Speech Analysis for Medical Diagnostics
From Senses to Sensors

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Mission
To advance knowledge and clinical practice through basic and applied research on speech & swallowing disorders.

- Conduct physiologic studies on speech and swallowing to develop predictive, explanatory models of impairment
- Develop computer-aided diagnostic tools for assessing speech and swallowing
- Test the efficacy of novel interventions to improve speech and swallowing
Disclosures
I have no relevant financial or nonfinancial relationship within the products or services described, reviewed, evaluated or compared in this presentation.

Major sources of funding

01 Speech as a diagnostic pathway
02 Clinical research applications
  • Speech diagnostics
  • Speech intervention
03 Future directions
Outline
Speech Analysis for Medical Diagnostics
From Senses to Sensors

01 Speech as a diagnostic pathway
02 Clinical research applications
  • Speech diagnostics
  • Speech intervention
03 Future directions

Speech Diagnostics
Research priorities set by needs of patients, SLPs, clinicians, & pharma

- How are we doing?
  • Need for better diagnostic tools
    • Few standardized speech assessments
    • Best current practices are largely subjective
      (e.g., ear and eye)
    • Recent studies suggest diagnostic accuracy is low for...
      • early detection of bulbar involvement
      • measuring response to intervention
        • minimal detectable change may be too large
          (Stipancic et al., 2018)
  • Exploring diagnostic efficacy of quantitative speech assessments in progressive MSD for improved...
    • early identification
    • progress monitoring
    • outcomes in efficacy trials
A biopsychosocial framework
Speech as a diagnostic pathway

- Neurologic
- Sensoriperceptual
- Anatomic
- Linguistic
- Cognitive
- Affect

The result of processes occurring in multiple domains…
...ultimately conveyed through the speech motor system

A biopsychosocial framework
Speech as a diagnostic pathway

- Neurologic
- Sensoriperceptual
- Anatomic
- Linguistic
- Cognitive
- Affect

Each domain is susceptible to neurologic dysfunction

Green & Nip, 2010; Nip & Green, 2013

Quantitative speech motor testing
Instrumentation-based protocol

https://www.jove.com/video/2422/a-protocol-for-comprehensive-assessment-bulbar-dysfunction

The Tools
Quantitative speech motor testing

Speech biomechanics
Stroboscopic capture technologies
High-speed videos
Acoustic analyses
Dynamic MRI
Quantitative
Automated
Data Reduction and Analysis Software
Speech biomechanics
Optical 3D motion capture

Optical 3D motion capture

Optical 3D motion capture

Optical 3D motion capture
Baby and parent
How to record speech movements

Speech and Feeding Disorders Lab

Optical 3D motion capture

Cortex software
www.motionanalysis.com
Example of lip movement data

22 features
• Number of repetitions
• Duration of task (s)
• Repetition rate (hz)

Healthy

Amyotrophic lateral sclerosis

3-D Electromagnetic Articulography (EMA)

Tongue sensors

Yurusova et al., 2011
What about the larynx?

“With all due respect…, you can’t argue with the fact that the tongue is superior to the larynx”

Roadmap to improved quantitative speech testing

- Refine protocols and instruments
  - Clinical feasibility
  - Accuracy

- Use as endpoints in clinical trials
  - Estimate effect size of intervention

- Test diagnostic efficacy
  - Variable screening (effect size, ROC)
  - Precision
  - Sensitivity & Specificity
  - Responsiveness
  - Validity
  - Added value

- Technology development
  - Speech biomechanics
  - Hardware
  - Algorithms
  - Feature engineering
  - Protocols

- Wide-spread clinical implementation requires...
  - efficient, simple protocols
  - evidence of diagnostic and predictive power
A 3000 millisecond Intermission

Outline
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01 Speech as a diagnostic pathway
02 Clinical research applications
  • Speech diagnostics
  • Speech intervention
03 Future directions
Clinical research applications

Speech Diagnostics

- Study 1: Early identification of bulbar motor involvement due to ALS
- Study 2: Mechanisms of speech decline in ALS
- Study 3: Differential diagnosis of subtypes of PPA

Speech Interventions & Management

- Study 4: The effect of Nuedexta on bulbar motor function in persons with ALS
- Study 5: Lip strength exercises on facial motor recovery following facial transplantation
- Study 6: Prolonging oral communication using technology in ALS

Study 1

Early detection of bulbar involvement in ALS
A comparison of self-report, clinician observation, & instrumental methods

Research question
Are current best practices for assessment adequate?

