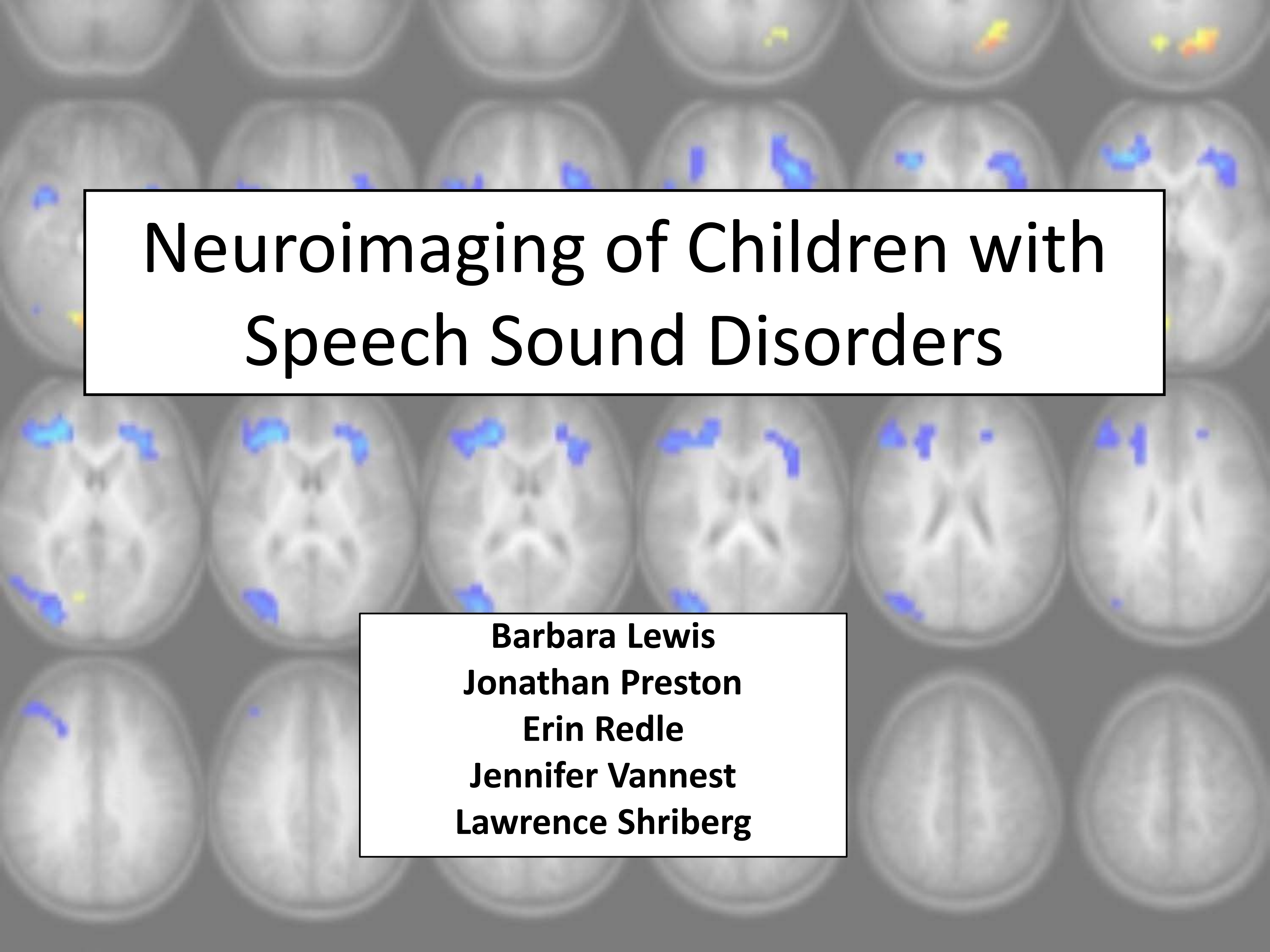

Neuroimaging of Children with Speech Sound Disorders

Barbara Lewis
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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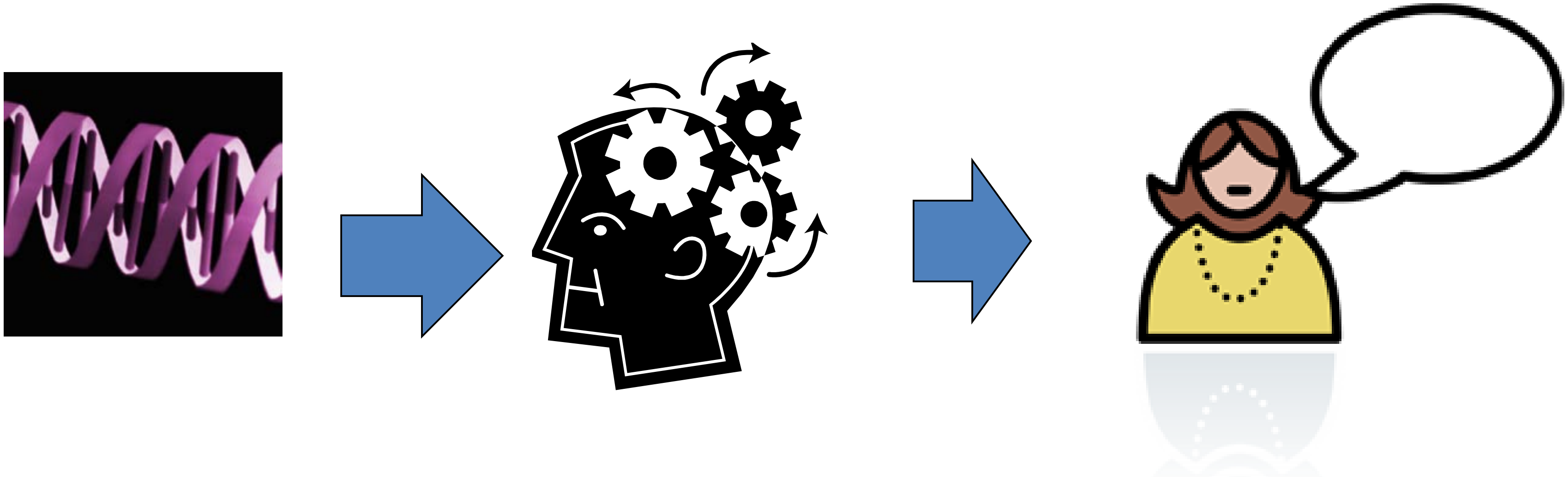
Imaging Genetics

