Neuroimaging of Children with Speech Sound Disorders

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Jonathan Preston
Erin Redle
Jennifer Vannest
Lawrence Shriberg
Outline of Presentation

• Introduction to the Session- Dr. Lewis
• Basic Principles of fMRI - Dr. Vannest
• Study 1:
  – Overview, participants, and paradigms – Dr. Redle
  – Madison CAS Phenotype – Dr. Shriberg
  – FMRI Study Results- Dr. Vannest
• Study 2: Dr. Preston
• Questions and Panel Discussion- All
Session Introduction

Neuroimaging of Children With Speech Sound Disorders

American Speech-Language-Hearing Association
National Convention, Atlanta, GA
November 16, 2012

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Imaging Genetics

1. Identify genes
2. Expression in Brain
3. Behavior
The Emerging Field of Imaging Genetics

• Imaging genetics is the use of imaging technology as a phenotype to evaluate how genes that influence disorders are expressed in the brain.

• Both genetics and environment are important in determining brain function. Integrating genetics with neuroimaging will improve our understanding of speech and language disorders.

• There is a need for novel analytic, statistical and visualization techniques.
Genetic Architecture of a Complex Trait

SSD, LI, or RD  
Neuroprocessing

Environmental factors
Scope of the problem

- Is there a link between speech sound and language disorders and dyslexia?
- Chromosomes 1, 3, 6, 15

[Grigorenko PNAS, Sept 3, 2003]
### Linkage Results for Spoken Language and Written Expression (Lewis et al., 2011)

<table>
<thead>
<tr>
<th>Chromosome</th>
<th>Spoken Language at Early Childhood</th>
<th>Written Expression at School-age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromosome 1</td>
<td>Articulation</td>
<td>Written vocabulary</td>
</tr>
<tr>
<td></td>
<td>Vocabulary</td>
<td>Reading decoding</td>
</tr>
<tr>
<td></td>
<td>Phon. Memory</td>
<td>Spelling</td>
</tr>
<tr>
<td>Chromosome 3</td>
<td>Articulation</td>
<td>Written vocabulary</td>
</tr>
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<td></td>
<td>Vocabulary</td>
<td>Spelling</td>
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<td></td>
<td>Phon. Memory</td>
<td>Reading decoding</td>
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<td>Speeded Naming</td>
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<tr>
<td>Chromosome 6</td>
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<td>Spelling</td>
</tr>
<tr>
<td></td>
<td>Phon. Memory</td>
<td></td>
</tr>
<tr>
<td>Chromosome 15</td>
<td>Oral Motor</td>
<td>Reading decoding</td>
</tr>
<tr>
<td></td>
<td>Articulation</td>
<td>Spelling</td>
</tr>
<tr>
<td></td>
<td>Phonological Memory</td>
<td></td>
</tr>
</tbody>
</table>
What are specific genes that may underlie speech sound disorders?

- **FOXP2**: Located on 7q13; a brain expressed transcription factor that affects brain development; identified in the KE family (Liegeios et al., 2003).
  
- **ROBO1 and ROBO2**: Located on chromosome 3; guides axons and influences neuronal axon growth; identified in dyslexics in Finland (Nopola-Hemmi et al., 2001).
  
- **KIAA0319, TTRAP, and DCDC2**: Located on chromosome 6; genes disrupt neuronal migration; identified in dyslexic by numerous research groups (Grigorenko et al., 2000; Smith et al., 2007).
  
- **BDNF**: Brain-derived neurotrophic factor related to nerve growth and differentiation in the brain (Stein, unpublished).
  
- **DYX8**: Region on chromosome 1 that demonstrates pleiotropy for SSD and dyslexia (Miscamarra et al., 2007).
  
- **Aromatase (CYP19A1)**: Located on 15q21.2; This gene regulates estrogen synthesis in specific brain areas. It is related to synaptic plasticity and axonal growth (Anthoni et al., 2012).
On the left, controls without a history of speech and language disorders show the expected activation in the language areas while repeating nonsense words. On the right, participants with a history of speech sound disorders show under activation of the language areas during repetition of nonsense words (Tkach et al., 2011).
Collaborative Study with CWRU, CCHMC, and U. Of Wisconsin

- **The first objective** is to compare neural substrates used in speech motor planning and production, fine motor planning and praxis, and visual-auditory perception in children with CAS, with speech delay and with typically developing children.