Dr. Kristen Allison

Approach

Identify cohort of "presymptomatic" participants with ALS

PATIENT SELF-REPORT

ALSFRS-R bulbar subscore
- 3 question: speech, swallowing, salivation
- 5-point scale: Subscore impairment: Normal function 0, Pre-symptomatic 0-12, Symptomatic >12

• 22 of 36 spinal-onset patients were identified as presymptomatic

Allison, K.M., Yunusova, Y., Wang, J., Berry, J.D., & Green, J.R., 2017
Identify cohort of "presymptomatic" participants

Test if speech performance is affected

Determine the most sensitive measure of bulbar involvement

Approach

• Estimate effect sizes for differences between controls & presymptomatic patients
  • Clinician speech severity rating (visual analog scale)
  • Quantitative speech testing

Clinician speech severity ratings

Visual analog scale

(Sussman & Tjaden, 2012)

• Inter-rater reliability coefficient = 0.52
  • Suggest limited range between normal & mild speech severity (presymptomatic) tested limits of auditory perception

• Blinded to diagnosis
• Amplitude normalized
• Randomized order

Quantitative speech measures

• 6 measures
  • Known to be responsive to early change in bulbar function
  (Green et al., 2013)

<table>
<thead>
<tr>
<th>Speech subsystem</th>
<th>Measure</th>
<th>Experimental Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>Percent pause time (%)</td>
<td>Reading of Bamboo passage</td>
</tr>
<tr>
<td>Phonatory</td>
<td>Max F0 (Hz)</td>
<td>High pitch &quot;whistling of A&quot;</td>
</tr>
<tr>
<td>Resonatory</td>
<td>Nasalance (%)</td>
<td>Sentence repetition &quot;Buy Bobby a puppy&quot;</td>
</tr>
<tr>
<td>Articulatory</td>
<td>Lip movement (mm/s)</td>
<td>Sentence repetition &quot;Buy Bobby a puppy&quot;</td>
</tr>
<tr>
<td></td>
<td>DDK rate (sylls/s)</td>
<td>Read correctly and clearly as possible on one breath</td>
</tr>
<tr>
<td></td>
<td>Articulation rate</td>
<td>Reading of Bamboo passage</td>
</tr>
</tbody>
</table>
Patients and Clinicians did not detect the onset of early speech symptoms that were evident in:
- pause time
- lip speed

Accuracy of SLPs’ detection of speech abnormality
Binary judgement = dysarthria/no dysarthria

- Blinded to diagnosis
- Amplitude normalized
- Randomized order

• 11 SIT sentences
• Inter-rater reliability = 82% agreement 2 SLPs

Accuracy of SLPs’ detection of speech abnormality
Binary judgement = dysarthria/no dysarthria

% of subjects rated as having dysarthria

42%
Healthy Controls

Accuracy of SLPs’ dysarthria diagnosis was low
42% of controls rated by SLPs as having dysarthria
Identify cohort of speech "presymptomatic" participants
Determine if speech performance differs from age-matched controls
Determine the most sensitive measure of bulbar involvement

✓ ROC
✓ Sensitivity & specificity

Results
ROC analysis
Most accurate diagnostic marker of early bulbar involvement?