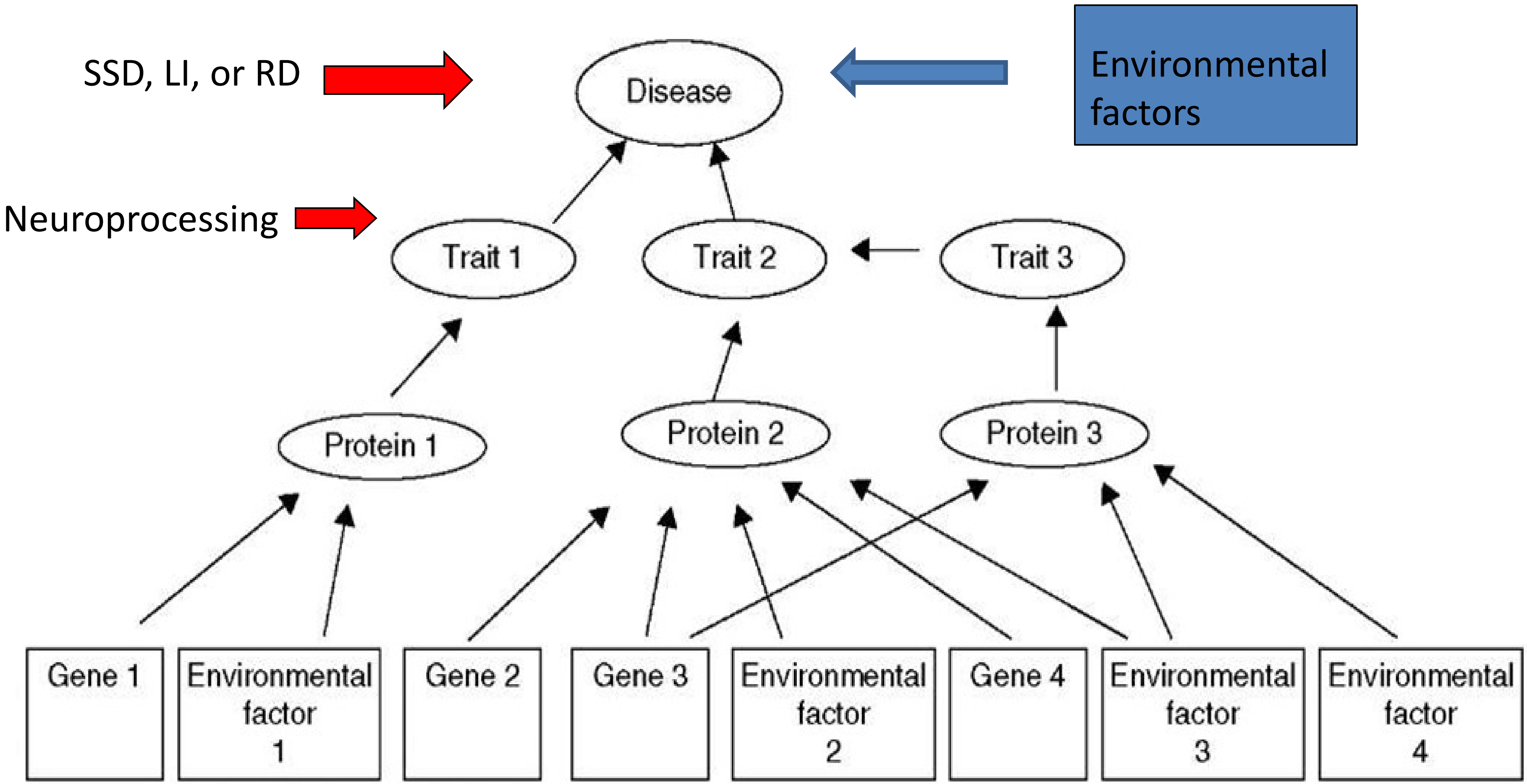


1. Identify genes 2. Expression in Brain 3. Behavior

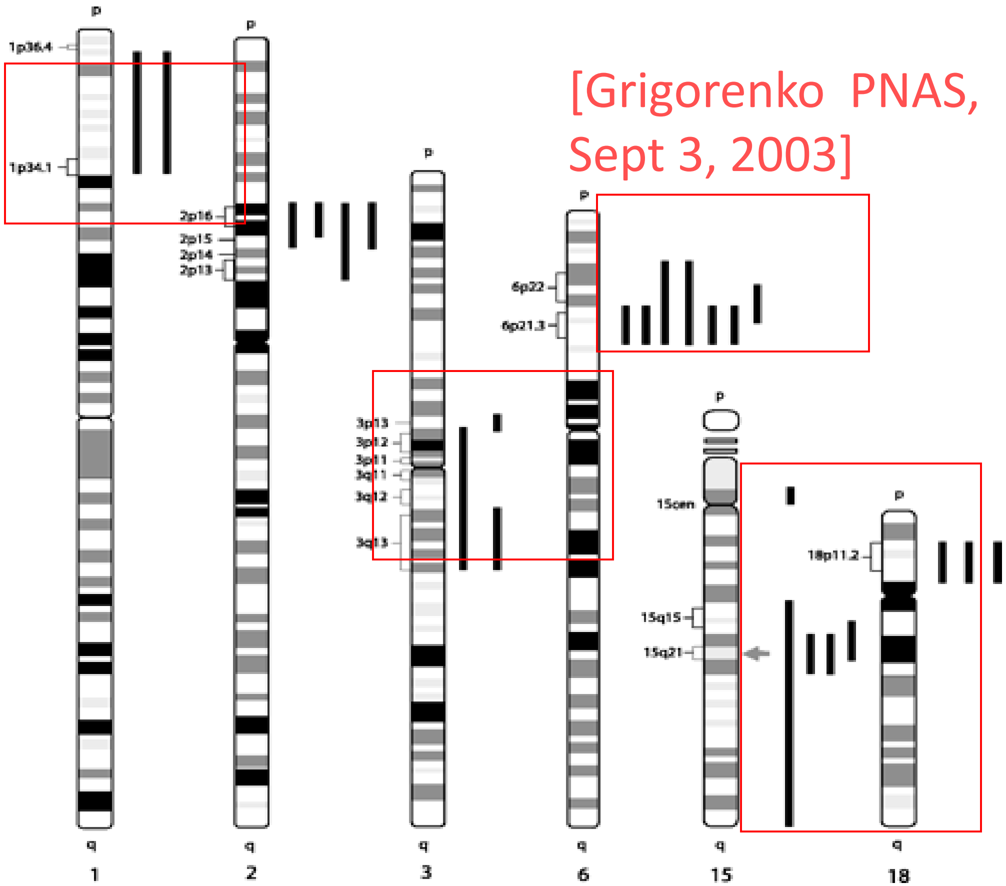
The Emerging Field of Imaging Genetics

- 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



Scope of the problem



[Grigorenko PNAS, Sept 3, 2003]

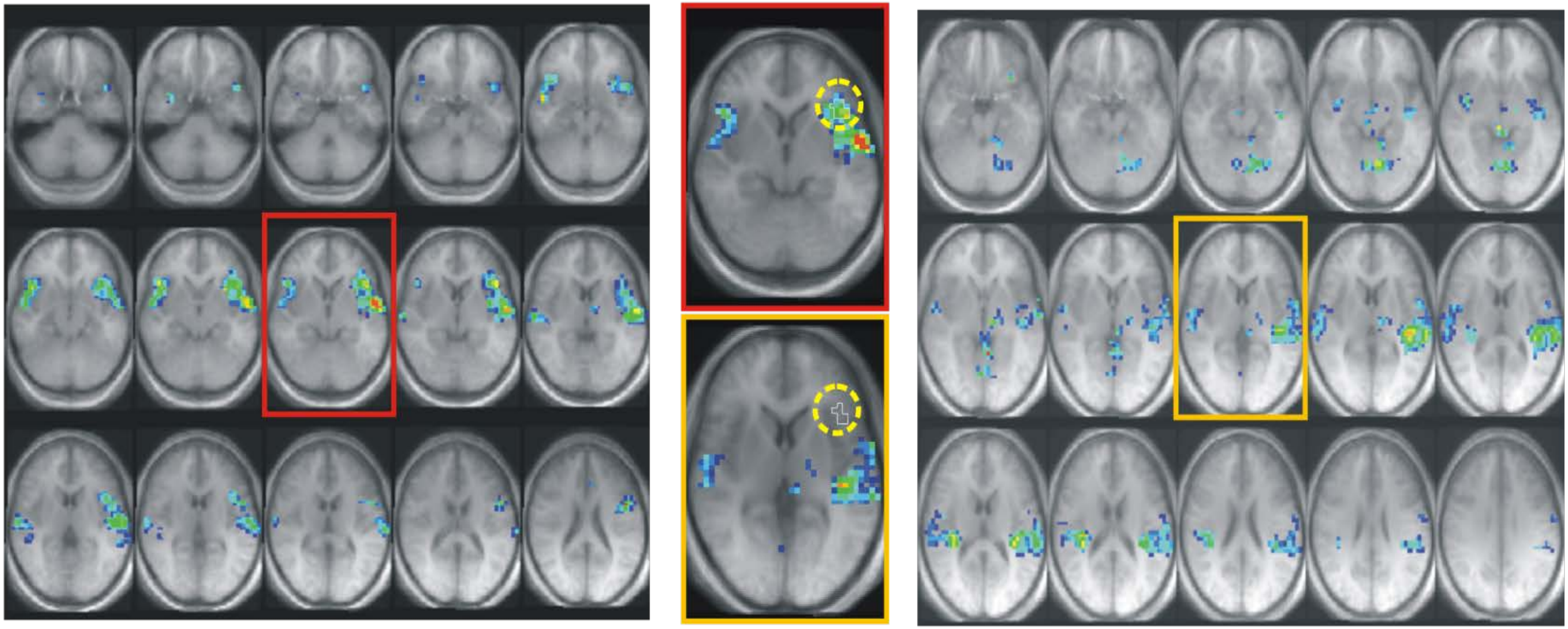
- Is there a link between speech sound and language disorders and dyslexia?
- Chromosomes 1, 3, 6, 15

Linkage Results for Spoken Language and Written Expression (Lewis et al., 2011)

Chromosome	Spoken Language at Early Childhood	Written Expression at School-age
Chromosome 1	Articulation	Written vocabulary
	Vocabulary	Reading decoding
	Phon. Memory	Spelling
Chromosome 3	Articulation	Written vocabulary
	Vocabulary	Spelling
	Phon, Memory	Reading decoding
	Speeded Naming	
Chromosome 6	Vocabulary	Spelling
	Phon. Memory	
Chromosome 15	Oral Motor	Reading decoding
	Articulation	Spelling
	Phonological Memory	

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.

