The Beat of Language Development: Does Rhythmic Regularity Facilitate Early Word Learning?

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Research Goals

The current study investigates how **rhythmicity** (i.e., temporal regularity) in **infant-directed (ID) speech** may support **early word learning**.

We hypothesize that **rhythmicity dynamically engages infants' cognitive processes in real time, which enhances word learning**, and that such learning processes are **anchored by underlying neural activity**.

We will apply novel **machine learning (ML) techniques** to leverage infants' multiple signals to predict learning.

Background

- Infants understand many words by 9 months[1].
- Caregivers label objects repeatedly, in ID speech.
- ID speech is more rhythmic than adult-directed speech[2].
- Rhythmicity can facilitate neural tracking (e.g., phase-locking to speech in the stress (delta) or syllable rate (theta); may relate to better comprehension in adults[3].
- Infants attend more to[4], learn better from[5], and more strongly neurally track[6] ID than adult-directed speech, however, whether this is specifically due to rhythmicity is unknown.
- We measure learning across multiple systems (Visual, Neural, Affective).
- ML techniques[7] will be used to predict learning outcomes.

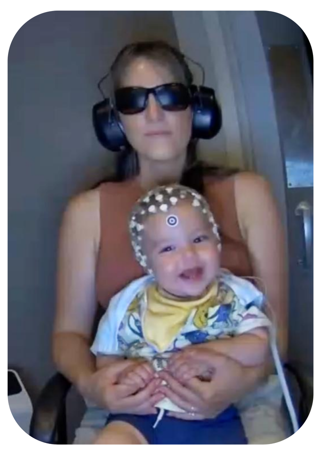
Predictions:

1. ↑ rhythmicity in ID speech will ↑ learning of novel words.
2. ↑ neural tracking will predict ↑ learning.
3. Neural tracking will predict vocabulary development at 18 months[8].
4. ML will be able to predict learning outcomes based on features extracted from online multimodal signals during familiarization.

Methods

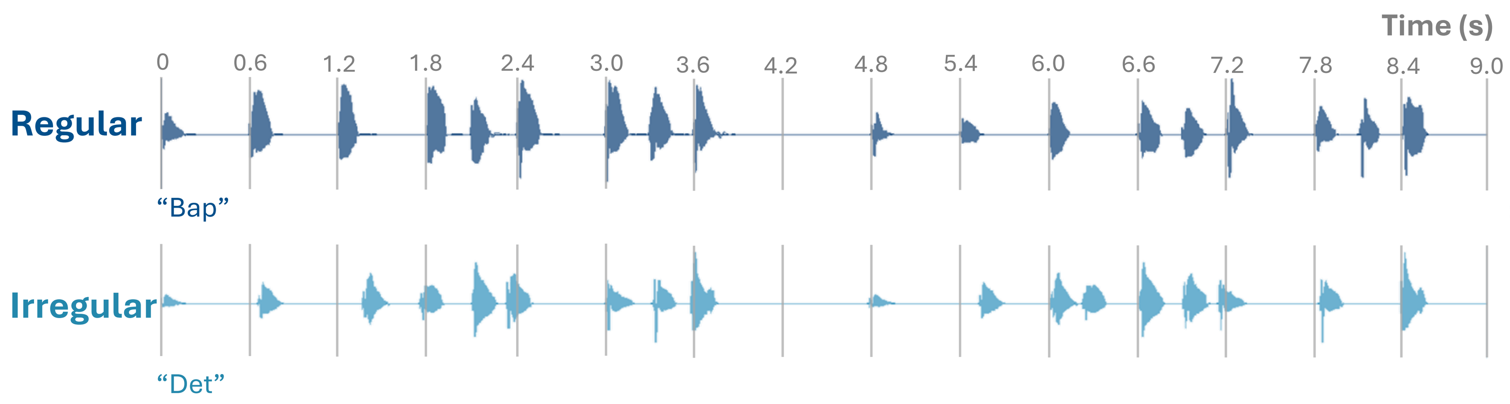
Participants & Questionnaires:

- 9- to 11-month-old infants (≥70% English exposure) (*N* = 25 infants so far)
- Vocal Development Landmarks Interview (Canonical subscale)
- Communicative Developmental Inventories (at 18 months)
- Music background questionnaire