Presymptomatic group from healthy controls

<table>
<thead>
<tr>
<th>Measure</th>
<th>AUC</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pause time (% of total time)</td>
<td>0.88</td>
<td>0.80</td>
<td>0.91</td>
</tr>
<tr>
<td>Lip speed (mm/s)</td>
<td>0.72</td>
<td>0.69</td>
<td>0.80</td>
</tr>
<tr>
<td>Artic rate (sylls/s)</td>
<td>0.72</td>
<td>0.69</td>
<td>0.73</td>
</tr>
<tr>
<td>Speaking rate (sylls/min)</td>
<td>0.71</td>
<td>0.82</td>
<td>0.54</td>
</tr>
<tr>
<td>Speech severity rating</td>
<td>0.52</td>
<td>0.93</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Conclusions

• Quantitative speech measures
  • most sensitive measures to early bulbar involvement

• Current best practices (i.e., PROs, clinician detection)
  inadequate for early detection

• Motivates additional research in to:
  • articulatory measures of bulbar involvement
  • multivariate diagnostic models (pause & DDK)
Clinical research applications

Speech Diagnostics
- Study 1: Early identification of bulbar motor involvement due to ALS
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Speech Interventions & Management
- Study 4: The effect of Nuedexta on bulbar motor function in persons with ALS
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- Study 6: Prolonging oral communication using technology in ALS

Study 2
Mechanisms of speech decline in ALS

Research question
What are the relative contributions of the speech subsystems to intelligibility loss?


Methods

- Participants
  - 66 persons with ALS (37 males + 29 females, Mean Age = 57 years)
  - Varied in location of disease onset
    - 15 bulbar, 41 spinal, 6 mixed, 4 unknown
  - Varied in speech severity
    - Intelligibility: 3% ~ 100%, Mean = 88, SD = 23
    - Speaking rate: 10 WPM ~ 275 WPM (Mean = 144, SD = 49)

- Data set
  - Longitudinal recording with multiple sessions
  - A multi-factorial database
    - 152 instrumental measures of the motor functions of the four speech subsystems
      - Respiratory
      - Phonatory
      - Articulatory
      - Resonatory
**Data analysis**

Data driven approach

Variable screening
152

Variable reduction
5

Subsystem model

- 2 articulatory
- 1 resonatory
- 1 phonatory
- 1 respiratory

Model intelligibility as a function of subsystem predictors (biphasic model)

**Data analysis**

Data driven approach

Variable reduction
Identify the most predictive variables for each subsystem
152 instrumental measures

Principal component analysis on sub-system variables

Exclude correlated variables

Select variables based on factor analysis

Data reduction identifies the most predictive variables for each subsystem

Individual-subsystem models - Predict intelligibility based on each subsystem

Multi-subsystem model - Predict intelligibility based on all subsystems

- Selection predictors of intelligibility
- Regression for missing data
- Variance inflation factor (VIF)
- Breusch-Pagan test

**Results**

A two-phase model of speech intelligibility decline

- Slow decline phase
- Rapid decline phase

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Slow decline phase</th>
<th>Rapid decline phase</th>
<th>Independent contribution</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articulatory</td>
<td>Vels of lip and jaw movements</td>
<td>DDK count</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Resonatory</td>
<td>Nasal airflow</td>
<td>-</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Phonatory</td>
<td>Maximum F₀</td>
<td>-</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>% Speech pauses</td>
<td>-</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
Clinical implications & future directions

- Several novel hypotheses were generated that require further exploration
  - A two phase model of intelligibility decline (slow, fast)
    - Respiratory declines were early, but weak predictors of intelligibility loss
    - Articulatory declines were the most responsive throughout the disease
    - Phonatory measures alone may not be good diagnostic indicators of bulbar ALS
- Optimizing articulation may be most efficacious treatment goal throughout the course of the disease
- Limitations of the model
  - Replication is needed
  - Further testing required to determine the...
    - Diagnostic accuracy of the model
    - Clinical significance of observed subsystem changes

Clinical research applications

Speech Diagnostics
- **Study 1**: Early identification of bulbar motor involvement due to ALS
- **Study 2**: Mechanisms of speech decline in ALS
- **Study 3**: Differential diagnosis of subtypes of PPA

Speech Interventions & Management
- **Study 4**: The effect of Nuedexta on bulbar motor function in persons with ALS
- **Study 5**: Lip strength exercises on facial motor recovery following facial transplantation
- **Study 6**: Prolonging oral communication using technology in ALS
Study 3
Assessing speech motor involvement in persons with primary progressive aphasia: Articulation rate

Research question
What is the diagnostic efficacy of articulation rate as a quantitative indicator of speech motor involvement in PPA?