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Basic Principles of fMRI

Neuroimaging of Children With Speech Sound Disorders

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

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Background: Functional Imaging

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

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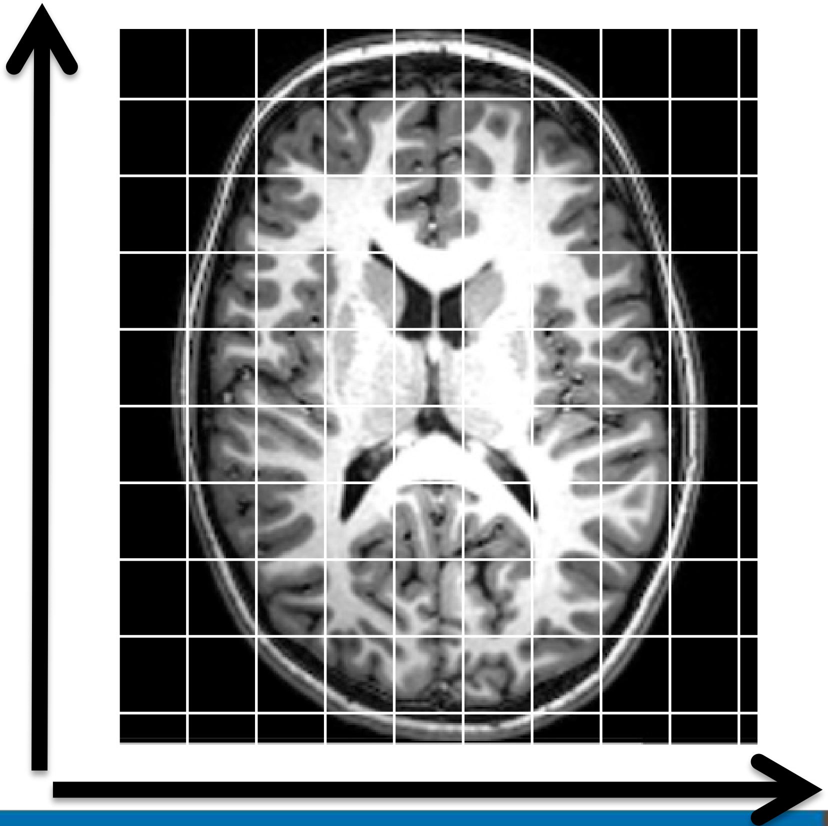
Magnetic Resonance Imaging (MRI)

- 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 <u>anatomy</u>.

<u>Functional</u> MRI (fMRI) studies brain <u>function</u>.

(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

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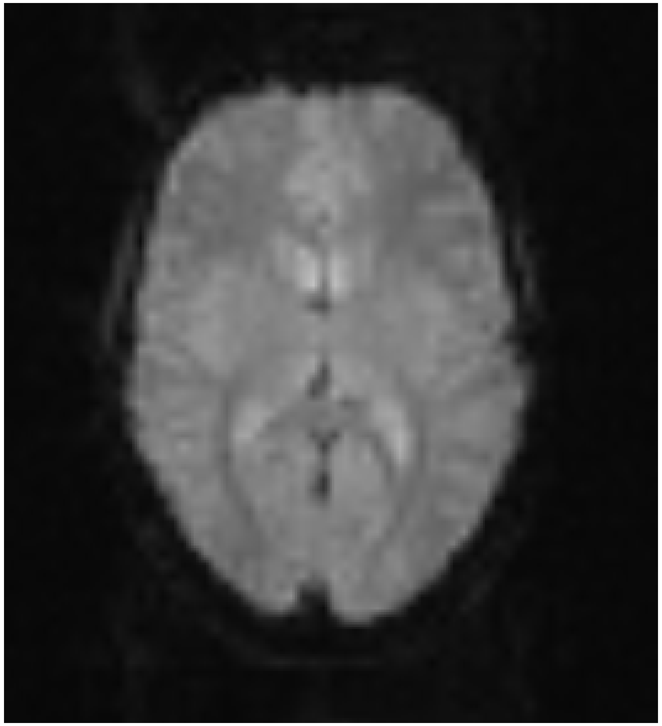
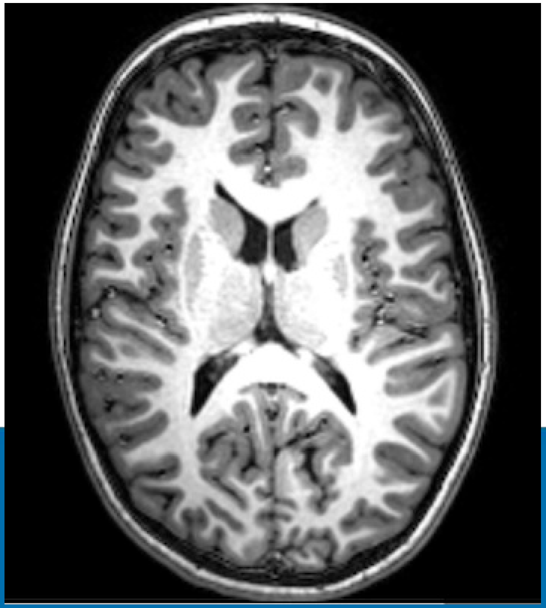


- Relatively low spatial resolution (for MRI)
- Sensitive to BOLD response
- 1 brain volume takes 2 sec to acquire
- Scan for 5-7 minutes
- Alternate between active and baseline conditions



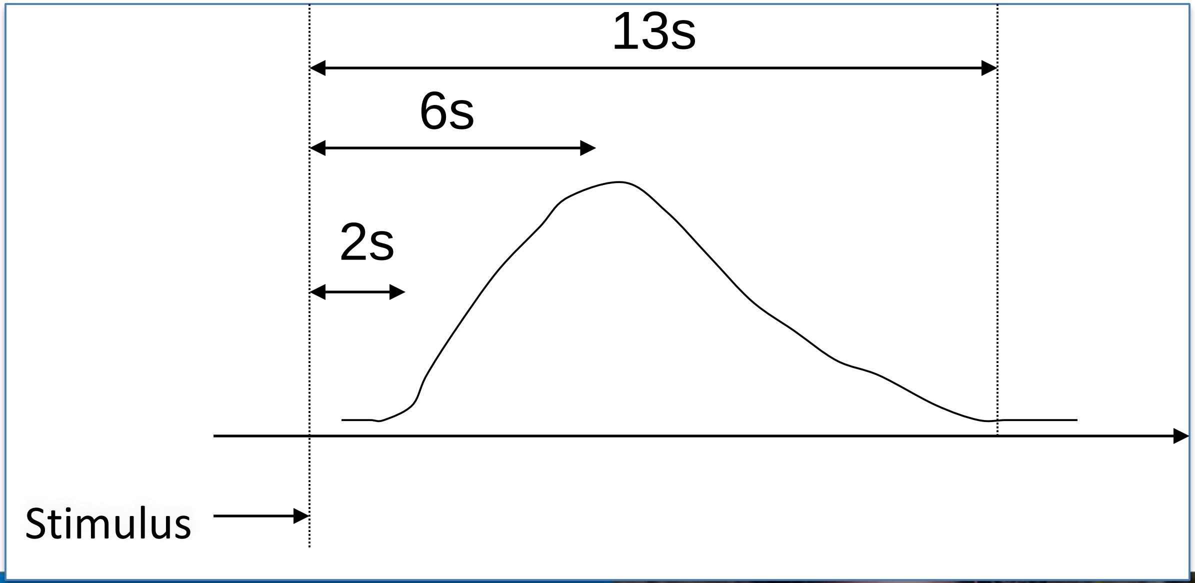
Structural Data

- 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.

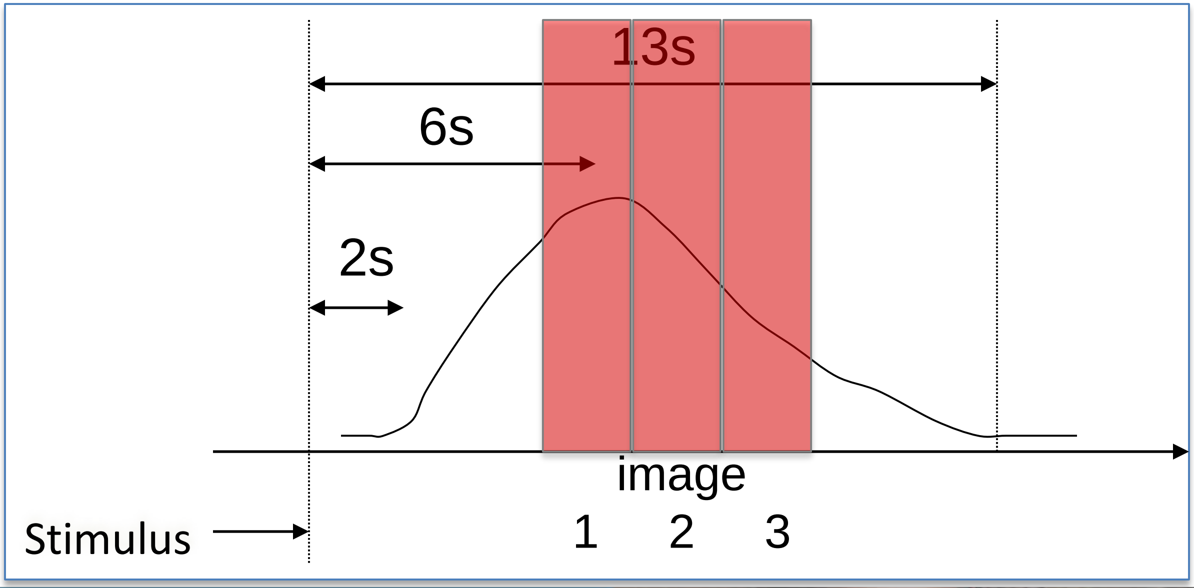
We also must take into account behavioral characteristics of the task during active and baseline conditions



fMRI: Experimental Design Issues

"HUSH" or "Sparse" techniques take advantage of the slow timing of the hemodynamic response

