Zen and art of vocal mechanics:
Vocal Tremor

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• Financial:
  – I am an affiliate instructor and receive royalties from MedBridge Inc related to my online courses on vocal tremor

• Non-Financial:
  – Research focus relevant to the presentation topic

Are tremor disorders diagnosed in the limbs the same as those affecting speech?

“You are never dedicated to something you have complete confidence in. No one is fanatically shouting that the sun is going to rise tomorrow.”

-Robert M Pirsig

Roadmap of Talk

What is tremor?
What is vocal tremor (VT)?
  – General characteristics
  – Conceptual model
Evaluation of Vocal Tremor
  – Auditory-Perceptual Patterns
  – Acoustic Patterns
  – Visual-Perceptual Patterns: Nasoendoscopy

WHAT IS TREMOR?

• An involuntary rhythmic oscillation of opposing muscle groups.
• One of the most common neurologic movement disorders.

1. Louis (2016); Elble (2016); Crawford & Zimmerman (2011)

Tremor Classification

• ACTION-INDUCED
  – Purposeful movement
  – Postural

• RESTING
  – Supported from gravity


Hallett (2014); Weiss (2016)
Neural Pathways for Tremor

- Neural "Oscillators"
  - Primary motor cortex
  - Cerebellum
  - Basal Ganglia Globus Pallidus Pathways
- Tremor Patterns
  - Initiation of tremor
  - Basal ganglia pathways
  - Amplitude of tremor
  - Cerebello-thalamocortical network

Hallet (2014); Louis (2010); Raethjen & Deuschl, 2012

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What is vocal tremor?

- Neurological voice disorder
- Involuntary rhythmic modulation of
  - PITCH (fo)
  - LOUDNESS (SPL)
- Can be a primary symptom, or associated with:
  - Essential Tremor
  - Dystonia
  - Parkinson Disease

Vocal Tremor (VT)

- General characteristics
  - Best perceived during sustained phonation task
  - Modulation of pitch and loudness can be further characterized
  - RATE (3-12 Hz)
  - MAGNITUDE (20-30%)
  - Significantly slower speaking rate than normal speakers (3 vs 5 syllables/s)
  - May improve (lessen) when drinking alcohol, depending on etiology

CONCEPTUAL MODEL

The acoustic consequence of tremor affecting structures within the speech mechanism resulting in an involuntary rhythmic modulation of the voice


HOW DO WE CONCEPTUALIZE VOCAL TREMOR PHYSIOLOGY?

1. Respiratory System Oscillation
   - Subglottal pressure modulation
   - Ho: SPL modulation

(Simulations provided by Brad Story, University of Arizona)
HOW DO WE CONCEPTUALIZE VOCAL TREMOR PHYSIOLOGY?

1. Larynx Oscillation
   - $f_0$ modulation (vocal fold length changes)
   - $H_0$: $f_0$ modulation
   - Glottal width modulation
   - $H_0$: SPL modulation ($f_0$ modeled as constant)

(Simulations provided by Brad Story, University of Arizona)

4. Vocal Tract
   - Pharyngeal diameter and length modulation
   - $H_0$: Formant modulation
     - $F_1$ and $F_2$ modulation associated with SPL modulations

(Simulations provided by Brad Story, University of Arizona)

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Guiding Principles for Detection and Evaluation of Vocal Tremor

- **Detection & Characteristics**
  - Important to compare sustained vs connected speech
  - Acoustic measures can be diagnostic
  - Laryngeal imaging confirms involved structures
- **Severity**
  - Compare between speech contexts
  - Ability to volitionally modify voicing duration

Auditory-Perceptual Evaluation

- Determine:
  - Presence/absence
  - Communication impact (i.e. severity)
VOCAL TREMOR BY SPEECH CONTEXT

Sustained Phonation vs. Connected Speech

Sometimes, the devil is in the details

"An experiment is never a failure solely because it fails to achieve predicted results."

-Robert M Pirsig

Vocal Tremor Severity by Voicing Duration

- Legato vs Staccato
  - Sample 1:
  - Sample 2:
Voicing durations under 500ms = normal or mildly severe vocal tremor

Vocal Tremor Evaluation Speech Tasks:

- **Sustained phonation using /a/ and /i/ (laryngeal muscle testing)**
  - Comfortable, High, Low Pitches (CT versus TA)
  - Comfortable + Loud (Interarytenoid, LCA)
  - Comfortable + Soft (PCA)
- **Connected Speech (severity judgments)**
  - Sentences with all-voiced speech sounds compared to
  - Sentences loaded with voiceless speech sounds
  - Conversation

**Comparison of two cases**

<table>
<thead>
<tr>
<th>Sustained Phonation</th>
<th>Connected Speech</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td></td>
</tr>
</tbody>
</table>

What is your perception of vocal tremor severity for each during sustained phonation? Connected speech?

**TAKE HOME POINTS:**

**Auditory-Perceptual Evaluation of Vocal Tremor**

- **DETECTION** = Sustained phonation
- **SEVERITY** = Connected speaking vs Sustained phonation
- **POTENTIAL FOR THERAPY:** Ability to reduce voicing duration ≤ 500 ms
Acoustic patterns can be diagnostic of vocal tremor.

Listener perceptual study by "source"

Perceptual threshold

- Larynx (Adduction/abduction)
- Larynx (Length change)
- Vocal tract
- Respiratory system

Acoustic measures

- Vocal tremor characteristics:
  - Identify representative 1-2 second segment of acoustic modulation to measure:
    - Rate
    - Magnitude/extent
  - Compare across fo, SPL, F1 and F2 patterns
  - Connected speech sample
  - Articulation rate

Acoustic analysis methods were superior to listener perception for detecting any of the sources of modulation studied.