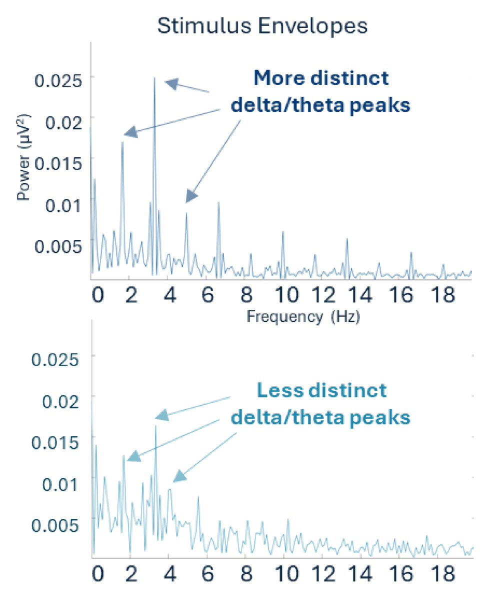


Object Stimuli: Novel objects from the NOUN database[8]; two familiar objects (Cat, Dog).

Auditory Stimuli: Monosyllabic pseudowords (+ 'cat', 'dog') repeated over intonation phrase in IDS, manipulated into **regular** (300 or 600 ms inter-onset-intervals) and **irregular** rhythms (jittered ± 20-100 ms).