- **The second objective** is to determine how well current clinical measures correlate with observed neurophysiological differences in speech motor planning and production in children with CAS, speech delay and typically developing children.

- **The third objective** is to determine how genes influence neural development result in neurological processing differences in children with CAS and speech delay as compared to typically developing children.
Clinical Implications

• An improved understanding of the genetic and neurological underpinnings of CAS and speech delay will:
  – Identify the biological mechanisms that underlie both typical and disordered speech.
  – Aid in the early identification of children at risk for CAS and speech delay.
  – Facilitate the development of more specific and effective therapies.
  – Early identification and more effective therapies will result in improved long-term academic, occupational and social outcomes.
References


References

Basic Principles of fMRI

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Assistant Director, Pediatric Neuroimaging Research Consortium
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Based on the assumption that the brain is “functionally segregated”

- isolate a particular process experimentally
- examine relative changes in neural activity – a comparison between “active” and “baseline” conditions
- E.g. listening to speech vs. listening to noise
Magnetic Resonance Imaging (MRI)

- Participant is placed in a strong magnetic field
- Radio transmitter/receiver around area to be imaged
- Safety concerns: magnetic items will be drawn to the center of the magnet

- Many other substances (especially metals) can cause distortions in images
- Electromagnetic interference in environment
- Significant acoustic noise
• White matter, grey matter and cerebrospinal fluid have 3 different magnetic properties. This allows the 3 different kinds of tissue to be separated with MRI.

• Gradients in the magnetic field are used as a “grid” to localize regions of tissue.
MRI vs. fMRI

**MRI** studies brain **anatomy**.

**Functional** MRI (fMRI) studies brain **function**.

(From Jody Culham’s fMRI for Newbies)
Process of interest -> Neuronal Activity -> Increased Metabolism and Bloodflow -> Increased Deoxygenated blood

Deoxygenated blood has magnetic properties and creates local changes in the magnetic field

**BOLD response:**
Blood Oxygen Level - Dependent
• Relatively low spatial resolution (for MRI)
• Sensitive to BOLD response
• 1 brain volume takes 2 sec to acquire
• Scan for 5-7 minutes
• Alternate between active and baseline conditions

Structural Data

• High spatial resolution
• 1 brain volume takes 6 min to acquire
fMRI: Experimental Design Issues

Because of the slow timing of the hemodynamic response, we try to optimize the design of fMRI experiments to be as sensitive as possible to relative increases in bloodflow.

We also must take into account behavioral characteristics of the task during active and baseline conditions.
“HUSH” or “Sparse” techniques take advantage of the slow timing of the hemodynamic response

Stimulus/response occurs in silent interval, then images are acquired
fMRI: Data Analysis

• Motion correction

• Group analysis
  o Normalize all participants’ brains to the same size
  o Look for voxels that have consistently greater BOLD response in the active versus baseline condition across all participants (statistically significant)
  o Correction for multiple comparisons across voxels
  o BOLD response can also be correlated with a behavioral measure
  o Comparisons between groups
fMRI: Speech and Language Networks

Price (2010)
References

Study 1: Functional Magnetic Resonance Imaging (fMRI) Study of Speech Production in Childhood Apraxia of Speech
This research was supported by grants from the National Institutes of Health, National Institute on Deafness and other Communication Disorders including DC000528, DC00496, and DC010188-02.
Collaborating Laboratories

- **Case Western Reserve University**
  - Barbara Lewis, PhD
  - Lisa Freebairn, M.A.
  - Jessica Tag, M.A.
  - Gerry Taylor, Ph.D.
  - Sudha Iyengar, PhD
  - Catherine Stein, Ph.D.
  - Allison Avrich B.S.
  - Robert Elston, PhD
  - Feiyou Qui, MS

- **University of Wisconsin Madison**
  - Lawrence D. Shriberg, Ph.D.