Background
Primary progressive aphasia (PPA)
- Motivation for research on speech diagnostics
  - Speech dysfluency is used to identify PPA variants

Speech Dysfluency
Semantic PPA (u/mN)
Logopenic PPA (u/mN)
Nonfluent PPA (u/mN)

- Accurate subtyping and speech assessment are important for improving....
  - Early diagnosis
  - Clinical monitoring of disease progression
  - Identifying neural basis of disorder
  - Selection of behavioral treatments
  - In the future, selection of pathology-specific biologically-based therapeutics

- Variants are associated with different underlying pathologies
  - Nonfluent > tau-positive pathology (Gorno-Tempini et al., 2011)
  - Semantic > ubiquitin-positive, TDP-43-positive pathology
  - Logopenic > AD pathology

Quantifying articulation rate
Task: Western Aphasia Battery (WAB) Picture Description

Articulation Rate
# syllables / speech duration

Speech Pause Analysis is custom MATLAB software used to detect speech vs. pause segments (Green et al., 2004)
Introduction

Why articulation rate?

- Prior finding (Cordella et al., 2017)
- Articulation rate is a sensitive measure of speech involvement in PPA, particularly the nfvPPA

Method

- Participants
  - Cross-sectional analysis
    - N=64 (22 nfvPPA, 23 lvPPA, 19 svPPA)
    - Severely stratified by Clinical Dementia Rating (CDR) language score
      - very mild (0.5), mild/moderate (1, 2)
  - Longitudinal analysis
    - N=39 (15 nfvPPA, 14 lvPPA, 10 svPPA)
      - Initial visit and approximately one-year
  - Imaging analysis
    - N=37 (15 nfvPPA, 10 lvPPA, 12 svPPA, 15 HC)

- Measures
  - Articulation Rate (syll/s)
  - MRI cortical thickness of motor speech ROIs using...
    - A parcellation scheme (Cai et al., 2014) with a granular representation of the speech network

Results

Baseline AR is reduced in nfvPPA even during mild stages
Results
AR declines more rapidly for nfvPPA

Fixed effects: intercept + time + diagnostic subgroup + time*diagnostic subgroup

Random effects: intercept | subject

nfvPPA vs lvPPA; p = .004
nfvPPA vs svPPA; p = .015

-0.69 syll/s/year - 0.04 syll/s/year - 0.14 syll/s/year

Results
Slower AR correlates with thinner cortex in premotor, supplementary motor areas

HYPOTHESIS-DRIVEN ROI ANALYSIS
POST-HOC WHOLE CORTICAL ANALYSIS

Conclusions
• For PPA, articulation rate is a good diagnostic measure for...
  • detecting speech motor involvement
  • progress monitoring
• Additional work is needed to determine efficacy as behavioral endpoint in clinical trials
• The neuroanatomic localization findings add support to the biologic validity of the measure
  • Exploratory whole brain analysis is warranted (i.e., basal ganglia, cerebellum)
Clinical research applications

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Study 4
The effects of Nuedexta® on speech motor impairment due to ALS
A short (30 day) phase II, double-blind, randomized, cross-over RCT trial

Research question
Does treatment with Nuedexta improve speech in persons with ALS?

