Language and the Learning Brain

Infant Language Acquisition

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What is Language For?

• Communicative function:
  ○ Shared meaning

• Symbolic function:
  ○ Representation

• Social function:
  ○ Social interaction

• Sociolinguistic function:
  ○ Language defines social grouping
... and language is highly engaging for infants!
Part I: The Sociocognitive Basis of Language Learning

Part II: Booting-Up Language Systems in the Brain

Part III: Early Language Production

Part IV: Dyslexia
Studying Infant Abilities

- Sucking
- Head-turn/ preferential looking
- Brain imaging
- Electroencephalography (EEG)
- Functional magnetic resonance imaging (fMRI)
- Functional near infrared spectroscopy (fNIRS)
Part I:

THE SOCIOCOCOGNITIVE BASIS OF LANGUAGE LEARNING
Cognitive Basis of Language

- Language as a special “extra” capacity
  (*Chomsky: LAD*)

OR

- Requires similar abilities to psychological development (*“Theory of Mind”*):
  - Perspective taking
  - Joint visual attention
  - Understanding communicative intent
Infant Propensity for Social Interaction

- **Bowlby:**
  
  “a warm, intimate and continuous relationship with the mother (or primary caretaker) is essential for mental health”

- **Piaget:**
  
  *inborn reflexes: rooting, sucking, grasping*
Social Mechanisms for Language

- Imitation (*others are like me*)
- Gaze and gaze following (*joint attention*)
- Contingency learning (*turn-taking*)
Imitation in Neonates
Infants Prefer Direct Gaze & Follow Gaze
Face-to-Face Contingent Interaction vs TV?

- 9-month-old American infants
- Native Mandarin Chinese adult playmates
- Live play vs TV exposure (identical material)
- Only “live” group learned Mandarin sounds
Infants are Rational Learners

% touches using head

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<tr>
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<th>hands occupied</th>
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The infants’ social abilities are fundamental for language learning: e.g. imitation, gaze following, contingency learning.

Infants are sensitive to adults’ intentions and goals, and are rational learners.
Part II

BOOTING UP LANGUAGE SYSTEMS IN THE BRAIN
Language Learning Starts in the Womb

- The foetus can hear by the 3rd trimester of pregnancy
- Speech sounds are low-pass filtered to foreground *prosody*
- Neonates can recognise their mothers’ voice  
  *(De Casper & Fifer, 1980)*
Language Learning Starts in the Womb

- Neonates can recognise a story that was read to them during pregnancy (De Casper & Spence, 1986):
  - Pregnant mothers read a story 2 times a day during the last 6 weeks of pregnancy (e.g., “The Cat in the Hat” by Seuss)
  - After birth, neonates heard recordings of a familiar story or a new story, read by a different female
  - Infants adjusted their sucking rates to hear the familiar story
Hierarchical levels of phonology at different ‘grain-sizes’:

- **WORD**
- **SYLLABLE**
- **ONSET-RIME**
- **PHONEME (segment)**

Prosodic Stress:

- Strong (S) – weak (w)

Word: “doctor”

Phonemes: “d”, “o”, “c”, “t”, “o”, “r”

- “doc” (S) “tor” (w)
Phonemes are the smallest units of sound that change meaning:

- “bat” - “pat”
- “bat” - “bet”
- “baŋ” - “bad”

In normal speech, many similar but non-identical sounds are produced (allophones). Our brain hears these variations categorically (i.e. as either /b/ or /p/). 

![Graph showing categorical perception of phonemes](chart.png)
Categorical Perception in Infants

- Infants show categorical perception of phonemes by 1 month of age (*Eimas et al.*, 1971)
In English, we divide the acoustic continuum from d – t into 2 phonemes.

In Hindi, there are additional d – t phoneme divisions.

Eng: /d/ | /t/

Hin: /d/ | /ɖ/ | /ʈ/ | /t/

Similarly, Salish (American Indian) has additional phoneme divisions in the g – k continuum, /k/ - /q/
Before 6 months, English infants perceive all phonetic boundaries (English, Hindi, Salish)

By the end of their first year, English infants no longer hear non-native phonetic boundaries (Hindi, Salish)
• Allophones of native phonemes are perceived as more prototypical than they actually are.
• Infants show this effect by 6 months.
EEG study on ‘native phoneme tuning’ (Ortiz-Mantilla et al, 2013):

- 6-month-old English infants listened to English (native) or Spanish (non-native) phoneme ‘deviant’ syllables *da da ta da da da d’a*

- Gamma oscillations in the anterior cingulate cortex could index ‘*nativeness*’
EEG longitudinal study (Kuhl et al, 2008):

- Better native discrimination at 7.5m = faster vocabulary growth over 14-30m
- Better non-native discrimination at 7.5m = slower vocabulary growth over 14-30m
“Segmentation problem” : Where are the syllables and words?

Solution: **Phonotactics** (statistics) and **Prosody** (rhythm)
Phonotactic Learning (Sound order)

- Words are composed of sequences of phonemes and syllables
- There are statistical patterns in these sequences called **transitional probabilities** (i.e., the likelihood that one sound follows another)
- Infants can learn transitional probabilities and use these to find words

“pretty baby” : “pre-tty” vs “ty-ba”
In English, many early words have a ‘Strong-weak’ (S-w) rhythm pattern:
“DA-ddy”, “MU-mmy”, “BA-by”, “BIS-cuit”

By 7.5 months, infants assume that the ‘S-w’ pattern indicates a word: occasional errors!