Stimulus/response occurs in silent interval, then images are acquired



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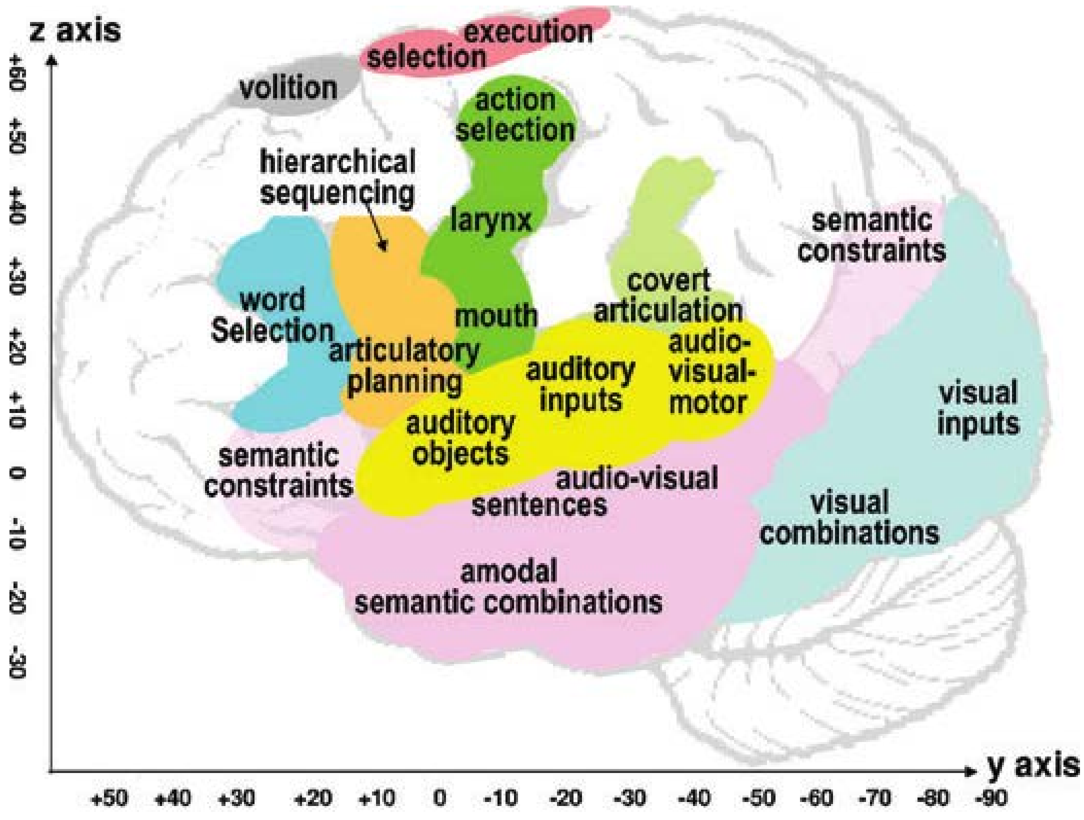
fMRI: Data Analysis

- Motion correction
- Group analysis
  - Normalize all participants' brains to the same size
  - Look for voxels that have consistently greater BOLD response in the active versus baseline condition across all participants (statistically significant)
  - Correction for multiple comparisons across voxels
  - BOLD response can also be correlated with a behavioral measure
  - Comparisons between groups

fMRI: Speech and Language Networks



Price (2010)

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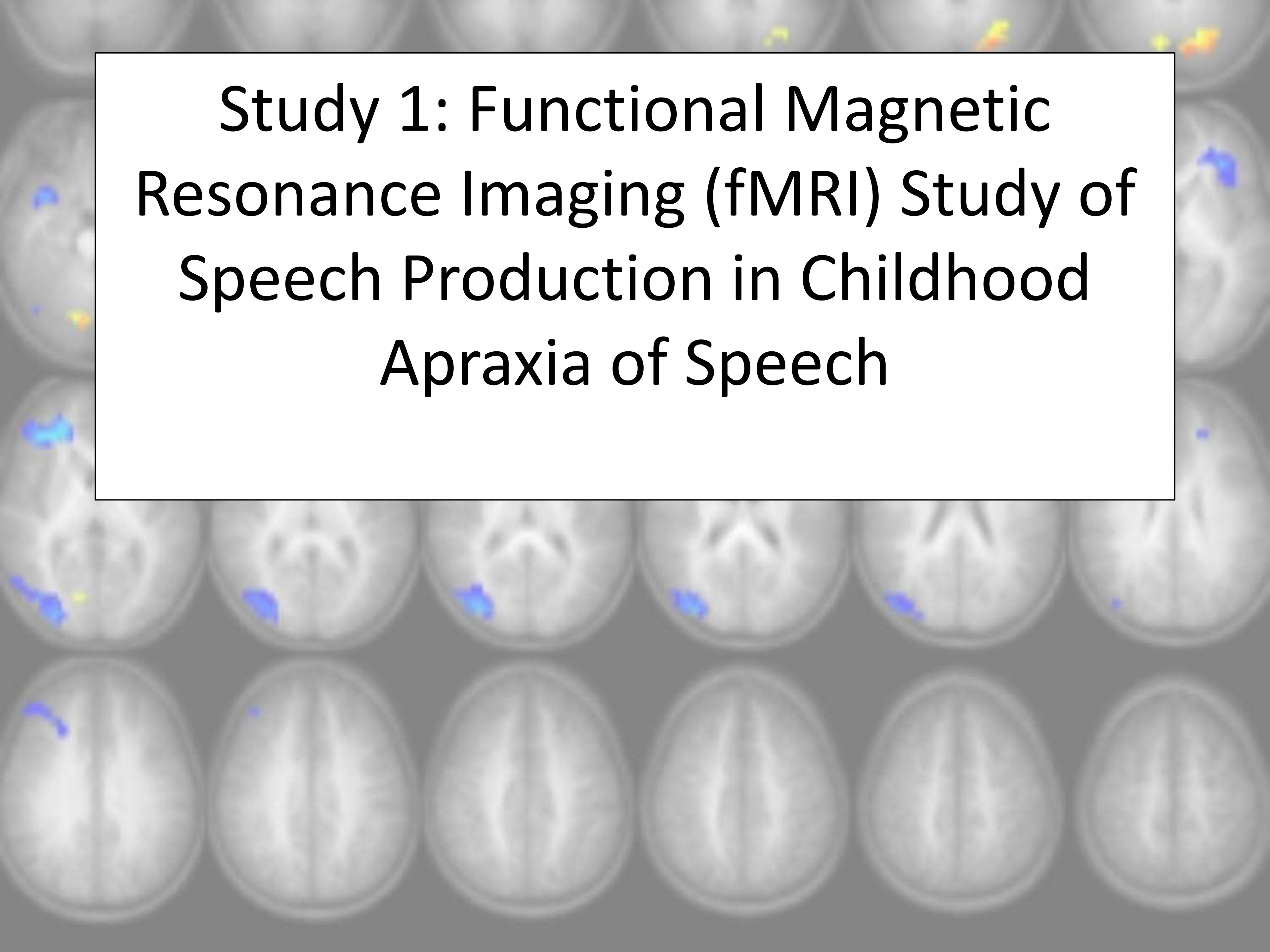
Study 1: Functional Magnetic Resonance Imaging (fMRI) Study of Speech Production in Childhood Apraxia of Speech



Grants Acknowledgement

- 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.

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Communication Sciences Research Center

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Overview, Participants, and Paradigms

Neuroimaging of Children With Speech Sound Disorders

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

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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 lentifrom 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

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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

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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

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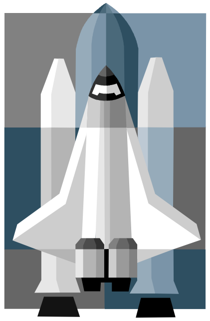
Scanning