- **Cincinnati Children’s Hospital Medical Center**
  - Erin Redle, PhD
  - Jennifer Vannest, PhD
  - Jean Tkach, PhD
  - Scott Holland, PhD
  - Thomas Maloney, M.S.
Overview, Participants, and Paradigms

Neuroimaging of Children With Speech Sound Disorders

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Quality Scholar, James M. Anderson Center for Health Systems Excellence
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**Background**

- SSDs, including CAS, arise from differences in neural substrates supporting speech production
- Several neuroimaging studies of the KE family (severe SSD, *FOXP2* gene mutation)
  - Structural imaging found gray matter volume differences in Broca’s area, pre-supplementary motor area (SMA), the caudate nucleus, and the lentiform nucleus in affected vs. non-affected family members (Vargha-Khadem et al., 1998)
  - Functional imaging also found differences in Broca’s area during over and covert speech tasks between affected and non-affected family members (Liegeois et al., 2003)
- Tkach et al., 2011
- Preston et al., 2012
- Better understanding of disorders may lead to more targeted and more effective interventions
Participants

• Children 5-12 years
  – Typical Speech Development (TSD)
  – Speech Sound Disorder
    • Speech Delay or Motor Speech Disorder- Not Otherwise Specified (MSD-NOS)
    • CAS

• Recruitment Sources
  – Neurodevelopmental Apraxia Clinic
  – Division of Speech Pathology
  – Community
Participants

• Inclusionary/exclusionary criteria

• All participants:
  • No known co-occurring neurological disorder, genetic disorder, hearing loss, history of cleft, chronic medical condition that would impact speech or language
  • ADHD is not exclusionary
  • Right-handed

• TSD: No diagnosed developmental disorder at any time history

• SSD:
  • Language: Able to complete all scanning/testing activities
Participants

Referral/Screening

fMRI Testing

Behavioral Testing
Scanning

• Overview of methods with young children
  – Before the visit
    • Video
    • Practice
  – Pre-scan prep
    • Review behavioral tasks
    • Mock scanner
    • Quick tour of scanner room
Scanning

• **Entering the scanner**
  • *SLOW process*, parents in scan room has varying effectiveness
  • Child “controls” the “spaceship” and “pilots” the spaceship with the buttons for raising and lowering the “Captain’s Seat”
  • Emergency button practice
  • Sit on the scanner bed, sit next to them if needed
  • Child tries the headphones on
  • Child talks to an adult through the headphones the child talks back so that they know they can communicate
  • Offer blanket, Children often don’t know how to say or don’t want to say that the temperature is uncomfortable

• **During the scan**
  • Make sure that they can see the movie (the projector is on)
  • Never ask the child if they are doing OK, tell them that they are doing a great job and ask if there is anything they want to tell us or if we can make them more comfortable
  • If the child gets upset while in the scanner, have them go see their parent and they may be willing to go back in
Scanning Protocol

• Total approximately 45-50 minutes
  – Anatomical scans (movie)
  – Functional scans (games)
    • Syllable repetition task (x2)(SRT)
    • Non-word imaging task (NIT)
    • Fine motor praxis task (FMPT)
  – Diffusion tensor imaging (movie)
Syllable Repetition Task
(Shriberg & Lohmeier, 2008; Shriberg et al., 2009; Lohmeier & Shriberg, 2011; Shriberg, Lohmeier, et al., 2012)

- During the SRT the child repeats phonetically simple phonemes (/b, d, m, n, ɑ/) in syllables
  - Syllables increase in length from 2-4 syllables (e.g. /badɑ/ ‘bada’)
- Phonetically simple phonemes chosen to eliminate confounding elements of many non-word repetition tasks; easier phonemes support accurate production
- Attempts to minimize performance as an confounder
- 18 spoken items, 18 listen items, HUSH acquisition
- Active condition of repetition contrasted with listening
- Responses recorded and scored
Sequence

Repeat Condition

Listen Condition

Images acquired

Images acquired

11 seconds per trial

/bada/

"/bada/"

(silence)
Fine Motor Praxis Task

• Novel task, developed to assess more complex finger tapping
• Hear sequence of 1-4 tones, bilaterally tap successive fingers to thumb matching the number of tones
• Contrasted with listening
• Total of 18 tapping trials, 18 listen trials
• Block acquisition
Sequence

