School Neuropsychology of Math and Math Disabilities

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Manitoba Association of School Psychologists
14-15 November 2013
Developmental Issues in Math Skill Development

Piaget’s Theory and Math

→ “Operational” thought and math schemas
→ One-to-one correspondence
→ Classification of objects
→ Seriation-sequential processing
→ Conservation
→ Quantity representation is symbolic
Developing Math Skills in School: Typical Instructional Sequence (Geary, 2001)

- Pre-Skills include subitizing (size differences), ordinality (< or >), serial counting, arithmetic (making things bigger or smaller)
- Skill acquisition, drill/practice, proficiency, automaticity
- Early instruction:
  - Concrete Objects (apple and apple, you have two apples)
  - Semi-Concrete Symbols (\/// + / = ///)
  - Abstract Numbers (4 + 2 = 6)
- Finger Counting, Verbal Counting, SUM (Count All) or MAX (seven plus two equals “2….3,4,5,6,7,8,9, the answer is 9”); MIN (“7….8,9, the answer is 9”), Math Fact Automaticity (7 + 2 = “9”)
- Hierarchical teaching: Addition, subtraction, multiplication, division, fractions (geometry, algebra, calculus)
- Math word problems and problem solving?
"Nonverbal" Learning Disability

Does NVLD = Math SLD?

(Rourke & Tsatsanis, 2000; Mesulam, 2000; Palumbo, 2007)

- Reading and spelling skills better than mechanical arithmetic
- Explicit verbal skills better than visual-spatial, tactile, complex motor
- Verbal IQ > Performance IQ
- Poor self-awareness
- Deficits in processing nonverbal social stimuli and cues during discourse
- Academic skills initially strong but decline with age
Is Math SLD Synonymous with NVLD?  
Dyscalculia and Gerstmann Syndrome  
(Helland, 2006; Shalev & Gross-Tsur, 2001)

- **Gerstmann Syndrome**: Neuropsychological Disorder known primarily in patient populations, but also occurs in SLD
- Most commonly seen following LEFT parietal damage
- Symptoms include:
  - Finger Agnosia
  - Left/Right Confusion
  - Dysgraphia
  - Dyscalculia (Supramarginal Gyrus? Angular Gyrus?)
Math Computation
- Quantity-Symbol (Number) Relationships (Coding?)
- Spatial Processing (Gv-Multi-step Problems)
- Sequential/Working Memory (Gsm-WM)
- Visual-Spatial-Motor Integration → (Gs, Gv-graphomotor)
- Computation (Gsm-WM, Gf, EF) vs. Math Fact Automaticity (Gc, Gs)

Math Word Problems
- Auditory Processing & Receptive Language (Gc)
- Semantics and Syntax (Gc)
- Word-Number Association (Gc)
- Working Memory (Gsm-WM)
- Novel Problem-Solving (Gf or Gq - Quantitative Reasoning)
- All Computation Components (and MORE Executive)
Hemispheric Functions, Psychological Tests, and Predicting Achievement

WISC-IV Digit Span

WISC-IV Block Design

Input
Auditory
Visual

Output
Verbal
Motor

WIAT-II Math Reasoning

WIAT-II Numerical Operations

Psychological processes matter more than stimulus input or response output!
# Meeting of the Minds
## Learning Disabilities Association of America 2012

<table>
<thead>
<tr>
<th>Cognitive to Achievement Grid</th>
<th>Visual-Spatial</th>
<th>Language</th>
<th>Working Memory</th>
<th>Long-Term Storage-Retrieval</th>
<th>Fluid Reasoning</th>
<th>Processing Speed</th>
<th>Phonological Awareness</th>
<th>Sensory-Motor Functions</th>
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<th>Rapid Automatic Naming</th>
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<td>Basic Reading Skills</td>
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WISC-IV/WIAT-II Math Disability Subtypes
(Hale, Fiorello, Miller, Wenrich, Teodori, & Henzel, 2008)

Mean Scaled Score

Fluid/Quantitative Reasoning
Mild Executive/Working Memory
Right Hemisphere SLD (NVLD)
Numeric-Quantitative Knowledge
Dyscalculia-Gerstmann Syndrome

WISC-IV Subtests
Si  Vo  Co  WR  In  DS  DF  DB  LNS  Ar  BD  PCs  MR  PCn  Cd  SS

Si  Vo  Co  WR  In  DS  DF  DB  LNS  Ar  BD  PCs  MR  PCn  Cd  SS
The Three Axes Interpretation

**Left Hemisphere**
- Routinized/Detailed/Local
- Convergent/Concordant
- Crystallized Abilities

**Right Hemisphere**
- Novel/Global/Coarse
- Divergent/Discordant
- Fluid Abilities

**Posterior**
- Sensory Input
- Comprehension

**Anterior/Superior**
- Executive Regulation and Supervision
- Motor Output

**Inferior**
- Executive Efficiency
- Precision of action
Math Computation/Fluency

Other Structures:
- Thalamus-Sensory Integration
- Basal Ganglia/Broca’s Area-Sequencing
- Oculomotor Circuit-Visual Tracking/Scanning

Motor Coordination (Supplementary Motor)
- Writing #’s (Exner’s Area)
- Handwriting #’s (Primary Motor)
- Sensory Feedback
- Primary & Secondary Somatosensory
- Math Knowledge
- Lexical/Semantic (Medial Temporal)
- Object Processing
- Automaticity Timing

Dorsal Stream
- Dorsolateral Prefrontal Cortex
- Direction (L) Spatial (R)
- #-Quantity Association (Supramarginal Gyrus)