- 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

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Scanning Protocol

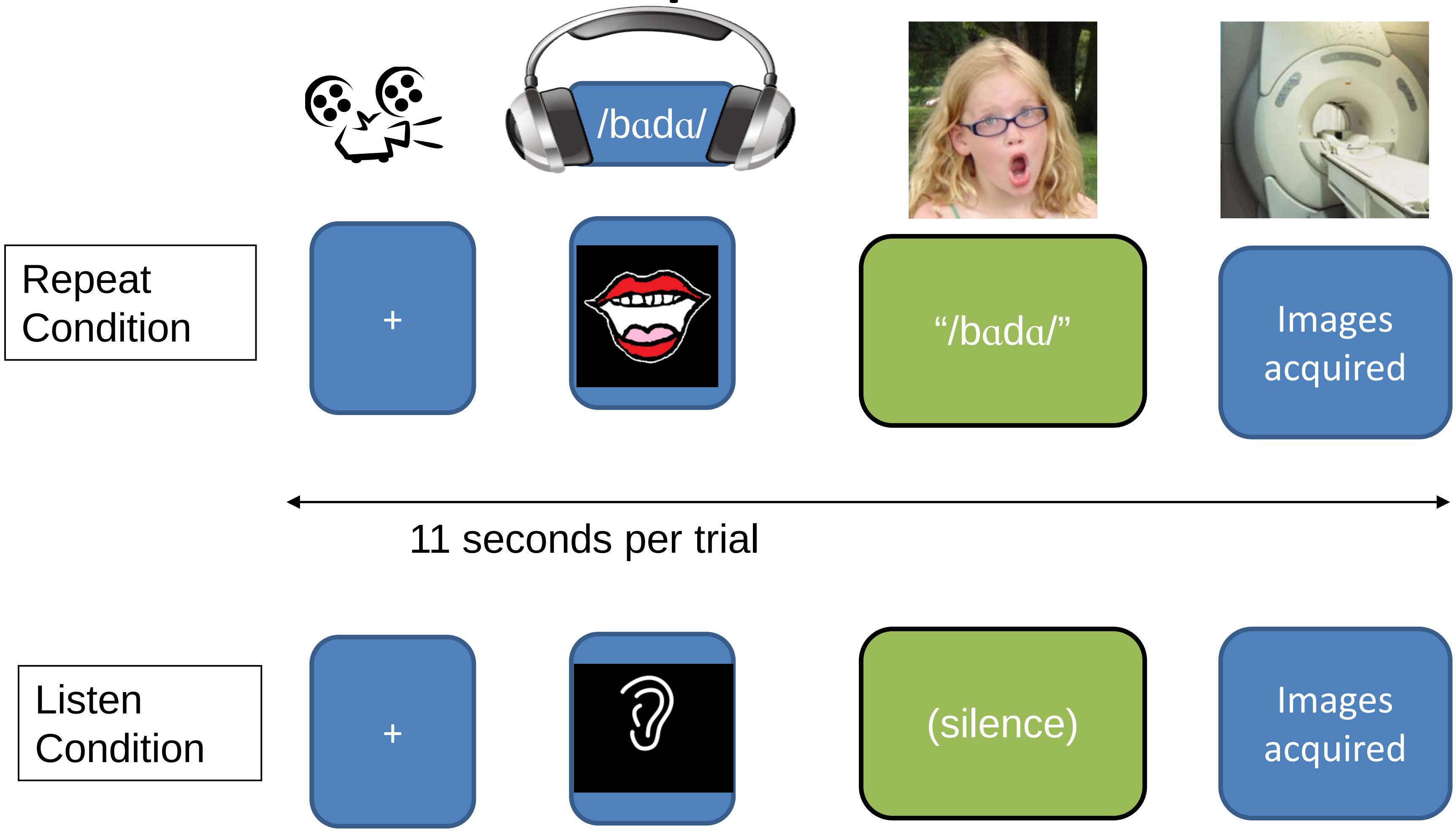
- Total approximately 45-50 minutes
  - Anatomical scans (movie)
  - Functional scans (games)
    - Syllable repetition task (x2)(SRT)
    - Non-word imaging task (NIT)
    - Fine motor praxis task (FMPT)
  - Diffusion tensor imaging (movie)

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. /bɑdɑ/ ‘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



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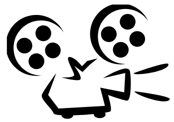
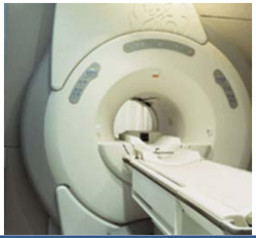
Fine Motor Praxis Task

- 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

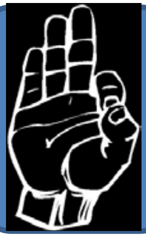




Images acquired

Tap Condition

+



Go

Listen Condition

+

Hands are still

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Behavioral Testing

- Speech
  - Goldman Fristoe Test of Articluation-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

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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

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Table 1
*Speech and Language Testing Results for Children in the TSD and SSD Groups Compared Using Two-tailed t-Test (with Standard Deviations in Parentheses)**

Test	TSD Mean (standard deviation)	SSD Mean (standard deviation)
GFTA Standard Score	104.8 (3.3)	78.3 (20.2)**
CELF Total Standard Score	103.0 (13.4)	79.6 (21.9)**
Concepts and Following Directions	12.3 (1.8)	8.1 (3.2)**
Word Structure	11.7 (2.3)	7.7 (4.2)*
Recalling Sentences	12.0 (2.8)	5.0 (2.8)**
Formulated Sentences	11.9 (3.0)	7.0 (4.4)**
Word Discrimination (TAPS) Standard Score	11.2 (2.0)	8.1 (2.5)**
CTOPP		
Phonological Awareness	103.4 (16.7)	83.2 (18.2)*
Phonological Memory	101.5 (7.5)	77.1 (13.9)**
Rapid Naming	98.2 (16.3)	87.3 (10.6)

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

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

Test	TSD Mean (standard deviation)	SSD Mean (standard deviation)
Full IQ	109.1 (9.6)	97.4 (11.9)*
Verbal IQ	108.4 (14.6)	94.9 (10.0)*
Performance IQ	107.7 (11.4)	99.8 (14.0)

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

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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)**

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

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

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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)**

Test	TSD Mean (standard deviation)	SSD Mean (standard deviation)
SRT Run 1	12.5 (3.8)	10.2 (4.0)
SRT Run 2	12.8 (3.0)	8.5 (3.3)**
Total SRT	25.9 (5.9)	17.6 (7.0)**

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

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Madison CAS Phenotype:
Premises, Methods, and Classifications

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Neuroimaging of Children With Speech Sound Disorders
American Speech-Language-Hearing Association
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Madison CAS Phenotype:

Four Premises

Premise 1

CAS is One of Three Subtypes of Motor Speech Disorders

Childhood Apraxia of Speech (CAS) is one of three subtypes of a class of Speech Sound Disorders (SSD) termed Motor Speech Disorders (MSD)

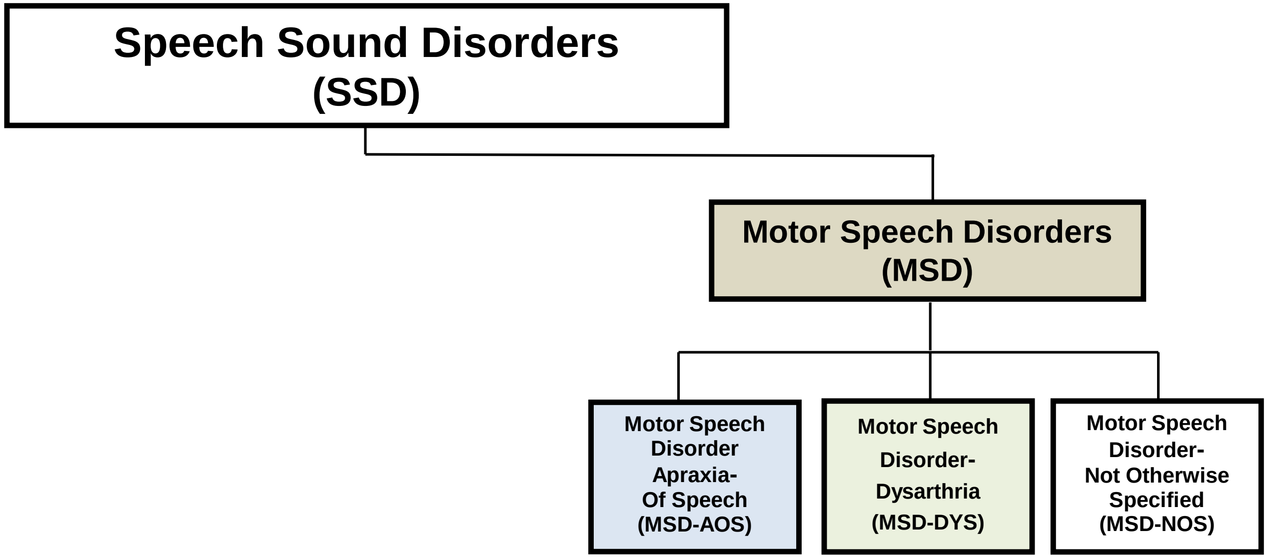
Cover term: Speech Sound Disorders (SSD)

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)

