EARLY SIGNATURE OF AUDITORY TEMPORAL PROCESSING IN PREMATURE NEONATES STUDIED THROUGH HIGH-RESOLUTION ELECTROENCEPHALOGRAPHY

Sahar Moghimi

Mohammadreza Edalati, Mahdi Mahmoudzadeh, Fabrice Wallois
Rhythm

The relative temporal relationship of auditory events

Temporal regularities are present at multiple hierarchical levels in both music and speech.

Temporal grouping of auditory events and perception of rhythmic patterns is central to how we recognize structure in sound sequences.
Rhythm Processing in the adult brain

Underlying functional network

Detection of rhythm deviant and the underlying oscillatory activity

Entrainment to rhythm

(Nozardan et al. 2011)

(Grahm et al. 2009)

(Edalati et al. 2020)
Rhythm is particularly an important feature of acoustic events because its temporal regularity enables predictions about upcoming sounds.
Rhythm and Temporal Regularities

higher level systems provide a prediction of the inputs to lower level regions and lower regions respond to failures to predict with an error term, which is propagated to higher areas.

Auditory acoustic regularities are transformed into predictions about current sensory signals via the interaction of E and R populations.
Rhythm processing, an early developing process

As early as twenty-five weeks gestational age (wGA), hearing is operational.

The fetus hears the isochronous rhythm of the maternal heartbeat, and respiration

Despite the attenuation of sound and distortion of its frequency content by the maternal tissue, the rhythmic information is preserved.

Deprivation of patterned sound experience and exposure to the extra-uterine environment could cause suboptimal auditory development.
Why rhythm

Rhythm processing in premature neonates, a developmental neurobiomarker of auditory temporal processing?

The first step characterization of the neural response...
Rhythm Perception in early development

- Can the premature neonate entrain to a rhythm? At what level? What are the underlying mechanisms?

- Can the premature neonate detect the violations from regular rhythmic structures? What are the underlying mechanisms?
Rhythm Perception, entrainment to an ambiguous rhythm

Can the premature brain group the auditory events as does the adult brain?

A combination of sounds and silence
Each sound a combination of drum sounds
Beat inter-onset-interval 333 ms

Rhythm I

Rhythm II

15 premature healthy neonates 29-34 wGA
50 blocks of 20 repetition for each rhythm
128 EEG recordings

In collaboration with Laurel Trainor, McMaster Institute for Music and the Mind, McMaster University, Canada
Rhythm Perception, entrainment to an ambiguous rhythm

HR-EEG

Preprocessing
Block averaging

Fourier transform
Normalization

Entrainment response to beat and meter frequencies
Rhythm Perception, entrainment to an ambiguous rhythm

Both stimuli elicited clear EEG responses frequency-locked to the rhythms, at frequencies corresponding to both beat and meter.

Premature neonate entrains to both beat and meter frequencies, and hence groups the auditory events.
Rhythm Perception, **entrainment to an ambiguous rhythm**

Extracting the beat information and grouping these beats into metrical hierarchies

- The role of premature birth on this process
- Its evolution in the course of development
- The underlying functional networks

29-34 wGA premature neonates

14-16 month-old infants

What is the functional neural networks underlying this process?

Cirelli et al. 2016
Rhythm Perception in early development

- Can the premature neonate entrain to a rhythm? At what level?
- Can the premature neonate detect the violations from regular rhythmic structures? What are the underlying mechanisms?
Rhythm Perception, violation detection

How violation of rhythmic structures is processed in the premature brain? What are the underlying mechanisms?

A simple rhythm in 2:4 meter with pure tones of 990 Hz. A 25 accent on the first beat to reinforce the meter

- 19 healthy premature neonates born at 30-34 wGA, tested during the first week of life
  - Paradigm: oddball
  - 128-electrode EEG recording
Rhythm deviant elicited an MMR that was followed by a subsequent negative deflection.

Soon after the onset of the establishment of thalamocortical circuits for auditory perception, the premature brain detect the violation from a rhythmic structure.

Premature brain creates a mismatch response to deviation from a regular rhythmic structure.
Rhythm Perception in early development

- Can the premature neonate entrain to a rhythm? At what level?
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Dynamic Causal Modeling

To make inferences about the effective connectivity between predefined sources and the modulation of the connection by the task.

Assume that ERPs are generated by temporal dynamics of a network of a few sources.

Describe temporal dynamics within and between sources by differential equations.

Each source projects to the sensors, following forward modeling.

Solve for the model parameters using Bayesian model inversion.

\[
\dot{x} = f(x, u, \theta)
\]

\[
p(\theta | y, m)
\]

\[
p(y | m)
\]

David et al. 2006
Garrido et al. 2007
Rhythm Perception, an immature mechanism?

In adults
Neural effective connectivity underlying the mismatch negativity

Mismatch response to frequency deviation

Mismatch response to duration deviation

Mismatch response to omission

Activated regions in response to auditory change detection

Garrido et al. 2007; 2008

Phillips et al. 2015

Chennu et al. 2016
Rhythm Perception, an immature mechanism?

Ventral pathway connecting the ventral inferior frontal gyrus to the temporal cortex in newborns

In adults
Neural effective connectivity underlying the mismatch negativity

In premature neonates
Neural effective connectivity underlying the mismatch response

Ventral pathway connecting the ventral portion of the inferior frontal gyrus to the temporal cortex via the extreme fiber capsule system

Perani et al. 2011

Activation of the frontal cortex during mismatch response in premature neonates

Mahmoudzadeh et al. 2013

Garrido et al. 2008
Rhythm Perception, an immature mechanism?

In the premature brain

- Is rhythm processing a low-level processing limited to the primary auditory cortex?
- Or does it involve a hierarchy of cortical processing with bottom-up and top-down dialogs?

(A)

- IFG
- STG
- A1

A1, primary auditory cortex; STG, superior temporal gyrus; IFG, inferior temporal gyrus
Processing of rhythm deviation in the premature brain is not limited to the primary auditory areas, and as in the case of adults, encompass a hierarchy of temporo-frontal cortical structures in a bottom-up and top-down stream.

Bayesian model selection over the 16 tested networks. The investigated model families: NI, no IFG models (1 - 4); F, models with only Forward connections between STG and IFG (5 - 10); FB, models with Forward and Backward connections between STG and IFG (11 - 16).

The winning model have both forward and backward connections with the frontal cortex.

Edalati et al. in review
Limitations

The neural network dynamics
The local excitatory-inhibitory interactions
Conclusions

Back to the questions

- Can the premature neonate entrain to a rhythm? At what level?
- Can the premature neonate detect the violations from regular rhythmic structures? What are the underlying mechanisms?

What is next?

- From a simple rhythm to more complex structures
- The evolution of the response in the course of development
- The impact of prematurity