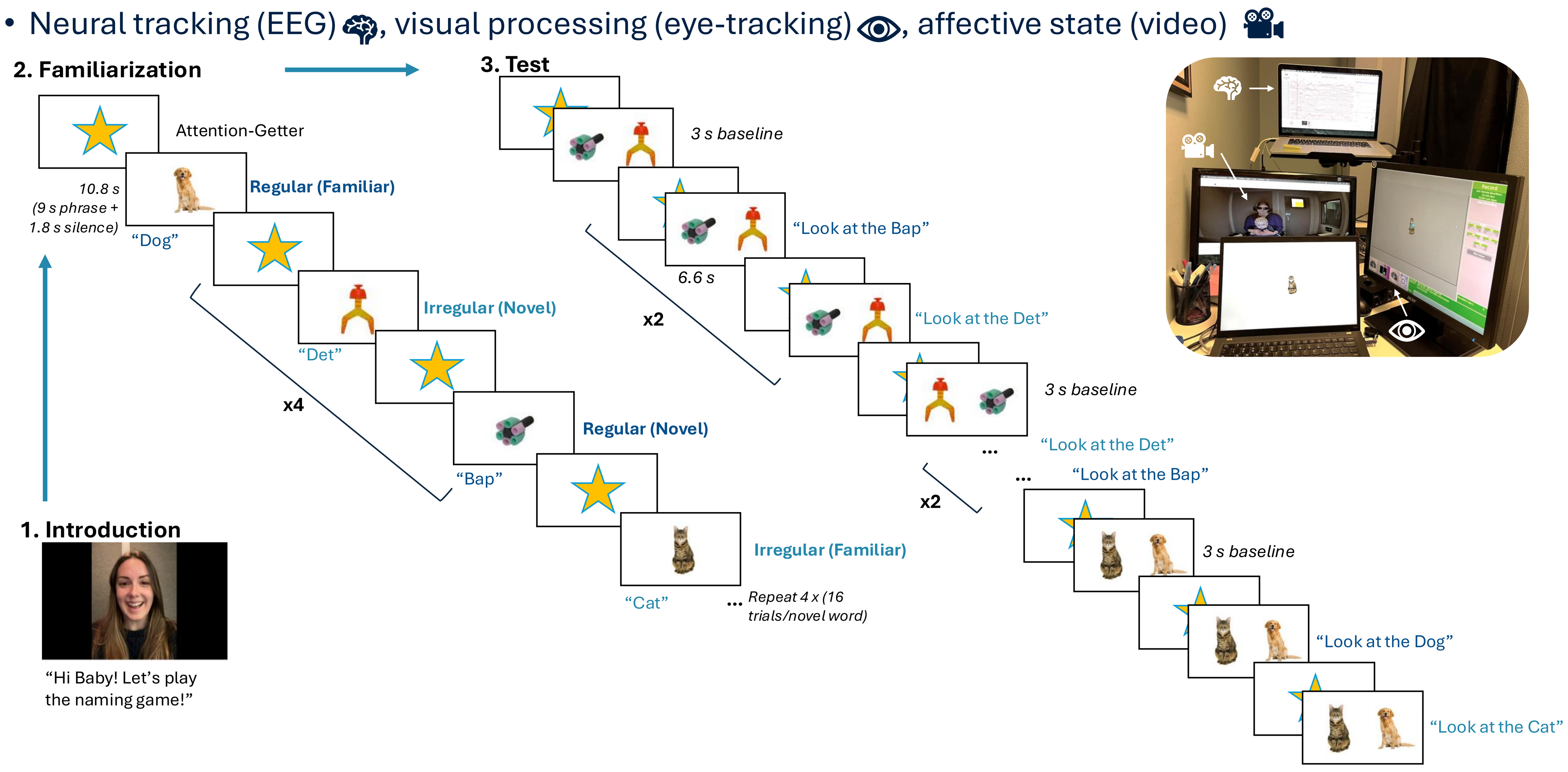


Scan to listen!



Object-Labelling Protocol

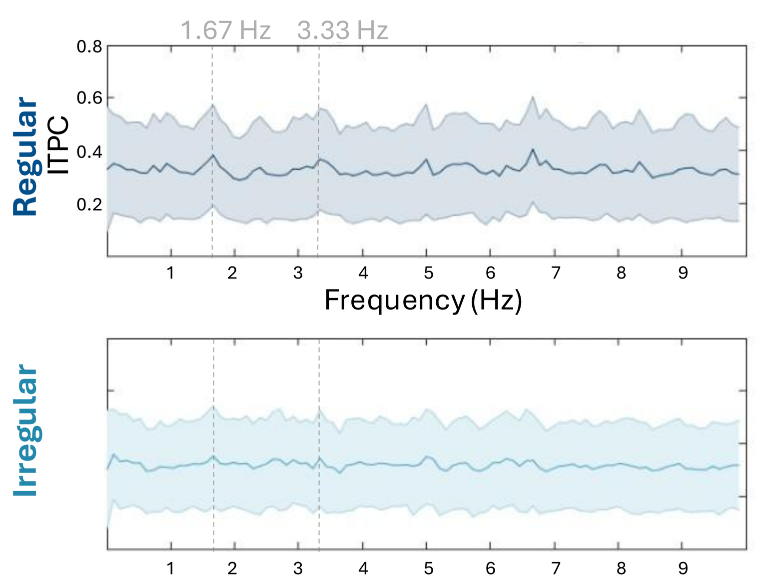
- Familiarization phase (regular or irregular rhythms), Test phase (paired objects)
  - 'Dog' and 'Cat' help set context of the task.
- Neural tracking (EEG), visual processing (eye-tracking), affective state (video)



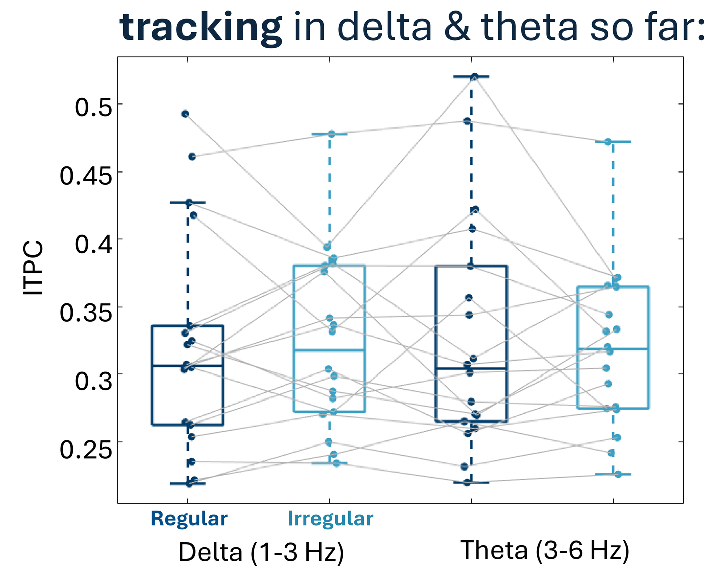
Preliminary Results & Implications

1. Neural Tracking

- Planned analysis: *Speech-brain coherence* in delta (~1-3 Hz)/theta (~3-6 Hz)
- Below, left: Preliminary *inter-trial phase coherence* (N = 18/25 infants) shows peaks at 600 ms (1.67 Hz) and 300 ms (3.33 Hz) rates are higher in **regular** case...