Tap Condition +

Listen Condition +

Images acquired

Hands are still
Behavioral Testing

- **Speech**
  - Goldman Fristoe Test of Articulation-2 (GFTA-2) (Goldman & Fristoe, 2000)
  - Oral Speech Motor Screening Examination-3 (Louis & Ruscello, 2000)
  - Selected components of the Madison Speech Assessment Protocol, including a conversational analysis

- **Language**
  - Clinical Evaluation of Language Fundamental-4 (CELF-4) Core Test (Semel, Wiig, & Secord, 2003)
  - Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen, & Rashotte, 1999)
  - Test of Auditory Processing Skills-3 (TAPS-3), Discrimination sub-test only (Martin & Brownell, 2005)

- Wechsler Abbreviated Test of Intelligence (WASI) (Wechsler, 2003)
- Purdue Pegboard
- School Function Assessment (SFA) (Coster, Deeney, Haltiwanger, & Haley, 1998)
- Parents complete a case history
- Hearing screening
Summary of Participants

• Total of 27 children completed scanning
  – 11 TSD (7.7 years, range 6-10, males=7)
  – 16 SSD (7.1 years, range 5-9, males=11)

• Behavioral testing*
  – 10 of 11 TSD completed
  – 15 of 16 SSD completed
<table>
<thead>
<tr>
<th>Test</th>
<th>TSD Mean (standard deviation)</th>
<th>SSD Mean (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFTA Standard Score</td>
<td>104.8 (3.3)</td>
<td>78.3 (20.2)**</td>
</tr>
<tr>
<td>CELF Total Standard Score</td>
<td>103.0 (13.4)</td>
<td>79.6 (21.9)**</td>
</tr>
<tr>
<td>Concepts and Following Directions</td>
<td>12.3 (1.8)</td>
<td>8.1 (3.2)**</td>
</tr>
<tr>
<td>Word Structure</td>
<td>11.7 (2.3)</td>
<td>7.7 (4.2)*</td>
</tr>
<tr>
<td>Recalling Sentences</td>
<td>12.0 (2.8)</td>
<td>5.0 (2.8)**</td>
</tr>
<tr>
<td>Formulated Sentences</td>
<td>11.9 (3.0)</td>
<td>7.0 (4.4)**</td>
</tr>
<tr>
<td>Word Discrimination (TAPS) Standard Score</td>
<td>11.2 (2.0)</td>
<td>8.1 (2.5)**</td>
</tr>
<tr>
<td>CTOPP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonological Awareness</td>
<td>103.4 (16.7)</td>
<td>83.2 (18.2)*</td>
</tr>
<tr>
<td>Phonological Memory</td>
<td>101.5 (7.5)</td>
<td>77.1 (13.9)**</td>
</tr>
<tr>
<td>Rapid Naming</td>
<td>98.2 (16.3)</td>
<td>87.3 (10.6)</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01
Table 2
Intelligence Testing Results for Children in the TSD and SSD Groups Compared Using Two-tailed t-Test (with Standard Deviations in Parentheses)*

<table>
<thead>
<tr>
<th>Test</th>
<th>TSD Mean (standard deviation)</th>
<th>SSD Mean (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full IQ</td>
<td>109.1 (9.6)</td>
<td>97.4 (11.9)*</td>
</tr>
<tr>
<td>Verbal IQ</td>
<td>108.4 (14.6)</td>
<td>94.9 (10.0)*</td>
</tr>
<tr>
<td>Performance IQ</td>
<td>107.7 (11.4)</td>
<td>99.8 (14.0)</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01
Table 3  
Fine Motor Dexterity and Functional Fine Motor Performance Test Results for Children in the TSD and SSD Groups Compared Using Two-tailed t-Test (with Standard Deviations in Parentheses)*

