Phonology, Dyslexia and the Brain: A Temporal Sampling Perspective

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Learning to read involves many senses …
Predicting Reading & Dyslexia Across Languages

Brain Language

Phonology

Reading

→
Phonological Development: Levels of Analysis

- **Behaviour**
  - Spoken language lexicon

- **Cognitive**
  - Phonetics
  - Phonology
  - “Phonological awareness”

- **Sensory**
  - Acoustics
  - Motor
  - Visual
Spoken/Written Language Processing

- Lexicon/Reading
- Phonetics
- Phonology
- Acoustics

Psychology
Psychology: Phonological Awareness
Shows Language Universal Development
(Ziegler & Goswami, 2005)

Preschool: large units
- syllables
- rhymes (onset/rime)
  - l – ast, bl - ast

With schooling: small units
- phonemes
  - b – l – a – s -t
Spoken/Written Language Processing

- Acoustics
  - Phonology
  - Phonetics
  - Lexicon/Reading
  - Neuroscience
The Brain and the Speech Signal: Many Complementary Sensory Cues

Spectrogram e.g. phonetics

NINE    SEVEN    TWO    THREE    TWO

Amplitude modulation  e.g. prosody, rhythm
Envelope and Fine Structure: Envelope = power-weighted average
Envelope: Importance of Rise Times

Modulation rates cued in part by rise times
Envelope is of Key Importance to Speech Processing

*Envelope studies:* showed that brain could recognise speech when very little or no spectral info. present

Recognition achieved on basis of envelope alone (Shannon 1995 - amplitude/temporal cues)

Can also *contrast* envelope and fine structure – work of Oxenham and colleagues

*Language* – envelope carries speech intelligibility

*Music* – fine structure carries the tune
Auditory Chimera Sentences

Perception mainly from fine structure
Not much from envelope

Perception mainly from envelope
Not much from fine structure
Envelope information most important for speech intelligibility
The Acoustic Signal: High Complexity

Spectrogram: emphasises formant structure

NINE  SEVEN  TWO  THREE  TWO

Amplitude modulation: emphasises speech rhythm
Low frequency envelopes are key structural cues
Many amplitude envelopes at different rates are nested in the overall AE. Leong, Stone, Turner, Gos 2014, JASA
Leong & Goswami 2015, PLoS One
AM Phase Hierarchy Models
Leong & Goswami (2015)
Unpacking the AM structure of nursery rhymes

"Mary Mary quite contrary"

'STRESS' AM ~ delta (~2 Hz)

'SYLLABLE AM' ~ theta (~5 Hz)

'ONSET/RIME' AM ~ beta (~20 Hz)

Spectral AM Phase Hierarchy: S-AMPH

PLoS One
Universal Sequence of Phonological Awareness Related to Nested AM Hierarchy in signal?

Leong & Goswami, 2015, *PLoS One*

Acoustic hierarchy helps support phonological learning??
Amplitude Modulations and Phonology

Amplitude envelope “rise times” are strong cues to speech rhythm, prosodic structure and syllable stress.
How Does the Brain Encode Modulation?

Neuroscience

Language Representations

Networks

Neurons

Simple neural coding mechanisms, like oscillation at different rhythmic rates, appear to be critical.

delta: 0.5 – 4 Hz
theta: 4 – 8 Hz
beta: 15 – 30 Hz
gamma: 30 – 50 Hz

Nested – delta at top
Levels of Analysis

Cognitive

Phonological difficulties

Brain Imaging –
Brain encodes energy patterns or amplitude modulations: oscillating networks phase re-set via ‘rise times’ in energy (amplitude rise times)

Sensory

Rhythmic difficulties?

Amplitude modulation & rise time?

Neural
The Brain Samples Information in Different Frequency Bands (delta, theta, gamma ..)

- **Speech signal**
  - **Rapid modulations**
    - Gamma networks
    - ~30 – 50 Hz
  - **Slow modulations**
    - Theta networks
    - ~4 – 8 Hz

- **Phase locking**

- **Binding for speech perception**

  - "phonemes"
  - "syllables"

  - Poeppel
  - Giraud
Is Phase Locking to Slower Modulations and Rhythmic Events Impaired in Dyslexia?

Phonetic information

Rapid modulations
Gamma networks
~30 – 50 Hz

Slow modulations
Theta networks
~4 – 8 Hz

Slow modulations
Delta networks
~0.5 – 4 Hz

Phonemes
(~35 Hz)

Syllables
(~ 5Hz)

Binding for speech perception

Rhythm Syllables Meter

? Stress

stressed syllables
(~ 2 Hz)
Modulation rates cued in part by rise times
Across Languages: Rise Time Impairments in DYS

English, French, Spanish, Hungarian, Chinese, Finnish…

… indicating speech envelope processing difficulties
Rise time thresholds in infants at family risk for dyslexia: Kalashnikova, Goswami, Burnham – in press
Dyslexia: Rise Time and Phonological Skills

Across languages, children with dyslexia show:

**Poor phonological awareness:** stress patterns ✗
syllables ✗
rhymes ✗
phonemes ✗

**Poor phonological memory:** eg memory for digits ✗

**Poor rapid naming:** naming pictures ✗
naming colours ✗
Levels of Analysis

Cognitive

Phonological difficulties

Rhythmic difficulties?

Amplitude modulation & rise time?