Background
- Researchers are actively searching for pharmacologic interventions for...
  - minimizing ALS motor symptoms
  - preserving or restoring motor function

- Only two FDA drugs approved for ALS
  - Riluzole
  - Edaravone

Green, J. R., Allison, K. M., Cordella, C., Richburg, B. C., Pione, G., Berry, J. D., Meade, E. A., Foss, E. P & Smith, R. A., 2018
Background

- Anecdotal reports of speech & swallowing improvements in response to Nuedexta®
  - An FDA-approved treatment for emotional lability associated with pseudobulbar affect (Smith et al., 2016)

- Nuedexta®
  - Combination of dextromethorphan (DM) and quinidine (Q)
  - The precise molecular mechanism of action of DM/Q are unknown
    - 26 potential binding sites (Werling et al., 2007)
    - A number of studies indicate that DM acts, at least in part, as an agonist at 5-HT-4Rs
    - Some evidence for neuroprotective effects of DM in nonclinical models of CNS injury (Werling et al., 2007)

Nuedexta® clinical trial

- Motivated initiation of clinical trial evaluating effect on speech and swallowing (Smith et al., 2016)
  - phase II, double-blind, randomized, cross-over

![Nuedexta® clinical trial](image)

Smith et al., (2016)

- Results indicated improvements in self-report scale (CNS-BFS score)

![Results indicated improvements in self-report scale](image)

Smith et al., (2016)
Primary endpoint: CNS-BFS

<table>
<thead>
<tr>
<th>Sample Questions: Speech</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. My speech is difficult to understand.</td>
</tr>
<tr>
<td>2. My speech is difficult to understand.</td>
</tr>
<tr>
<td>3. My speech is difficult to understand.</td>
</tr>
<tr>
<td>4. My speech is difficult to understand.</td>
</tr>
<tr>
<td>5. My speech is difficult to understand.</td>
</tr>
<tr>
<td>6. My speech is difficult to understand.</td>
</tr>
<tr>
<td>7. My speech is difficult to understand.</td>
</tr>
</tbody>
</table>

- 3 domains: 7 questions; 1-5 (6) score
- Best score: 21; worst score: 112

Smith et al., (2016)

Nuedexta® clinical trial

- Smith et al., (2016) report only included data from patient self-report or clinical ratings
- No quantitative, objective analyses of speech and swallowing
- Approx. 30% were non-responders

- Current study
  - To determine if Nuedexta® has a measurable change on speech?
  - Data
    - Pre and post recordings of Rainbow Passage from 10 participants

Variables

- Quantitative speech measure using SPA algorithm
  - [Green et al., 2004]

- Speech severity rating using DME [Zraick & Liss, 2000]
  - 3 experienced Speech-Language Pathologists
  - Inter-rater reliability coefficient = .86 - .94
  - SLPs assigned a number to each recording relative to a modulus (moderate dysarthria severity scale not from dataset, arbitrarily assigned a severity level of 100)

- PROs speech subscores
  - ALSFRS-R
  - CNS-BFS (Smith et al., 2017)
### Variables