“The **DOC-tor** is busy” ✔
“Her gui-**TAR** is nice” ✗
• EEG study on ‘native rhythm discrimination’ in 3m-old and 6m-old infants (Pena at el, 2010)

• Spanish infants listened to:
  (A) Spanish (native rhythm)
  (B) Italian (native-like rhythm)
  (C) Japanese (non-native rhythm)
Results:

- In 3 month-old infants, there is the same gamma band response to Spanish and Italian, but not to Japanese.
- By 6 months, gamma-band oscillations distinguish Spanish from Italian & Japanese (native tuning)
Prosodic cues are emphasised in “Motherese” or Infant Directed Speech (IDS)

- Higher pitched, slower, louder

IDS is spontaneously used by mothers and fathers, across cultures!
Motherese supports language learning

Infants of mothers who produce clearer IDS ("vowel hyperarticulation") have better speech perception skills (Liu et al, 2003)
Motherese

- Vowel hyperarticulation does not occur in *pet-directed speech* (i.e. it is specific for infant language learning)

*Burnham et al, 2002 (Science)*
Babies are born able to discriminate all the phonetic boundaries used in human languages.

The infant brain specialises over the first year of life, creating prototypes for native speech sounds.

Infants solve the problem of speech segmentation using phonotactic (statistical) & prosodic (rhythm) cues.

Motherese exaggerates phonetic and prosodic cues, and supports babies’ language learning.
Part III

EARLY LANGUAGE PRODUCTION
Vocalisation begins from birth, and infant babbling is well-established by 7 – 10 months:

- 0 – 2 months: “comfort sounds”
- 2 – 3 months: “gooing”
- 4 – 6 months: “marginal babbling”, trills, squeals
- 7 months +: “canonical babbling”
Infants across cultures babble the same sounds in the same order. Early sounds are easier to produce (e.g. “plosive”, “nasal”): /d/ /b/ /m/ /n/ /g/ /t/. Strings like “dadada” and “mamama” emerge early.
The intonational and prosodic patterns of infants’ babble follows the “language” being babbled (e.g. French, Cantonese, Arabic).

Infants babble also reflects the frequency of phonemes in the language:

- French has more words with /b/, /p/, /m/, /f/, /v/ than English. French babies babble these sounds more.
Hand Babble

- Hand babble has a different rhythmic signature that marks it as communicative
Part IV

DYSLEXIA
Developmental Dyslexia

- Difficulty in learning to read despite normal IQ
- Affects ~7% of children (~2 per class)
- ‘Core deficit’ in phonology
  - Caused by abnormal auditory processing?
• In dyslexia, poor reading and phonology is associated with poor rhythm (beat) perception

1) Amplitude rise time discrimination
   English, French, Spanish, Hungarian, Chinese, Dutch...
   (Goswami, 2011)

2) “Dee Dee” task
   “Harry Potter” = DEEdee DEEdee
   (Goswami, Gerson & Astruc, 2010)

3) Direct stress perception
   “MIIitary” vs “miIIitary”
   (Leong, Hamalainen, Soltesz & Goswami, 2011)
Neural Models of Speech Processing

- Observation: Neuronal oscillatory activity in the brain occurs at the same timescales as major phonological units:
  - DELTA (stress)
  - THETA (syllables)
  - GAMMA (phonemes)
**Proposal**: The speech energy pattern associated with different phonological units *entains* neuronal oscillations in the brain.
Neural Models of Speech Processing

- **Result**: Concurrent sampling (parsing) of speech at multiple timescales (*Poeppel*, 2003)

  - Rapid Modulations: Gamma Networks, 20 – 50 Hz
  - Slow Modulations: Theta Networks, 4 – 8 Hz

  - Binding for Speech Perception

  - **DYSLEXIA?**
    Goswami (2011) TICS

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[Image of rapid and slow modulations, phonemes and syllables, and a diagram of speech signal with annotations.]
Atypical Oscillatory Activity in Dyslexia

- **Neural entrainment study** *(Hamalainen et al, 2012)*
  - Fluctuating white noise at 2, 4, 10, 20 Hz
  - Predict reduced entrainment at slow rates
  - Predict normal or enhanced entrainment at fast rates

2 Hz *(stress rate)*

10 Hz *(phoneme rate)*

- **More research is needed...**
# A Multi-Level Theoretical Framework

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The diagram illustrates the connections between biological, cognitive, and behavioural aspects, with environmental influences indicated by arrows pointing towards the right.
Language (Environment) Changes the Brain

PHONOLOGICAL REPRESENTATIONS OF WORDS

Vocabulary size and rate of expansion

Linguistic factors
Eg. sonority profile, syllable structure

Crossmodal factors
Eg. lip reading

Speech processing skills
(input and output)

Phonological neighbourhood density

Word frequency/
familiarity/
Age of acquisition

Language (Environment) Changes the Brain
THANK YOU FOR YOUR ATTENTION!