Early precursors to language development: implications for intervention

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Financial Disclosure

- In terms of a relevant financial relationship, Dr. Paula Tallal is a founder of Scientific Learning Corporation and on the Board of Directors and receives compensation for this.
- In terms of a relevant non-financial relationship with Scientific Learning Corporation, Dr. Tallal doesn’t have a relevant non-financial relationship.

Precurors to Language Development

- Our research has focused on understanding the neurobiological and environmental basis of individual differences in language development and disorders.
- We began our research program with the observation that many children with specific developmental language impairments (SLI) and reading deficits have particular difficulty at the phonological (speech) level of language.
Our earliest studies led to the discovery that language impaired children have particular difficulty in both perceiving and producing brief, rapidly successive signals, specifically in the tens of millisecond time range.

### Importance of Auditory Processing for Language

![Graph showing percent correct responses over interstimulus intervals (ISIs) for control and language impaired children.

**Children with weak language development can’t sequence 2 tones at rapid presentation rates.**

<table>
<thead>
<tr>
<th>Interstimulus Interval (ISI) in milliseconds</th>
<th>Percent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-40ms - Phonemes</td>
<td>90%</td>
</tr>
<tr>
<td>40-350ms - Syllables</td>
<td>80%</td>
</tr>
</tbody>
</table>

Tallal & Piercy (1973, Nature)

Rapid auditory processing (RAP) can be studied in infants born into families with or without a history of language learning impairments.

An operantly conditioned head-turn procedure is used to reward an infant for discriminating a change in a 2-tone sequence.
This baby has learned that something interesting happens to her left when the two tones are different.

Rapid auditory processing threshold at 7.5 months predicts language comprehension at 36 months.

Rapid auditory processing (RAP) at 6 months predicts developmental language delay at 3 years.

RAP thresholds at 6 months and male gender together accurately classified 91.4% of 3 year olds who scored in the impaired range on the Verbal Reasoning Scale of the Stanford-Binet.

There were no significant correlations between RAP and non-verbal outcomes.
Dr. April Benasich records electrophysiological brain activity (event-related potentials - ERPs) from infants.

Electrophysiological differences (mismatched response - MMR) to rapid tone sequences are observed in infants with a family history of language learning impairment.

- No significant group difference in mismatch response at 300ms ISI
- Infants with LI family history show significantly reduced MMR at 70ms ISI
- Significant group differences at 70ms ISI occur primarily in left hemisphere

Benasich et al. (in press) Neuropsychologia.

Many speech sounds (phonemes) differ only by brief spectral and/or temporal changes, specifically within 10's of milliseconds.
Steady-state vowel portions of syllables do not incorporate brief spectral or temporal changes.

Language impaired children have selective deficits in discriminating those speech sounds that differ by rapidly changing acoustic cues.

Speech can be computer modified to slow down the fast acoustic changes.
Children with language learning impairments show significant improvement in syllable discrimination when brief spectrotemporal changes are extended in time.

For speech, 10’s of milliseconds can change the meaning of a word. These waveforms are identical except for an inserted 100ms silent gap, yet we hear two different words. In order to be able to learn to read and spell we need to hear these small acoustic differences in words and become aware that it is these acoustic differences that the letters represent.

Hierarchical Regression Analysis for Language Measures at 2 and 3 years Predicting to 5 year Language Outcome Measures

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Hierarchical Regression Analysis for Language Measures at 2 and 3 years Predicting to 7 year Reading Outcome Measures

There is a highly significant correlation between nonsense word reading and rapid auditory processing in dyslexics


Subsequent studies discovered that difficulty in both perceiving and producing brief, rapidly successive signals:
1) extended to attention, sequencing and memory problems
2) extended to other populations of struggling learners (ADHD, Autism)
3) extended to English Language Learners (ELL)
Our model suggests that intervention for rapidly improving language and literacy skills should include both:

- strengthening the underlying **perceptual and cognitive building blocks** for learning (memory, attention, processing speed and sequencing)
- strengthening the fundamental **linguistic building blocks** (phonology, semantics, morphology and syntax).