Example of acoustic measures

- Rate = cycles/second
- Amplitude
  - Measure the maximum and minimum value for each cycle of modulation
  - \(\frac{(X_{\text{max}} - X_{\text{min}})}{(X_{\text{max}} + X_{\text{min}})} \times 100 = X\%
  - SPL amplitude in dB SPL is on a logarithmic scale
  - Convert dB SPL measures to Pascals (linear)
Example of Acoustic Measures

<table>
<thead>
<tr>
<th>Modulation</th>
<th>F1 Max (Hz)</th>
<th>F1 Min (Hz)</th>
<th>F1 Mod (Hz)</th>
<th>F1 Mod (Mag)</th>
<th>F0 Sort</th>
<th>F0 Mean (Hz)</th>
<th>F0 Mean (STD)</th>
<th>Abs Pres Max (Pa)</th>
<th>Abs Pres Max (STD)</th>
<th>Abs Pres Mean (Pa)</th>
<th>Abs Pres Mean (STD)</th>
<th>Abs Pres Mod (Pa)</th>
<th>Abs Pres Mod (STD)</th>
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<td>228.00</td>
<td>27.0</td>
<td>5.6%</td>
<td>68.30</td>
<td>66.40</td>
<td>0.052</td>
<td>0.042</td>
<td>0.010</td>
<td>10.9%</td>
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<td>230.00</td>
<td>21.0</td>
<td>4.4%</td>
<td>68.10</td>
<td>66.30</td>
<td>0.051</td>
<td>0.041</td>
<td>0.010</td>
<td>10.3%</td>
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<tr>
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<td>229.00</td>
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<td>66.70</td>
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<td>227.00</td>
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<td>68.60</td>
<td>66.00</td>
<td>0.054</td>
<td>0.040</td>
<td>0.014</td>
<td>14.9%</td>
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<td>5.6%</td>
<td>68.10</td>
<td>65.90</td>
<td>0.051</td>
<td>0.039</td>
<td>0.011</td>
<td>12.6%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**average**

- F0 rate: 4.5 Hz
- Extent: 5.7%
- SPL rate: 4.5 Hz
- Extent: 6.9%
- F1 rate: 5 Hz
- Coefficient of variation: 0.05%
- F2 rate: 5 Hz
- Coefficient of variation: 0.05%

**Speaking Rate (syllables/sec)**

- Average rate: 2.5

**Association of Formant Modulation with Vocal Tract Tremor**

Ji A., Story B., Durbin-Johnson B., & Barkmeier-Kraemer, JM

**Hypothesis:**
- Vocal Tract Oscillation = Formant modulation (F1 and/or F2)
- N=12 subjects diagnosed with VT who underwent a standard clinical voice evaluation.
  - Acoustic Recordings
  - Endoscopic Evaluation

**FINDINGS:**
- Only those exhibiting oscillation of vocal tract structures showed formant modulation.
- The posterior pharyngeal wall (p=0.04) and base of tongue (p=0.021) were found to be significant for F1 and F2 modulation, respectively.


**Acoustic Measures can be Diagnostic of Vocal Tremor**

- Acoustic recordings can detect vocal tremor when it is not perceptible
- Formant modulation is indicative of vocal tract structure involvement

**Nasoendoscopic Imaging**

- Diagnostic of tremor versus other movement disorders
- Influences treatment recommendations
  - Identify upper airway structures with tremor
Nasoendoscopic Imaging

- **Videoendoscopy**
  - Evaluation of gross laryngeal and pharyngeal motion and structure (halogen light)

- **Videostroboscopy**
  - Evaluation of vocal fold vibratory characteristics and structure (xenon or LED light)

Advanced Technological Laryngeal Imaging

Flexible Scope

Scope Placement

Rigid Scope Placement

Laryngeal Imaging: Methods

- **Light Source Differences**
  - **Videoendoscopy**
    - Constant halogen light source
  - **Videostroboscopy**
    - Xenon or LED strobe light source

Nasoendoscopic Imaging Exam

- Overall laryngeal structure
- Vocal fold structure and symmetry
- Glottic configuration during vocal fold closure
- Vocal fold vibratory patterns
- Supraglottal activity


NASOENDOSCOPIC IMAGING

Vocal Tremor Scoring System (Bove’ et al, 2006)

- Rate the severity of tremor (using nasoendoscopy) in the
  - Supraglottis
  - True vocal folds (VF)
  - Base of tongue
  - Pharynx
  - Soft palate

Severity rating scale:
- 0 = none,
- 1 = mild/intermittent,
- 2 = moderate, or
- 3 = severe

- Those with tremor severity ≥ within the true VFs responded best to Botox treatment
- Those with tremor outside the larynx did worse.
NASOENDOSCOPIC IMAGING: Visual-Perceptual Assessment

- Determine the prominent structure(s) contributing to the vocal tremor
  - **Laryngeal structures**
    - Easiest to perceptually detect
  - **Base of tongue and oropharynx**
    - Detected easily perceptually
    - Associated with modulation of F1 and F2
    - May undermine Botox® treatment benefit
  - **Respiratory system is sometimes involved**
    - Associated with slow rate (~3 Hz) SPL modulation

Vocal Tremor Case Example

Revisiting the Conceptual Model: Tremor Examples

Summary

- Vocal tremor is a neurological voice problem
  - action-induced tremor affecting speech structures
- The voice evaluation should elucidate the
  - Auditory-Perceptual and
  - Acoustic characteristics of vocal tremor across speech tasks
- Nasoendoscopic imaging of affected structures can:
  - Inform affected structures and musculature, and
  - Confirm tremor as the source of voicing patterns
- Voice evaluation findings for vocal tremor are critical to treatment planning

DISCUSSION

References

References