<table>
<thead>
<tr>
<th>Test</th>
<th>TSD Mean (standard deviation)</th>
<th>SSD Mean (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purdue Pegboard Pin Test Right Hand</td>
<td>11.8 (1.5)</td>
<td>8.7 (1.8)**</td>
</tr>
<tr>
<td>Purdue Pegboard Pin Test Left Hand</td>
<td>10.1 (1.8)</td>
<td>7.8 (1.3)**</td>
</tr>
<tr>
<td>Purdue Pegboard Pin Test Combined</td>
<td>8.3 (1.7)</td>
<td>6.5 (1.8)*</td>
</tr>
<tr>
<td>School Function Total Assessment</td>
<td>36.3 (.5)</td>
<td>34.0 (2.8)</td>
</tr>
<tr>
<td>Using Materials</td>
<td>100.0 (0.0)</td>
<td>97.4 (4.2)</td>
</tr>
<tr>
<td>Clothing Management</td>
<td>68.0 (0.0)</td>
<td>62.5 (8.1)</td>
</tr>
<tr>
<td>Written Work</td>
<td>47.2 (1.3)</td>
<td>39.0 (8.0)*</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01
Table 4
SRT Results for Children in the TSD and SSD Groups During Scanning Compared Using Two-tailed t-Test (with Standard Deviations in Parentheses)*

<table>
<thead>
<tr>
<th>Test</th>
<th>TSD Mean (standard deviation)</th>
<th>SSD Mean (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRT Run 1</td>
<td>12.5 (3.8)</td>
<td>10.2 (4.0)</td>
</tr>
<tr>
<td>SRT Run 2</td>
<td>12.8 (3.0)</td>
<td>8.5 (3.3)**</td>
</tr>
<tr>
<td>Total SRT</td>
<td>25.9 (5.9)</td>
<td>17.6 (7.0)**</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01


Madison CAS Phenotype: Premises, Methods, and Classifications

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Madison CAS Phenotype:
Four Premises
Childhood Apraxia of Speech (CAS) is one of three subtypes of a class of Speech Sound Disorders (SSD) termed Motor Speech Disorders (MSD).

Cover term: Speech Sound Disorders (SSD)
Class term: Motor Speech Disorders (MSD)
Subtype terms:
- Motor Speech Disorder-Apraxia of Speech (MSD-AOS)
- Motor Speech Disorder-Dysarthria (MSD-DYS)
- Motor Speech Disorder-Not Otherwise Specified (MSD-NOS)
Premise 1
CAS is One of Three Subtypes of MSD

- Speech Sound Disorders (SSD)
  - Motor Speech Disorders (MSD)
    - Motor Speech Disorder Apraxia Of Speech (MSD-AOS)
    - Motor Speech Disorder Dysarthria (MSD-DYS)
    - Motor Speech Disorder Not Otherwise Specified (MSD-NOS)
Premise 2
A Transcoding Deficit Differentiates CAS from Speech Delay, MSD-DYS, and MSD-NOS

Speech Disorders Classification System (SDCS)

I. Etiological Processes (Distal Causes)
   - Genomic and Environmental Risk and Protective Factors
   - Neurodevelopmental Substrates

II. Speech Processes (Proximal Causes)
   - Encoding/Memory (Representational)
     - *Transcoding (Planning/Programming)
   - **Execution (Neuromotor)

III. Clinical Typology
   - Speech Delay (SD)
     - Speech Delay-Genetic (SD-GEN)
     - Speech Delay-Otitis Media With Effusion (SD-OME)
     - Speech Delay-Developmental Psychosocial Involvement (SD-DPI)
   - Speech Errors (SE)
     - Speech Errors - /s/ (SE-s/)
     - Speech Errors - /r/ (SE-/r/)
   - Motor Speech Disorders (MSD)
     - *Motor Speech Disorder-Apraxia Of Speech (MSD-AOS)
     - **Motor Speech Disorder-Dysarthria (MSD-DYS)
     - Motor Speech Disorder-Not Otherwise Specified (MSD-NOS)
Premise 3: Genetic and Behavioral Findings in CAS are Consistent With a Multiple Domain Disorder

- **FOXP2 – CAS Studies**
  - **FOXP2** expression is bilateral and widespread, including gene regulation in pathways for vision, audition, speech, and other domains (e.g., Horng et al., 2009)
  - Histories of cognitive, auditory-perceptual, language, motor, and psychosocial deficits (Rice et al., 2012; Shriberg et al., 2006; Tomblin et al., 2009)