Ventral Stream
- Math Computation/Fluency
- Direction (L) Spatial (R)
- #-Quantity Association (Supramarginal Gyrus)
- Motor Coordination (Supplementary Motor)
- Writing #’s (Exner’s Area)
- Handwriting #’s (Primary Motor)
- Sensory Feedback
- Primary & Secondary Somatosensory
- Math Knowledge
- Lexical/Semantic (Medial Temporal)
- Object Processing
- Automaticity Timing
Functional and Structural Alterations of the IPS in a Developmental Dyscalculia

(Molko et al., 2003)

• Intraparietal sulcus (IPS) activation in calculation tasks (images are controls)
• Activity was greater in approximate calculations, related to number sense
• “Zones of Overlapping” important for sound-symbol association (decoding), number-quantity association (math computation), and language comprehension (receptive aphasia)
Math Computation and Brain Functioning: Does complexity of operation affect fMRI activation?  
(Menon, Rivera, White, Glover, & Reiss, 2000)

A. Rate of Presentation: Influence of frontal-subcortical circuits (orbital-inferior frontal and insula)

B. Number of Operands: Importance of parietal (angular gyrus/IPS) and motor frontal-subcortical circuit (supplmentary motor cortex)
Math Reasoning
(Add Language, Fluid, and Increased Executive)

Other Structures:
ALL Previous Math Computation and Math Fluency Structures
Math Reasoning (including Computation/Fluency Skills)

- Motor Coordination (Supplementary Motor)
- Writing (Exner’s)
- Speaking (Broca’s)
- Auditory Processing
- Math Knowledge
- Lexical/Semantic (Medial Temporal)
- Handwriting #’s (Primary Motor)
- Sensory Feedback
- Primary & Secondary Somatosensory
- Direction (L)
- Spatial (R)
- #-Quantity Association (Supramarginal Gyrus)
- Language Comprehension (Wernicke’s Area)
- Object Processing
- Automaticity Timing
- Dorsal Stream
- Ventral Stream
- Prefontal Cortex
Prefrontal (dorsolateral, ventral-lateral, and cingulate) circuit involvement greater in young children more than older children, with increasing parietal (left supramarginal and IPS) and hippocampal, involvement in older children

→ Relevance for dyscalculia?
Comparing Dyscalculic and Typical Math Performers
(Kucian et al., 2006)

DD < Control only in approximate calculation \(\Rightarrow\) Number sense the main problem in dyscalculia?
Comparing Dyscalculic and Typical Math Performers
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Hank and Math Word Problems: Why Doesn’t He Get It?

- **Referral:** A careful, well-behaved boy who does well in school, Hank’s teacher reported he learned his addition and subtraction facts quickly. When he turns in his homework or takes tests requiring math computation skills, he seldom makes an error. He responds quickly to most of the math questions asked in class (within a second or two). However, Hank struggles with math word problems. For instance, given “Johnny had 6 apples, he ate two, and gave one to Sam, how many apples are left?”, Hank said “5”? What is the possible problem?

- **Hypotheses:** Hank has good math computation and math fact automaticity skills (so supramarginal gyrus, temporal lobe functioning, cerebellar automaticity, and frontal retrieval of facts all good). However, he struggles with math word problems – this could be because of poor receptive language (possibly Wernicke’s Area), working memory (possibly dorsolateral), and/or fluid reasoning (right hemisphere/frontal) problems, or mental flexibility that is the problem.
Linking Assessment to Intervention for Children with Math Difficulties and Disabilities
Individualized Strategies for Managing Mathematics
(Floyd et al., 2003; Geary, 2001; Hale et al., 2002; Mazzocco, 2001)

Math Computation
• Quantity-Symbol (Number) Relationships (Coding?)
• Spatial Processing (Gv-Multi-step Problems)
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Potential Intervention
• Manipulatives and conservation tasks for concrete-abstract number association
• Graph paper or self-line drawing for columns
• Metacognitive including checklist; arrow templates in multi-step problems; rehearsal
• OT; graphomotor, tactile, spatial, or integration
• Metacognition, self-talk, checklists, flashcards, repetition, retrieval strategies, cued recall
Individualized Strategies for Managing Mathematics
(Floyd et al., 2003; Geary, 2001; Hale et al., 2002; Mazzocco, 2001)

Math Word Problems
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Potential Intervention
- Speech/language service; receptive language; semantic mapping
- Sentence task analysis; semantics/syntax relationships
- Identify quantity/operand words in text
- Metacognitive strategies; mnemonics, paired associates, chunking, rehearsal
- Improve executive, external cues, brainstorming, deductive/inductive thought, estimation, self-monitoring/evaluation
SNAP-FIT (Student Neuropsychological Assessment Profiles for Innovative Teaching) Walt Case Study
Summary and Implications

• Early conceptualizations of brain functions and math disorders have been replaced.
• Left hemisphere is related to details, prior learning, automatic, and explicit math knowledge.
• Right hemisphere is related to global/holistic and novel problem solving, spatial problems less common.
• Frontal/executive problems lead to difficulty in solving math algorithms and math problem solving.
• Increasing specialization of inferior parietal regions with increasing competency, suggesting importance of frontal functioning in young children or older children with disability.
Summary and Implications (continued)

- Numerical Operations and Math Reasoning differences found among typical children and children with math SLD, support deficit (not delay) model and require specialized instruction.

- Cognitive Hypothesis Testing (CHT) leads to effective math SLD identification and service delivery.

- Linking assessment results to intervention using problem solving consultation and single subject designs ensures data-based decision making for ecological and treatment validity.
THANK YOU!

QUESTIONS? COMMENTS?

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