### Language Literacy Continuum

- Perceptual weakness
- Weak phonological representations
- Oral language weakness
- Reading, writing, spelling problems
- Learning and academic problems
- **Struggling students**

### Goals for Intervention

- Strengthen Perceptual/Cognitive Skills
- Sharpen phonological representations
- Enhance oral language abilities
- Strengthen reading, writing, spelling
- Reduce learning and academic problems
- Successful students
For English Language Learners - Children who were not exposed to English as their first language did not have sufficient repetitive stimulation needed to set up the distinct phoneme categories for English phonemes – which are critical for learning both spoken and written language. Need to retrain their brain using neuroplasticity training methods to create automaticity in the neural firing patterns that sharpen phonological representations in the brain – which are the foundation needed to develop proficiency in English.

Implications for intervention

For children with language-based learning disabilities - Children are struggling with spoken and/or written language have specific deficits in processing rapidly changing sounds. As a consequence they have failed to build distinct and automatic phoneme categories – which are critical for learning both spoken and written language. Need to retrain their brain using neuroplasticity training methods to create automaticity in the neural firing patterns needed to sharpen phonological representations.

Implications for intervention
Over the first year, infants are mapping language representations as they tune into the native language environment. Construction of sensory maps across development has been widely studied in animal models and demonstrates that cortical representations of the sensory environment are continuously modified by experience. One critical time period for optimizing language mapping appears to be early in the first year. However, studies had not yet determined whether an interactive experience with prelinguistic stimuli will sharpen auditory discrimination abilities and acoustic mapping. Thus Benasich et al. attempted to differentiate typical maturational changes versus the effects of prelinguistic exposure and training.
Participants

Active Experience Group: 18 (10M) typically developing infants completed a pretest at 4-months of age followed by a training period and posttest at 7-months.

Passive Experience Group: 17 (9M) typically developing infants.

Naïve Control Group: 14 (7M) healthy infants tested at 7 months of age.

The study employed a mixed longitudinal and cross-sectional design that ensured both within-age and within-subject controls.

Active Auditory Exposure Impacts Acoustic Mapping

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Active Auditory Exposure Impacts Acoustic Mapping

Training

Participants in the ACTIVE group completed an interactive acoustic training period beginning one week after the pretest (4-months of age + 2 weeks). Infants came once a week for 6 weeks and were trained on 3 different types of stimuli: 800-1200Hz complex tones; bandpass noise; 800-1200Hz sweeps.

Participants in the PASSIVE group were passively exposed in 6 weekly sessions to exactly the same temporally-modulated auditory sequences as used in the active condition. Two blocks of stimuli were presented in random order at each session, ten minutes at 40ms ISI and ten minutes at 70ms ISI.

Participants in the NAÏVE CONTROL group were never exposed to the training stimuli.

ERP stimuli and presentation

Complex tone pairs with either a 300 or 70 ms within-pair interstimulus interval (ISI).

Tones had a fundamental frequency of 800 or 1200Hz with 15 harmonics (6-dB roll-off per octave).

AND 4 different types of stimuli including sweeps, noise with gaps, complex tones and duration changes.
Benasich et al. investigated the neural correlates of acoustic mapping in infants with dense array EEG/ERP before and after a 6-week interactive, progressive acoustic experience delivered via an operantly-conditioned go/no-go (G/N-G) paradigm.

The task was designed to focus attention on salient information in these non-linguistic stimuli that had relevance for subsequent linguistic mapping and to gradually entrain widening subsets of auditory neurons.

The results revealed more efficient mapping of acoustic input containing linguistically-relevant cues. Sharpening of acoustic discrimination, in the tens-of-milliseconds range critical to phonemic perception, was evident for trained stimuli. The impact of interactive acoustic experience was found only for performance on fast-rate stimuli (70ms ISI).
Multi-deviant Generalization Stimuli

This was not a specific and isolated "practice" effect. These processing abilities generalized to new, different stimuli that the infants had not previously experienced, that were similar in acoustic structure and incorporated rapid spectro-temporal change.

Stimuli:
- Standard: 70ms, 800Hz tone
- Three Deviants:
  - Frequency: 70ms 1200Hz complex tone
  - Duration: 30 ms 800Hz tone
  - Gap: 70ms 800Hz tone with a 20ms silent gap.