- **CAS Studies in Idiopathic, Neurogenetic, and Complex Neurodevelopmental Contexts**
  - Histories of cognitive, auditory-perceptual, language, motor, and psychosocial deficits (Laffin et al. 2012; Raca et al., 2012; Shriberg, Lohmeier, et al., 2012; Worthey et al., 2012)
Premise 4: 
Behavioral Markers of CAS Are Central to the Identification of Biomarkers and Theory

The inclusionary criteria (segmental and suprasegmental signs) that comprise the behavioral markers in studies of CAS will have significant impact on the success of two primary goals of next-generation CAS research

- **Identification of Biomarkers:**
  - Identification of biomarkers of CAS from neuroimaging and other methods

- **Theory Confirmation:**
  - Development and testing of alternative accounts of speech processing in CAS derived from emerging cognitive neuroscience frameworks (e.g., DIVA [Terband, Guenther, Maassen, others]; dual-stream models [Hickok, Poeppel, others])
Madison CAS Phenotype:
Methods
Methods
A Four-Sign Diagnostic Marker to Discriminate CAS from Speech Delay

Classification Criterion for CAS:
Positive Finding on at least three of four signs of CAS

<table>
<thead>
<tr>
<th>Sign</th>
<th>Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Appropriate Pauses (AP)</td>
<td>+</td>
</tr>
<tr>
<td>Low Articulatory Rate (AR)</td>
<td>+</td>
</tr>
<tr>
<td>Low Appropriate Stress (AS)</td>
<td>+</td>
</tr>
<tr>
<td>Low Accurate Transcoding (AT)</td>
<td>+</td>
</tr>
</tbody>
</table>

Any 3 or more = CAS

\(^a\) Shriberg, Strand, Jakielski, & Lohmeier (2012)
Methods

Three of the Four Diagnostic Signs Are Obtained from the MSAP Conversational Speech Sample

Low Appropriate Pauses (AP)$^a$

A 10-category pause typology and acoustic displays are used to derive the percentage of appropriate pauses

Low Articulatory Rate (AR)$^a$

The pause data and acoustic displays are used to derive an average articulation rate (syllables/second)

Low Appropriate Stress (AS)

Codes from the Prosody-Voice Screening Profile (PVSP: Shriberg, Kwiatkowski, & Rasmussen, 1990) are used to derive the percentage of utterances without excessive-equal stress and other types of inappropriate stress

$^a$Low (+) = z-score < 1 SD from the mean of a referent group of same age-gender typical speakers.
The Fourth Diagnostic Sign is Obtained from the Syllable Repetition Task (SRT)\textsuperscript{a}

**Sign: Low Accurate Transcoding (AT)**

| 1. bada       | 10. dabama       |
| 2. dama       | 11. madaba       |
| 3. bama       | 12. nabada       |
| 4. mada       | 13. banada       |
| 5. naba       | 14. manaba       |
| 6. daba       | 15. bamadana     |
| 7. nada       | 16. danababana   |
| 8. maba       | 17. manabada     |
| 9. bamana     | 18. nadamababa   |

\textsuperscript{a} Shriberg & Lohmeier (2008); Shriberg et al. (2009); Lohmeier & Shriberg (2011); Shriberg, Lohmeier, et al. (2012)
Methods
Low Accurate Transcoding\textsuperscript{a}

\textbf{Examples of Inaccurate Transcoding}

<table>
<thead>
<tr>
<th>SRT Item</th>
<th>Homorganic Nasal</th>
<th>Heterorganic Nasal</th>
<th>Non-Nasal</th>
</tr>
</thead>
<tbody>
<tr>
<td>bada</td>
<td>\textbf{ banda}</td>
<td>bamda</td>
<td></td>
</tr>
<tr>
<td>mada</td>
<td></td>
<td></td>
<td>marda</td>
</tr>
<tr>
<td>nabada</td>
<td></td>
<td></td>
<td>nabavda</td>
</tr>
</tbody>
</table>

\textbf{AT Percentage} = \frac{1 - \text{No. of Additions}}{\text{No. of Eligible Stop Consonants}} \times 100