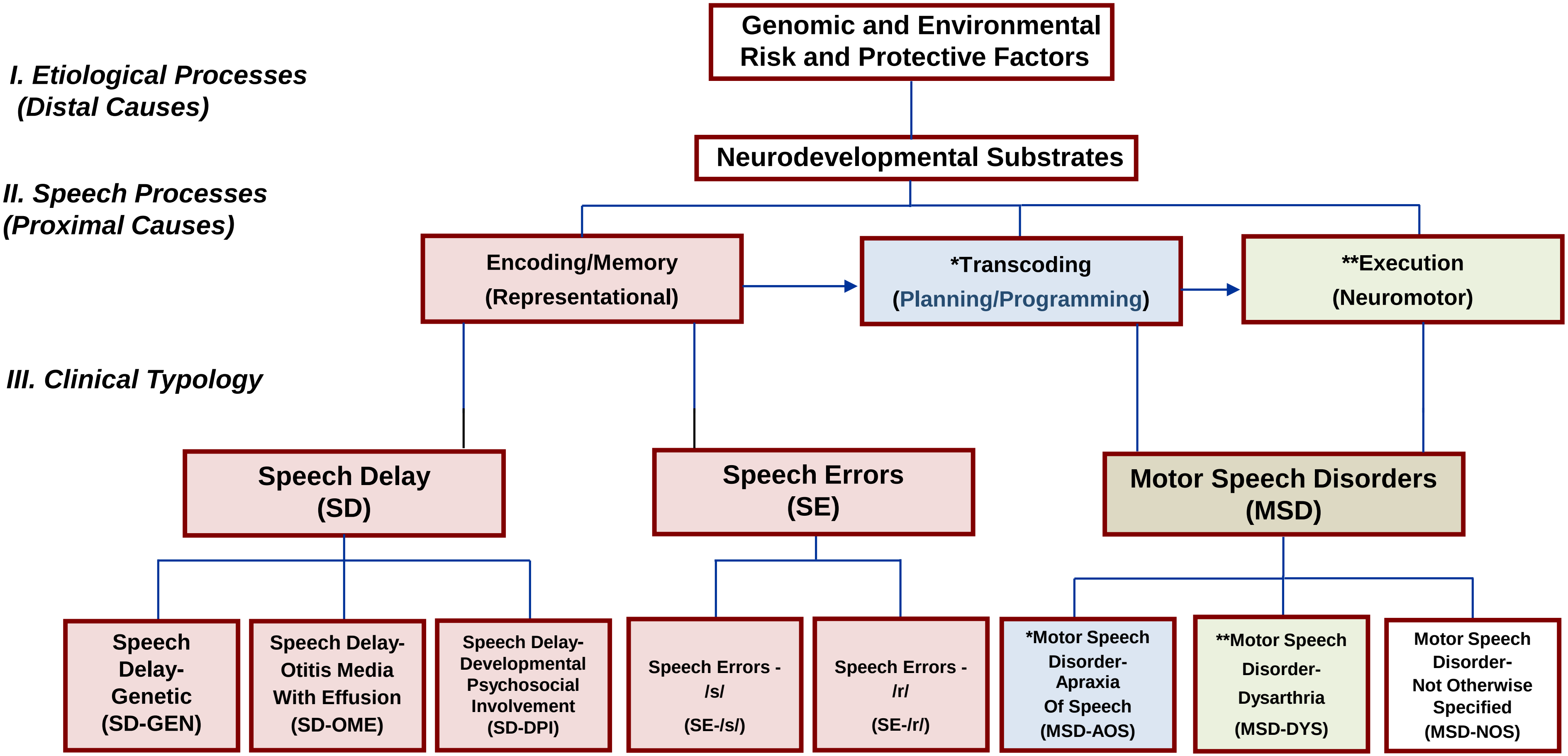
Premise 1
CAS is One of Three Subtypes of MSD



Premise 2

A Transcoding Deficit Differentiates CAS from Speech Delay, MSD-DYS, and MSD-NOS

Speech Disorders Classification System (SDCS)



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[a]

Classification Criterion for CAS:

Positive Finding on at least three of four signs of CAS

Sign	Finding
Low Appropriate Pauses (AP)	+
Low Articulatory Rate (AR)	+
Low Appropriate Stress (AS)	+
Low Accurate Transcoding (AT)	+
	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.

Methods

The Fourth Diagnostic Sign is Obtained from the Syllable Repetition Task (SRT)[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. danabama
8. maba	17. manabada
9. bamana	18. nadamaba

[a] Shriberg & Lohmeier (2008); Shriberg et al. (2009); Lohmeier & Shriberg (2011); Shriberg, Lohmeier, et al. (2012)

Methods

Low Accurate Transcoding[a]

SRT Item	Homorganic Nasal	Heterorganic Nasal	Non-Nasal
	Examples of Inaccurate Transcoding		
bada	**banda**	**bamda**	
mada			**marda**
nabada			**nabavda**

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

Low AT = < 80%

[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

Participants	Age (yrs)	Percentage of Consonants Correct (PCC)	3/4 Sign Diagnostic Marker (+ = Positive CAS Sign)				Total Number of Positive CAS Signs
			Pausing	Rate	Stress	Transcoding	
CAS							
CIN02	8	54.5	+	+	+	+	4
CIN05	8	87.8	+	–	+	+	3
CIN06	10	88.0	+	+	+	+	4
CIN11	8	78.6	+	+	+	–	3
CIN22	6	77.1	+	+	+	+	4
Mean	**8.0**	**77.2**					**3.6**
Speech Delay or MSD-NOS							
CIN08	8	79.6	+	–	–	–	1
CIN10	8	86.1	+	–	–	+	2
CIN13	6	78.9	–	+	–	+	2
CIN14	8	68.5	+	–	–	–	1
CIN15	6	83.5	+	–	–	–	1
CIN20	8	92.1	+	–	–	+	2
Mean	**7.3**	**81.5**					**1.5**
Controls							
CIN03	8	93.4	+	–	–	–	1
CIN07	9	95.8	–	–	+	–	1
CIN09	8	93.9	–	–	–	–	0
CIN16	8	95.2	–	–	–	*[a]	0
CIN17	8	98.6	–	–	–	–	0
CIN18	7	89.5	+	+	–	–	2
CIN19	6	94.8	+	+	–	–	2
Mean	**7.7**	**94.5**					**0.9**

[a]SRT not administered

63.7% agreement with referral diagnosis

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Preliminary Results

Neuroimaging of Children With Speech Sound Disorders

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

Jennifer Vannest, Ph.D.

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Cincinnati Children's

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

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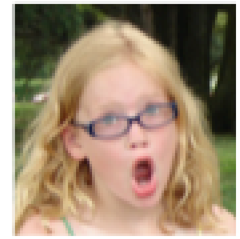
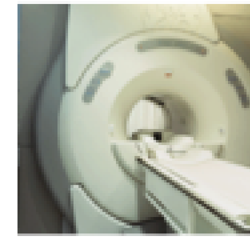
Syllable Repetition Task





Repeat Condition

+

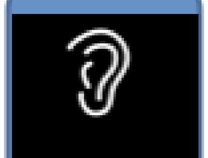
"/bada/"

Images acquired

11 seconds per trial

Listen Condition

+



(silence)

Images acquired

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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 5

*Speech and Language Testing Results for TSD and SSD Children Included in the SRT Analysis Using Two-tailed t-Test (with Standard Deviations in Parentheses)**

Test	TSD Mean (standard deviation)	SSD Mean (standard deviation)
GFTA Standard Score	102.8 (2.9)	77.0 (19.1)**
CELF Total Standard Score	103.8 (18.0)	82.7 (22.8)
Concepts and Following Directions	12.3 (2.2)	8.5 (4.7)
Word Structure	11.8 (3.2)	7.7 (4.2)*
Recalling Sentences	12.2 (3.9)	5.6 (3.4)*
Formulated Sentences	12.0 (2.5)	7.6 (4.7)*
Word Discrimination (TAPS) Standard Score	11.4 (2.6)	8.1 (2.6)*
CTOPP		
Phonological Awareness	113.8 (12.1)	86.0 (23.1)*
Phonological Memory	104.5 (1.7)	76.0 (18.2)*
Rapid Naming	103.8 (19.4)	85.3 (6.4)

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

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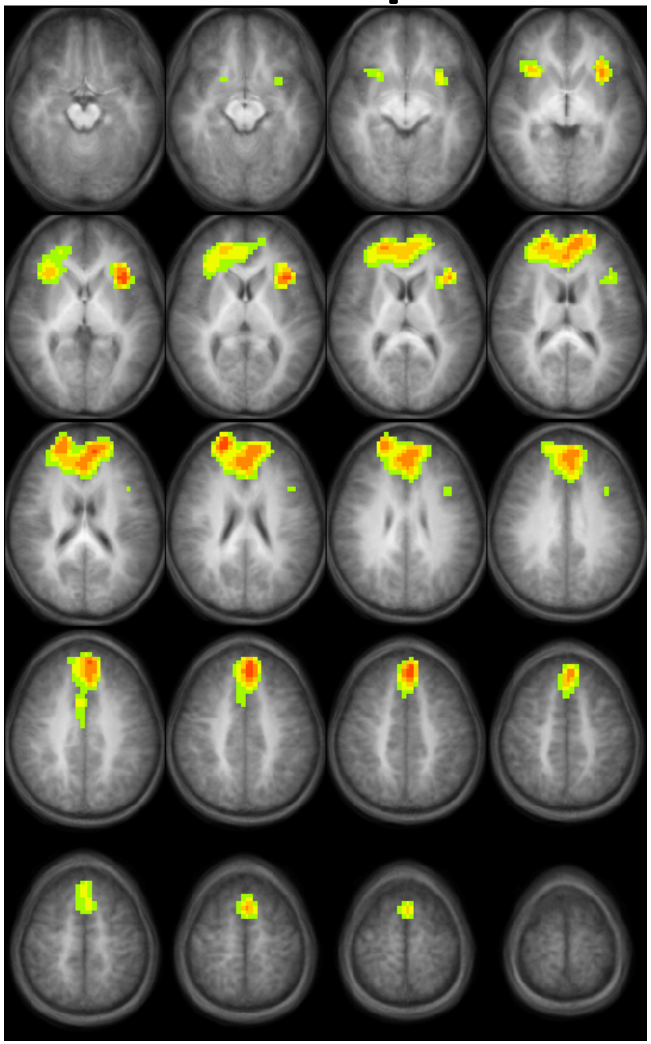
Table 6
*Intelligence Testing Results for TSD and SSD Children Included in the SRT Analysis Using Two-tailed t-Test (with Standard Deviations in Parentheses)**