<table>
<thead>
<tr>
<th>Measure Phase</th>
<th>Pre (Mean (SD))</th>
<th>Post (Mean (SD))</th>
<th>p</th>
<th>Effect size (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALSFRS-R Total Active</td>
<td>36.55 (6.6)</td>
<td>36.91 (7.3)</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>ALSFRS-R Total Placebo</td>
<td>35.91 (6.3)</td>
<td>35.45 (6.1)</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>ALSFRS-R Speech Active</td>
<td>2.18 (0.9)</td>
<td>2.36 (0.9)</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>ALSFRS-R Speech Placebo</td>
<td>2.45 (0.9)</td>
<td>2.36 (0.9)</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>CNS-BFS Speech Active</td>
<td>22.82 (9.3)</td>
<td>21.27 (9.6)</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>CNS-BFS Speech Placebo</td>
<td>23.18 (9.1)</td>
<td>22.36 (9.9)</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>SLP severity rating (0-30) Active</td>
<td>16.91 (16.6)</td>
<td>15.15 (14.9)</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>SLP severity rating (0-30) Placebo</td>
<td>16.10 (16.6)</td>
<td>15.50 (14.9)</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Total pause duration Active</td>
<td>0.79 (0.2)</td>
<td>0.62 (0.1)</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>Total pause duration Placebo</td>
<td>0.78 (0.2)</td>
<td>0.62 (0.1)</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>Speech pause duration Active</td>
<td>22.96 (11.5)</td>
<td>21.39 (11.5)</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Speech pause duration Placebo</td>
<td>22.60 (11.5)</td>
<td>21.39 (11.5)</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Total pause duration Active</td>
<td>16.87 (18.6)</td>
<td>13.58 (14.2)</td>
<td>0.04</td>
<td>*</td>
</tr>
<tr>
<td>Total pause duration Placebo</td>
<td>16.87 (18.6)</td>
<td>18.10 (19.1)</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td># Pause events Active</td>
<td>20.6 (17.2)</td>
<td>17.3 (10.9)</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td># Pause events Placebo</td>
<td>19.4 (13.6)</td>
<td>20.3 (15.5)</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Pause event duration Active</td>
<td>0.75 (0.2)</td>
<td>0.70 (0.2)</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Pause event duration Placebo</td>
<td>0.78 (0.2)</td>
<td>0.82 (0.3)</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>Percent pause time Active</td>
<td>2.19 (0.7)</td>
<td>2.49 (0.7)</td>
<td>0.02</td>
<td>*</td>
</tr>
<tr>
<td>Percent pause time Placebo</td>
<td>2.32 (0.8)</td>
<td>2.29 (0.6)</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Speaking rate Active</td>
<td>125.09 (44.3)</td>
<td>127.22 (46.0)</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Speaking rate Placebo</td>
<td>121.94 (44.3)</td>
<td>119.43 (46.0)</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Articulation rate Active</td>
<td>168.64 (48.0)</td>
<td>161.49 (48.6)</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Articulation rate Placebo</td>
<td>163.60 (49.6)</td>
<td>159.15 (48.2)</td>
<td>0.33</td>
<td></td>
</tr>
</tbody>
</table>

* = statistically significant

### Results

- Cohen’s D Effect sizes = abs (post – pre) active phase

#### % pause time decreased during the active phase
- grey lines = individual data
- red lines = mean data

- Change in % pause time was driven by...
  - longer speech segments
  - slightly shorter pauses

- Table showing statistical data with p-values and effect sizes.
Conclusions

• Provides additional evidence for the positive impact of nuedexta on...
  • one or more of the neural systems that control speech motor function
• Supports the high responsiveness of....
  • pause measures for detecting subclinical changes in bulbar motor function

Significance

• Limitations
  • Short trial, low dosage, and small number of participants
• Observation of subclinical changes in speech are important for improved drug discovery
  • Suggests “nonresponders” received some physiological benefit from the drug
• Findings justify additional research
  • Can the benefits can be amplified?
    • increased dosages
    • longer exposures
  • when the drug is combined with other therapeutic agents
  • The mechanisms of improved speech
    • affect cognition? respiratory drive? articulation?
  • Characteristics of patients who respond to treatment?

Clinical research applications

Speech Diagnostics
  • Study 1: Early identification of bulbar motor involvement due to ALS
  • Study 2: Mechanisms of speech decline in ALS
  • Study 3: Differential diagnosis of subtypes of PPA

Speech Interventions & Management
  • Study 4: The effect of nuedexta on bulbar motor function in persons with ALS
  • Study 5: Lip strength exercises on facial motor recovery following facial transplantation
  • Study 6: Prolonging oral communication using technology in ALS
Study 5
Restoring facial motor function following facial transplantation

Research question
Pilot study on the safety and efficacy of lip strength training on lip motor recovery and speech

Background
• Over 38 facial transplantations completed worldwide since 2005
• 12 in the United States
• 8 at Brigham & Women’s Hospital

Eligibility
• Severe facial disfigurement
• Loss of facial function for speech and feeding
• Pass evaluations of... mental and emotional health
coping skills
communication skills
ability to manage post-transplant care
• No history of chronic neurologic conditions
• Not pregnant
• Good health
• no serious medical problems, such as diabetes, heart disease or untreated cancer
• no recent infections
• Nonsmokers
Compatibility considerations

• Blood type
• Tissue type
• Skin color
• Comparable ages of donor and recipient
• Compatible facial size of donor and recipient