Low AT = \textless 80\%

\textsuperscript{a} Addition of a nasal consonant was the most common addition (92\%) in Shriberg, Lohmeier, et al. (2012)
Madison CAS Phenotype: 
Classifications
## Madison Speech Sound Disorders Classifications

<table>
<thead>
<tr>
<th>Participants</th>
<th>Age (yrs)</th>
<th>Percentage of Consonants Correct (PCC)</th>
<th>3/4 Sign Diagnostic Marker (+ = Positive CAS Sign)</th>
<th>Total Number of Positive CAS Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pausing Rate Stress Transcoding</td>
<td></td>
</tr>
<tr>
<td><strong>CAS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIN02</td>
<td>8</td>
<td>54.5</td>
<td>+       +       +       +</td>
<td>4</td>
</tr>
<tr>
<td>CIN05</td>
<td>8</td>
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<td>+       –       +       +</td>
<td>3</td>
</tr>
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<td>CIN11</td>
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<td>78.6</td>
<td>+       +       +       –</td>
<td>3</td>
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<tr>
<td>CIN22</td>
<td>6</td>
<td>77.1</td>
<td>+       +       +       +</td>
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<tr>
<td><strong>Mean</strong></td>
<td><strong>8.0</strong></td>
<td><strong>77.2</strong></td>
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<td><strong>3.6</strong></td>
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<td><strong>Speech Delay or MSD-NOS</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>CIN08</td>
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<td>79.6</td>
<td>+       –       –       –</td>
<td>1</td>
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<tr>
<td>CIN10</td>
<td>8</td>
<td>86.1</td>
<td>+       –       –       +</td>
<td>2</td>
</tr>
<tr>
<td>CIN13</td>
<td>6</td>
<td>78.9</td>
<td>–       +       –       +</td>
<td>2</td>
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<tr>
<td>CIN14</td>
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<td>68.5</td>
<td>+       –       –       –</td>
<td>1</td>
</tr>
<tr>
<td>CIN15</td>
<td>6</td>
<td>83.5</td>
<td>+       –       –       –</td>
<td>1</td>
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<tr>
<td>CIN20</td>
<td>8</td>
<td>92.1</td>
<td>+       –       –       +</td>
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<tr>
<td><strong>Mean</strong></td>
<td><strong>7.3</strong></td>
<td><strong>81.5</strong></td>
<td></td>
<td><strong>1.5</strong></td>
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<td><strong>Controls</strong></td>
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<td></td>
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<tr>
<td>CIN03</td>
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<td>93.4</td>
<td>+       –       –       –</td>
<td>1</td>
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<td>CIN07</td>
<td>9</td>
<td>95.8</td>
<td>–       –       +       –</td>
<td>1</td>
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<tr>
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<td>93.9</td>
<td>–       –       –       –</td>
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<tr>
<td>CIN16</td>
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<td>95.2</td>
<td>–       –       –       *&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>CIN17</td>
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<td>98.6</td>
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<tr>
<td>CIN18</td>
<td>7</td>
<td>89.5</td>
<td>+       +       –       –</td>
<td>2</td>
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<td>CIN19</td>
<td>6</td>
<td>94.8</td>
<td>+       +       –       –</td>
<td>2</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>7.7</strong></td>
<td><strong>94.5</strong></td>
<td></td>
<td><strong>0.9</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup>SRT not administered

63.7% agreement with referral diagnosis


References

Preliminary Results

Neuroimaging of Children With Speech Sound Disorders

American Speech-Language-Hearing Association
National Convention, Atlanta, GA
November 16, 2012

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Assistant Director, Pediatric Neuroimaging Research Consortium
Cincinnati Children’s Hospital Medical Center
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fMRI Data Analysis

- Each fMRI data set was coregistered to correct for motion. Single volumes highly contaminated by motion were removed from analysis.
- Participants with less than 50% of volumes in each condition remaining were not included in further analysis.
- Spatial normalization into Talairach space.
- General linear model and paired t test were implemented to identify voxels activated by each task for each participant.
- Random-effects analysis was performed to determine significant group activations.
- All results p<.05 corrected.
Syllable Repetition Task