Dyslexia = difficulties in recovering prosodic (rhythmic) structure from the speech signal?

Role of rise time sensitivity and oscillations?

Sensory

Neural
Do children with dyslexia have rhythmic and prosodic difficulties?

**Meter: Strong and weak “beats”**

Music: Strong/weak beats

Speech: Stressed/unstressed syllables

Amplitude Envelope

"MA -ry MA -ry QUITE con -TRA -ry"
Metrical Musical Rhythms?

Rise time signals the attack time of different musical instruments

Metrical same-different task: 2 Hz beat

3 / 4 time
4 / 4 time

Huss et al., 2011; Goswami et al., 2013, Cortex
Musical Metrical Same-Different Task: 10 Yrs

Correct responses

No. correct/36

CA

DYS

RA

30

20

10

**
## Musical meter and reading

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What about general rhythm perception?

e.g. tapping tasks

1.5 Hz (666 ms)  
2 Hz (500 ms)  
2.5 Hz (400 ms)

Thomson & Goswami, 2008  
*J. Physiology Paris* (9 yr olds)
Tapping to a Rhythm (1.5, 2 or 2.5 Hz) (inter-tap interval variability)
Rhythmic tapping and reading

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Dyslexia and Non-speech Rhythm

Children with dyslexia show rhythmic impairments with musical rhythm and when “tapping to the beat”

Perception on simple musical rhythm and tapping tasks is a significant predictor of reading development

Suggests rhythmic awareness and phonology are related developmentally
Prosodic ("Beat") Structure in Language

e.g. “dee dee” tasks

“Jack and Jill went up the hill”

“Harry Potter”

Goswami et al. 2010, Reading & Writing
Goswami et al., 2013, J Memory Lang
DeeDee Tasks: 12 Yr Olds

nursery rhymes  famous

% correct

**

% correct

CA  DYS  RA

30  50  70

nursery rhymes famous
DeeDee Tasks: 9 Yr Olds

% correct

**

famous

CA
DYS
RA
Perceiving syllable patterning in speech

Children with dyslexia show sensory impairments in perceiving prosodic patterning (alternating strong and weak syllables – “metrical structure”)

Suggests that prosodic / rhythmic perception plays a key role in phonological development
**Role of Rise times/ Oscillations:**
Dyslexia and atypical neural entrainment?

*Temporal Sampling Theory (Goswami 2011, 2015)*

![Diagram showing the relationship between speech signal and different networks]

- **Speech signal**
  - Rapid modulations
    - Gamma networks
    - ~30 – 50 Hz
  - Slow modulations
    - Theta networks
    - ~4 – 8 Hz
  - Slow modulations
    - Delta networks
    - ~0.5 – 4 Hz

**Phonetics:**
- ba - pa

**Rhythm**
- Syllables
- Meter
How Does the Brain Encode Modulation?

Neuroscience: MEG EEG

Language Representations

Networks

Neurons

Simple neural coding mechanisms, like oscillation at different rhythmic rates, appear to be critical.

delta: 0.5 – 4 Hz
theta: 4 – 8 Hz
beta: 15 – 30 Hz
gamma: 30 – 50 Hz

Nested – delta at top
Entrainment to Speech by Children with Dyslexia: AV, A, V  

Power et al., 2013

“ba ba ba ba ba ba ba..” (2 Hz rate)
Significant difference in preferred phase in the delta band for DYS vs control children:
Auditory and Auditory-Visual Conditions
Delta band:

DYS = sig entrainment but different preferred phase

Delta band:

DYS CA
Stimulus-induced modulation of oscillatory delta processes functionally atypical in dyslexia

Rise time difficulties = brain less efficient at phase resetting low-frequency oscillatory networks?

=> DYS entrain to a less informative portion of the speech signal

Would affect perceptual organisation of speech at all linguistic levels via the oscillatory (AM) hierarchy
Gave 200 semantically unpredictably sentences to children

Speech degraded by noise vocoding (forces greater reliance on envelope perception)

Measured quality of neural encoding of the sentences using stimulus reconstruction in EEG

“Arcs flew their cough”
Dyslexic children show poorer encoding of 2 Hz envelopes, even when compared to RL controls (younger children)
Brain Response 0 – 2Hz vs Stimulus Envelope (black line)

CA controls

Dyslexic

RL controls
Universal Sequence of Phonological Awareness Related to Oscillatory Sampling Efficiency?

Leong & Goswami, 2015, *PLoS One*

Acoustic hierarchy helps support phonological learning??

Oscillations = neural mechanism for mapping energy patterns in the input (a hierarchical relational structure – delta at top)
Educational Remediation?

Can musical and motor rhythms impact the oscillatory networks for processing speech?

Music: Strong/weak beats

Speech: Stressed/unstressed syllables

Amplitude Envelope

"MA -ry MA -ry QUITE con -TRA -ry"
Bhide, Power & Goswami (2013)

Music+motor intervention for poor readers (10 weeks): Drumming, singing, marching, poetry, hand-clap games...

Effect sizes:
- Reading 0.73
- NWR 0.95
- Spelling 0.90
- Rhyming 1.0
Implications of TS Theory for Remediation
(Ideally prior to schooling)

“Entraining the oscillators” – use music + motor activities to emphasise the rhythms and metrical structure of speech

- nursery rhymes
- poetry
- music and singing

Other rhythmic experiences:
- dancing
- marching
- playing instruments