq$ - 0.5) negative correlation

Results: RFF onset cycle 1



- Range:
  r = - 0.79 to 0.46
- 42% exhibited at least a moderate ($r \leq$ - 0.5) negative correlation

Discussion

- Kinematic stiffness ratios and RFF are significantly related
- RFF offset and onset may capture different physiological phenomena
- Individual variation

Limitations and Future Research

- Participants with VH
- Self-perceptions of laryngeal tension (self-rating)
- High-speed imaging

Questions?

Acknowledgements

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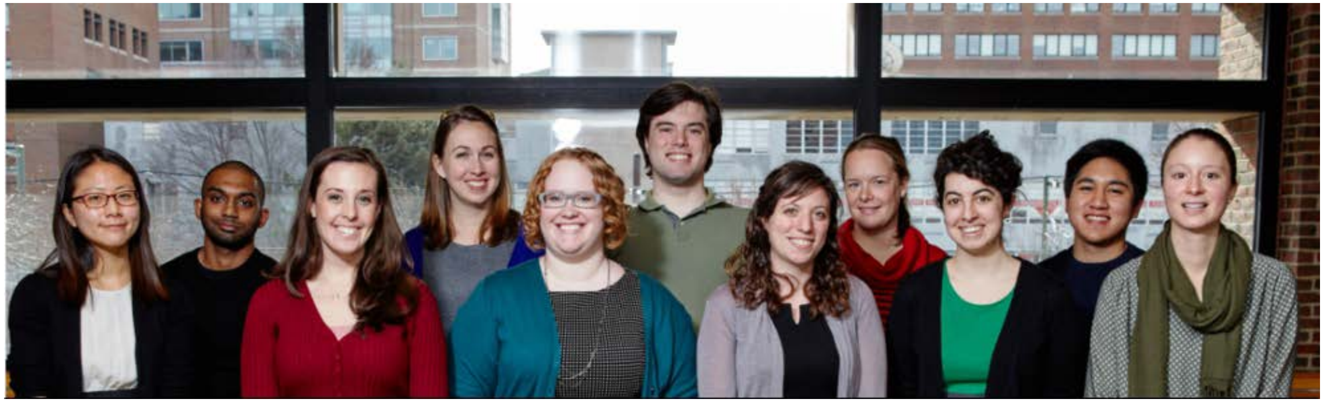
- Daryush Mehta, PhD



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