11 seconds per trial

Repeat Condition + /bada/ "bada" Images acquired

Listen Condition + (silence) Images acquired
Syllable Repetition Task

- TSD n=6 (4F, mean age 8.0 years)
  - SRT total score mean= 25.2
- SSD n=8 (2F, mean age 7.5 years)
  - SRT total score mean= 19.6
- Madison Protocol
  - 4 SD
  - 2 Insufficient data, 1 to-be-analyzed
  - 1 CAS
<table>
<thead>
<tr>
<th>Test</th>
<th>TSD Mean (standard deviation)</th>
<th>SSD Mean (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFTA Standard Score</td>
<td>102.8 (2.9)</td>
<td>77.0 (19.1)**</td>
</tr>
<tr>
<td>CELF Total Standard Score</td>
<td>103.8 (18.0)</td>
<td>82.7 (22.8)</td>
</tr>
<tr>
<td>Concepts and Following Directions</td>
<td>12.3 (2.2)</td>
<td>8.5 (4.7)</td>
</tr>
<tr>
<td>Word Structure</td>
<td>11.8 (3.2)</td>
<td>7.7 (4.2)*</td>
</tr>
<tr>
<td>Recalling Sentences</td>
<td>12.2 (3.9)</td>
<td>5.6 (3.4)*</td>
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<tr>
<td>Formulated Sentences</td>
<td>12.0 (2.5)</td>
<td>7.6 (4.7)*</td>
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<tr>
<td>Word Discrimination (TAPS) Standard Score</td>
<td>11.4 (2.6)</td>
<td>8.1 (2.6)*</td>
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<td>CTOPP</td>
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<td>Phonological Awareness</td>
<td>113.8 (12.1)</td>
<td>86.0 (23.1)*</td>
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<td>Phonological Memory</td>
<td>104.5 (1.7)</td>
<td>76.0 (18.2)*</td>
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<tr>
<td>Rapid Naming</td>
<td>103.8 (19.4)</td>
<td>85.3 (6.4)</td>
</tr>
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</table>

* p <.05, ** p <.01
### Table 6
*Intelligence Testing Results for TSD and SSD Children Included in the SRT Analysis Using Two-tailed t-Test (with Standard Deviations in Parentheses)*

<table>
<thead>
<tr>
<th>Test</th>
<th>TSD Mean (standard deviation)</th>
<th>SSD Mean (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full IQ</td>
<td>110. (13.2)</td>
<td>94.2 (13.1)</td>
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<tr>
<td>Verbal IQ</td>
<td>104.5 (15.7)</td>
<td>100.2 (15.7)</td>
</tr>
<tr>
<td>Performance IQ</td>
<td>108.3 (11.5)</td>
<td>97.7 (14.9)</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01
Syllable Repetition Task: Repeat > Listen

TSD

SSD

R

L
Syllable Repetition Task: Regression with task performance

Higher SRT score $\rightarrow$ lower level of activation
Fine Motor Praxis Task

1. **Tap Condition**: +
   - Images acquired

2. **Listen Condition**: +
   - Hands are still

---

Cincinnati Children's®
Fine Motor Praxis Task

• Age-matched groups (n=12)
  – TSD n=6 (8.3 years, 3 males)
  – SSD n=6 (8.0 years, 3 males)

• For this limited group, no significant differences in SFA scores or IQ scores

• Purdue Pegboard Scores significantly different for right hand (p=.001) but not for left hand and combined

• Madison Protocol
  – 3 SD
  – 2 Insufficient data
  – 1 CAS
Fine Motor Praxis Task: Tap>Listen
Fine Motor Praxis Task: SSD>Controls
Summary

• Children with SSD have similar activation of speech motor networks to TSD children during a speech production task
  ○ slightly more right-lateralized pattern in SSD

• Level of activation is highly tied to task performance across groups: less activation associated with better performance
Summary

• Children with SSD have higher levels of activation than TSD during a manual fine motor praxis task

• Regions of maximum difference between groups were in R parahippocampal and fusiform gyrus
  ○ Associated with long-term memory and recognition of familiar objects i.e. body parts

• Additional data will be needed to potentially differentiate subtypes of SSD