Warning!
Extensive injuries will be displayed

Before and After

Perehoda et al., 2018
Deficits following surgery

• Persistent challenges following surgery include:
  • impaired facial expression
  • reduced speech intelligibility
  • impaired chewing and swallowing

What is she saying?
18 month follow up

Lip strengthening intervention

• Single patient case study
• 8-week protocol
• Practice schedule
  • 10 reps 3x per day at 60% of maximum compression
• Feedback
  • pressurized bulb attached to pressure gauge

Assessment of motor recovery

Facial MoCap & EMG
Results and Conclusion

- The intervention resulted in modest gains in lip strength & lip kinematics
- Provides motivation for:
  - Increasing load to 80% of maximum strength
  - Testing on other patients

Clinical research applications

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Study 6

Virtual talker
A device that generates speech from lip movement

Goal
- Prolong oral communication in persons with oral paresis due to neurologic disease or laryngectomy
Virtual Talker
A device that generates speech from facial movement

Goal
• Prolong oral communication in persons with oral paresis due to neurologic disease or laryngectomy

Speech Movements \[\rightarrow\] Phrase \[\rightarrow\] Speech playback

My name is Jordan

The mouth as an optimal channel of communication
Natural Requires no special training
Flexible Leaves hands and eyes free
Efficient Has high data rate

3D Electromagnetic Articulograph

<table>
<thead>
<tr>
<th>3D Articulograph</th>
<th>UL</th>
<th>Upper Lip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LL</td>
<td>Lower Lip</td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>Tongue Tip</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>Tongue Blade</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>Tongue Body Front</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>Tongue Body Back</td>
</tr>
</tbody>
</table>
Machine learning classification of mouth movements

Demo: Offline phrase recognition

Virtual talker prototype
Future directions for synthesizer

- Ongoing system tuning
  - Decrease latency of recognition and synthesis
  - Increase vocabulary size
- Test efficacy of approach for persons with impaired articulation
- Work on flexible modes of speech synthesis output
  - Text-to-speech (TTS) technology

Outline
Speech Analysis for Medical Diagnostics
From Senses to Sensors

01 Speech as a diagnostic pathway
02 Clinical research applications
  - Speech diagnostics
  - Speech intervention
03 Future directions

Advantages
quantitative speech testing

- Objective, repeatable, precise
- Can detect sub perceptible & subclinical changes
- Are robust to an unstable phonatory source (voice) & excessive nasality
Roadmap to improved quantitative speech testing

Refine protocols and instruments

Use as endpoints in clinical trials

Quantitative speech testing

Technology development

Test diagnostic efficacy

• Wide-spread clinical implementation requires...
  • efficient, simple protocols
  • evidence of diagnostic and predictive power

Barriers to clinical implementation

• Price of equipment
  • Optical motion camera systems: $8k-$200k
• Data reduction requires expertise & time consuming
• Wide-spread clinical implementation requires...
  • Efficient, simple protocols
  • Evidence of diagnostic and predictive power

MOUTHMETRICS Project

To develop a low-cost & clinician-friendly facial motor assessment tool using 3D depth sensing cameras

Green, Richburg, Markan, & Berry, 2016
Facial tracking using depth sensing

Infrared depth sensing camera

MouthMetrics
A low-cost, comprehensive facial motor assessment tool
Module 1. Static exam of facial morphology

Anatomical snapshot

Module 2. Dynamic testing of facial motor function

Diadochokinetic task (DDK)

Automated DDK Analysis

22 features
- Number of repetitions
- Duration of task (s)
- Repetition rate (Hz)

Rong et al., (2018). Automatic extraction of abnormal lip movements from the alternating rate task in amyotrophic lateral sclerosis. IJSLT
Clinical report of facial motor structure & function exam

Cellphones for monitoring ALS in the wild

Machine learning diagnostic models
Roadmap to improved medical speech analytics

- Refine protocols and instruments
- Use as endpoints in clinical trials
- Technology development
- Test diagnostic efficacy

Questions?

Thanks!