Test	TSD Mean (standard deviation)	SSD Mean (standard deviation)
Full IQ	110. (13.2)	94.2 (13.1)
Verbal IQ	104.5 (15.7)	100.2 (15.7)
Performance IQ	108.3 (11.5)	97.7 (14.9)

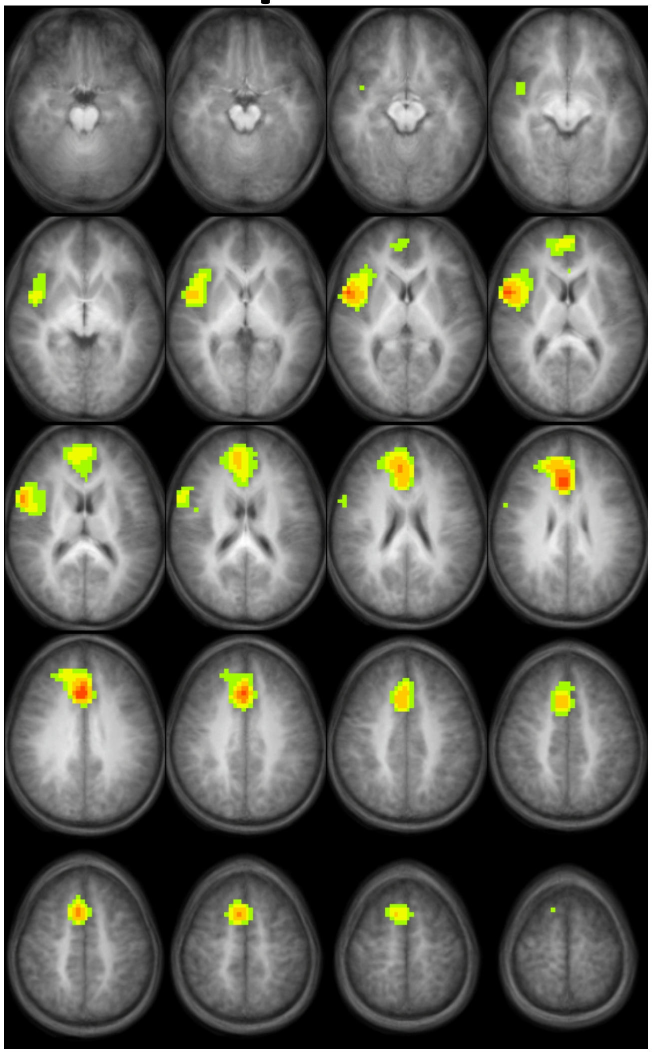
* p <.05, ** p<.01

Syllable Repetition Task: Repeat>Listen

R



TSD



SSD

L

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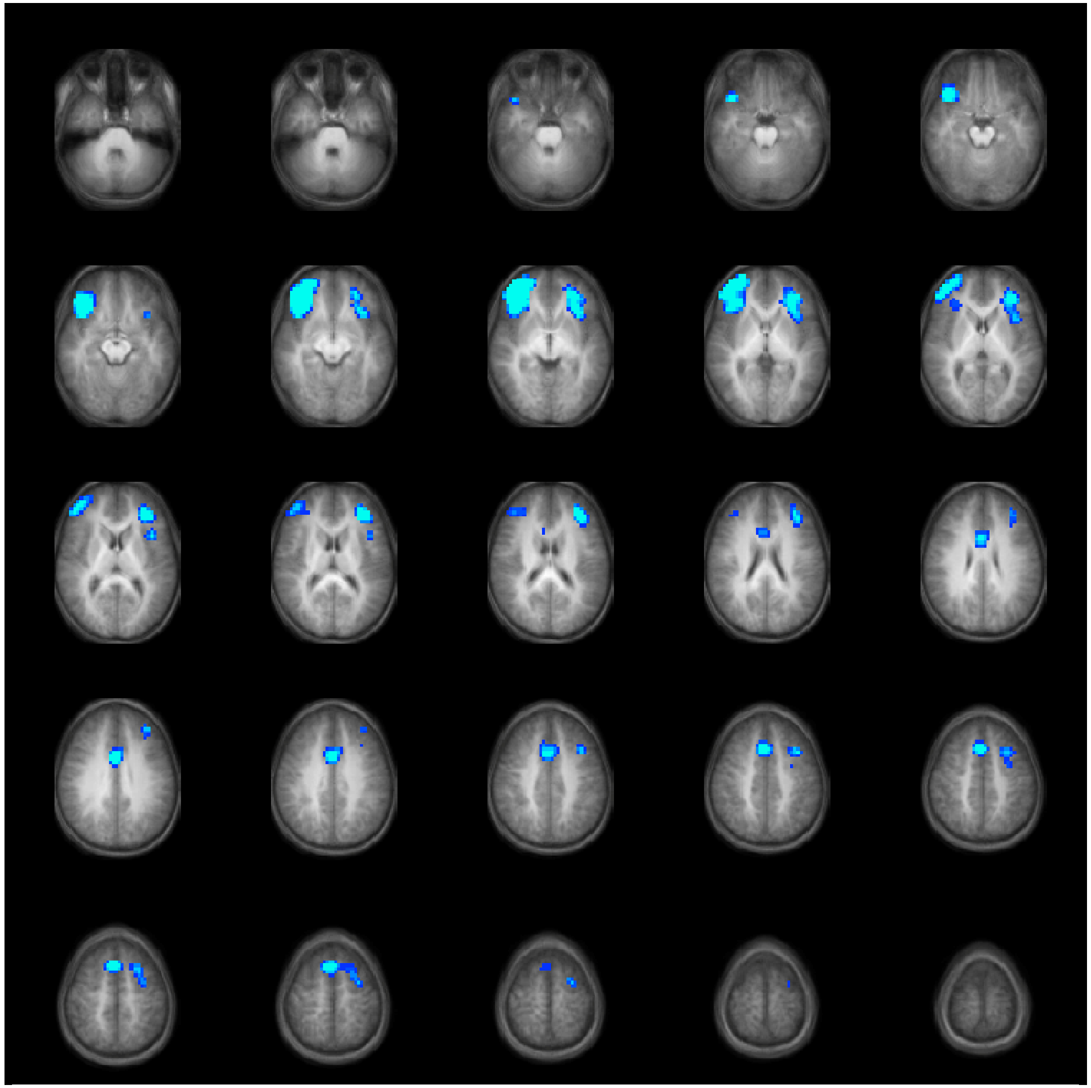
Syllable Repetition Task: Regression with task performance

R



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Higher SRT score → lower level of activation

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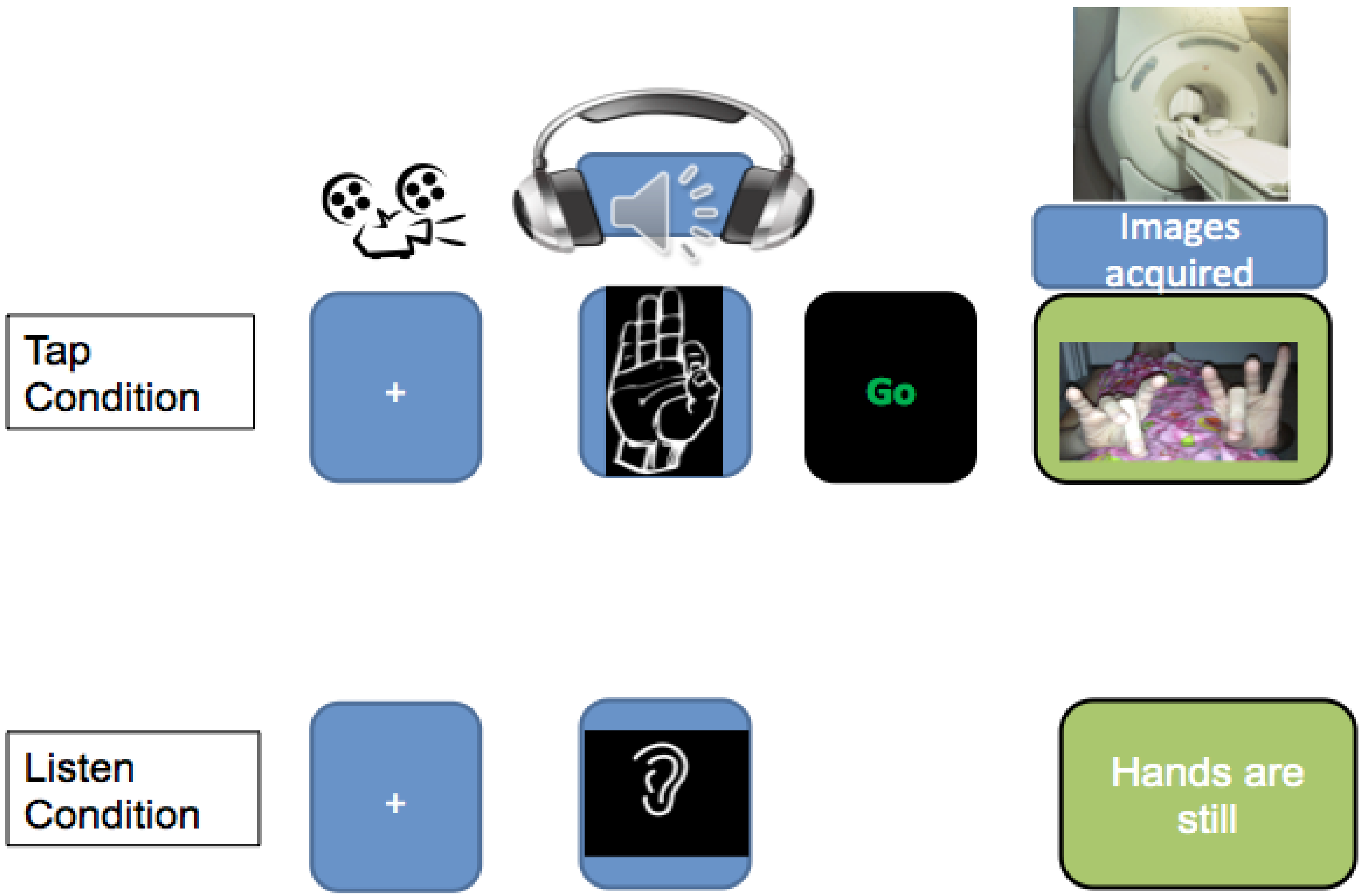
Fine Motor Praxis Task