...But **no suggestion of stronger tracking** in delta & theta so far:



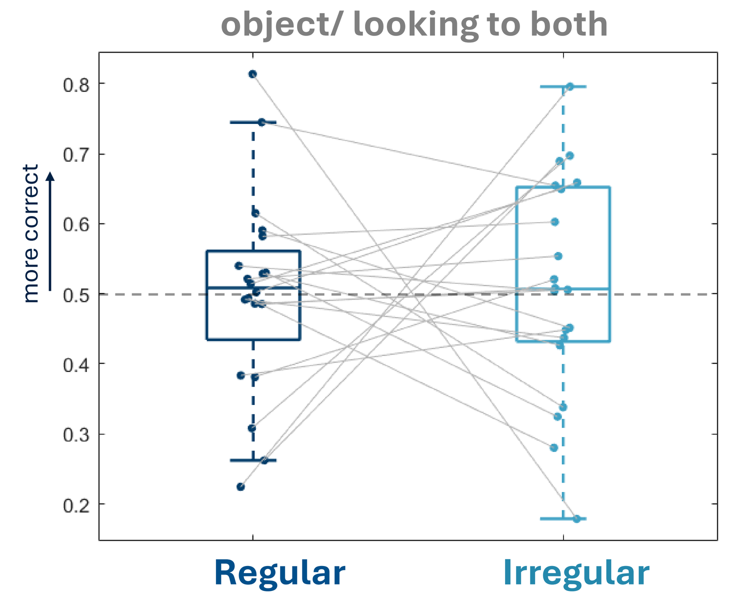
Implications/Next Steps

- Next steps: data collection, speech-brain coherence, eye-tracking data cleaning, neural results → learning outcomes, and developing the ML pipelines.
- Implications for understanding the role of rhythmicity in infant language acquisition.
- Potential to apply developed ML models to predict learning outcomes in real-time.

2. Infant Learning Outcomes (looking time)

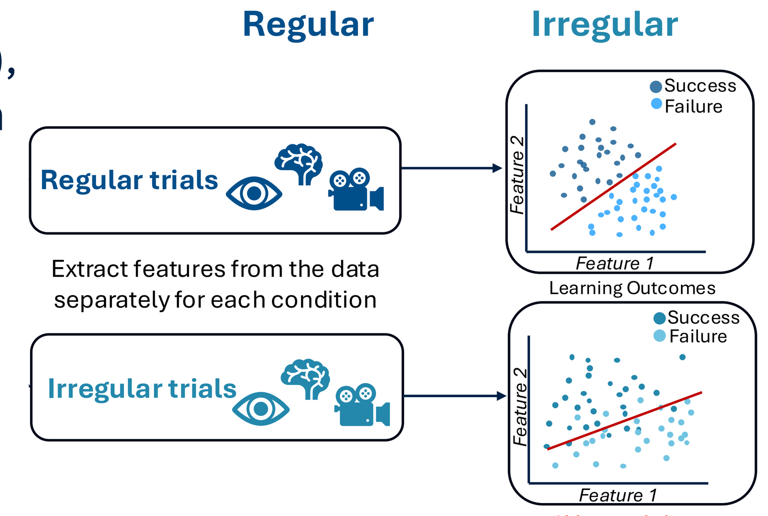
- Preliminary results *(see Right)* (N = 20/25 infants with useable test trials) show high variability across infants; **no suggestion of better learning in regular condition** so far.
- Planned mixed linear effects models will test predictions 1-3, including individual factors (e.g., age, language background).

Proportion of Looking time to correct object/ looking to both



3. Machine Learning

- Planned exploratory ML methods (prediction 4), will predict learning outcomes at test based on data for familiarization:
  - Start with eye-tracking data (e.g., fixations, saccades), then explore other signals.
  - Start with classic classifier models *(see example Right)*, then explore deep learning techniques.



*Not real data

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