Updates in the assessment of hyperfunctional voice disorders

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NIDCD
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College of Health & Rehabilitation Sciences: Sargent College
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.

- 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

![Images showing glottic angles from 0° to 41°]

- **Time (s)**
- **Angular Velocity (deg/s)**
- **Glottic Angle (deg)**

**MAX Extent**

**MAX Velocity**

**asymmetric sigmoid fit**

**Stiffness Ratio**

\[
\frac{\sigma_{MAX}}{\theta_{MAX}}
\]

Stepp, Hillman, & Heaton 2010
Results

\[ p = 0.03^* \]

(One-tailed Mann-Whitney Test)

Stepp, Hillman, & Heaton 2010
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?

RFF
Relative Fundamental Frequency (RFF)

\[ RFF \text{ (ST)} = \frac{12 \log_{10}(f/f_{ref})}{\log_{10}(2)} \]
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*
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
RFF in VH

- Controls (N=15)
- Voice Disorder (N=82)

Source: Stepp, Hillman, & Heaton 2010
RFF: measure of vocal hyperfunction

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RFF: measure of laryngeal tension?

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- Modulation of RFF in individuals with VH:
  - Effects of *surgery*
  - Effects of successful *voice therapy*
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
- Effects of surgery in individuals with VH
- Effects of voice therapy in individuals with VH
RFF: Clinical translation

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

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 $\rightarrow$ <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

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

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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

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

- Automated RFF algorithms
- 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

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>$F$</th>
<th>$p$</th>
<th>$\eta_p^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFF offset cycle 10</td>
<td>1, 79</td>
<td>27.5</td>
<td>&lt; 0.001</td>
<td>.29</td>
</tr>
<tr>
<td>RFF onset cycle 1</td>
<td>1, 79</td>
<td>6.1</td>
<td>0.016</td>
<td>.08</td>
</tr>
</tbody>
</table>
Results: RFF offset cycle 10

- **Range:**
  \[ r = -0.9 \text{ to } 0.2 \]

- 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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