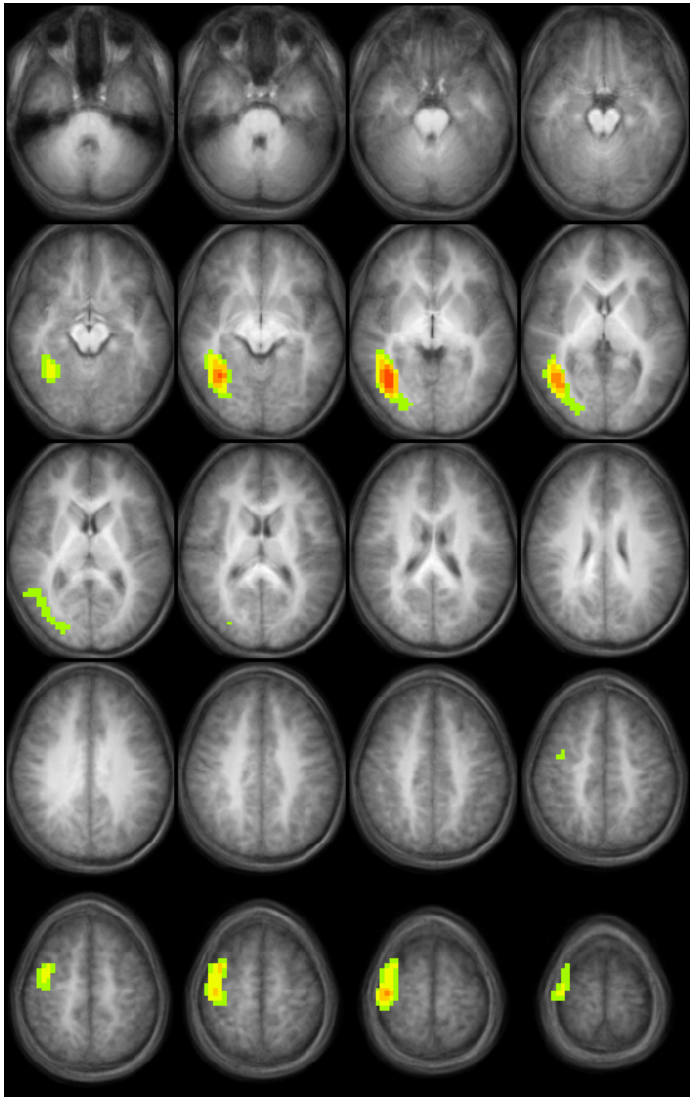


Fine Motor Praxis Task

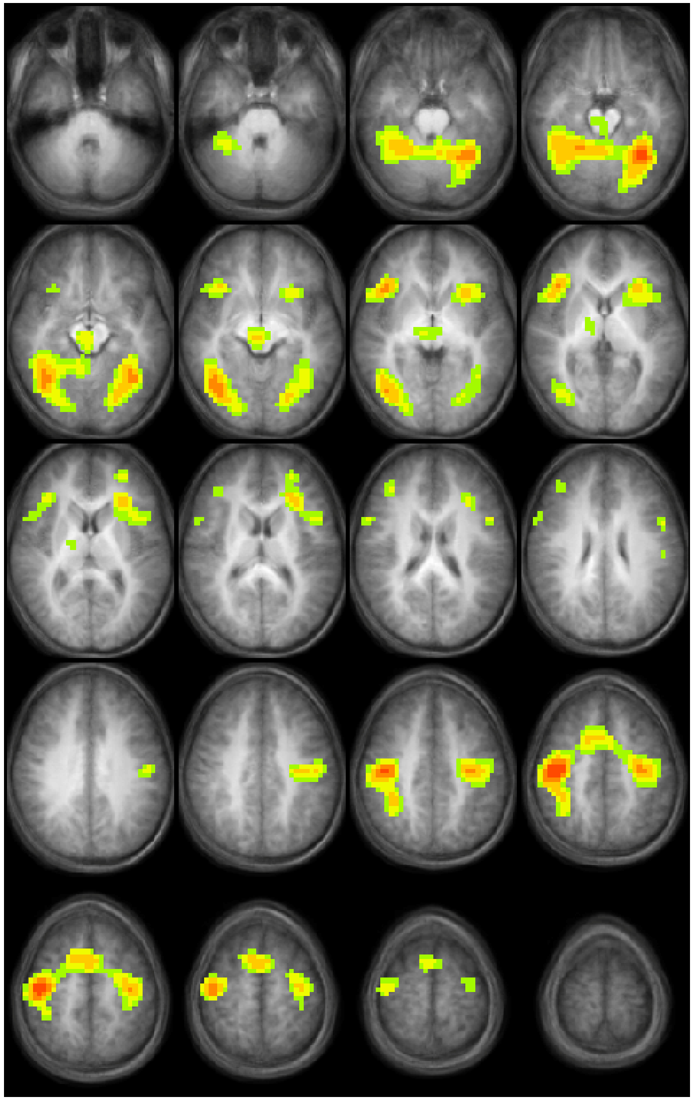
- Age-matched groups (n=12)
  - TSD n=6 (8.3 years, 3 males)
  - SSD n=6 (8.0 years, 3 males)
- For this limited group, no significant differences in SFA scores or IQ scores
- Purdue Pegboard Scores significantly different for right hand (p=.001) but not for left hand and combined
- Madison Protocol
  - 3 SD
  - 2 Insufficient data
  - 1 CAS

Fine Motor Praxis Task: Tap>Listen

R



TSD



SSD

L

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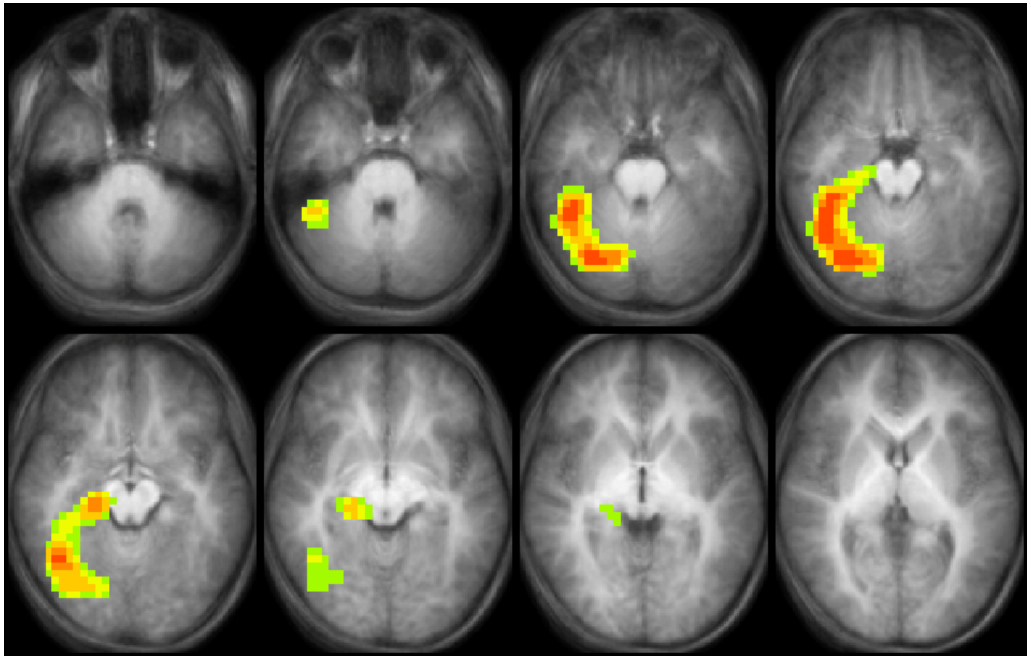
Fine Motor Praxis Task: SSD>Controls

R



L

Summary

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

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

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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
  - o 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

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