Neural Representations of Sequences

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Temporal Dynamics of Learning

Time and Space/Nitz 2013
**Time is an organizing principle of the world**
*Le temps est un principe organisateur du monde*
*Ο χρόνος είναι μια οργανωτική αρχή του κόσμου*

- Sequences underlie much of what we learn
- The brain is organized according to temporal patterns as is our world
- The ability of the brain and the world to integrate is crucial
Time is an organizing principle of the brain

**STDP**  **Spikes**  **Local Field Potentials**  **Cortical EEG**

Temporal Dynamics of Learning
How are temporal sequences organized?

- Temporal patterns are learned and recognized
- Temporal pattern recognition is basic for perception, language, and cognitive processing
- Deficiency in rapid temporal processing underlies some learning deficits
How do brain circuits learn sequences?

Naive model
Time matters for processing...

These wave forms are *identical* except for the artificially inserted gap and a compensating shrinkage of the waveform.
Time matters for processing...

“say”

“stay”

These wave forms are *identical* except for the artificially inserted gap and a compensating shrinkage of the waveform.
Time matters for learning...

Interstimulus Interval (ISI) in milliseconds

Percent Correct

Control

Language Impaired

< 40ms - Phonemes

40-350ms - Syllables

TONEDURATION = 75 msec
Tone 1 = 100 Hz,
Tone 2 = 300 Hz

Tallal & Piercy (1973) *Nature*.

6-8 year old language impaired children can’t do the task at short ISI’s: correlation, or causation?
# Timescales of investigation

<table>
<thead>
<tr>
<th>Timescales of investigation</th>
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*Temporal Dynamics of Learning*
Different behavioral states are associated with distinct patterns of brain activity.

Penfield and Erickson, 1941
Brain Activation Improves Stimulus Fidelity in the Cortex

- Rodent Audition (Harris): Neural encoding of auditory temporal patterns is highly nonlinear and depends on brain state.

From the Harris Lab
Rodent Audition (Harris): Neural encoding of auditory temporal patterns is highly nonlinear and depends on brain state.
Cortical Representation is Degraded in the Inactivated State

Auditory clicks:

- **inactivated**

- **activated**

Thalamic Activity Represents the Stimulus in **both** States

- **inactivated**

- **activated**

Minces, Harris, Chiba
Burst Spiking of a Single Cortical Neuron Modifies Global Brain State

Li, Poo, and Dan, Science 2009

Temporal Dynamics of Learning
## Timescales of investigation

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Gamma Power and Language Learning

April Benasich

- Your brain is a giant oscillator (Buzsaki)
- EEG power in the gamma band of this oscillation (~40Hz) has been implicated in attention, perception, memory, language, and neural synchrony
- Gamma power increases throughout development.
- Can we use gamma power in toddlers to predict language ability?
Resting Gamma Power at 36 months of age predicts language skills at 4 and 5 years of age

From Benasich Lab with Harris
Brain dynamics matter for learning...

- These results suggest brain dynamics are important for cognitive function.
- Early diagnosis means we can now think about early interventions - perhaps a "FastForWord for toddlers" that can ameliorate the problems that these children face.
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<td>• In an inactivated state, cortical processing of the stimulus is degraded in Auditory, Visual, and Tactile modalities.</td>
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<td>• Thalamic processing of the stimulus is maintained in the inactive state for auditory information but not for visual.</td>
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<td>• Stimulus fidelity is enhanced by an activated brain state for all modalities.</td>
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<td>• Cortical activation can be achieved via neuromodulation from a subcortical source (Basal Forebrain Acetylcholine) or locally (a single bursting cortical neuron) or from training.</td>
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<td>• Natural activation in the form of gamma oscillations in babies predicts later language acquisition.</td>
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<td>• Early identification can allow for early intervention.</td>
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How can we drive temporal processing at rapid timescales, while also driving group synchrony?
Gamelan, Attention, and Synchrony!
Synchronizing with an isochronous beat

- **Target beat**
- **Player**
- **Monitor unison with target beat:** 10s of ms
- **Adjust following interval accordingly:** 10s of ms
- **Estimate and reproduce interval:** 100s of ms
- **Filter out Non-targets**
Temporal Dynamics of Learning

**10s of ms**
- Details of note shaping, beat to beat alignment

**100s of ms**
- Note to note and beat to beat movement

**10s of seconds**
- Rhythmic or melodic motives or themes

**minutes**
- Melodic phrases and chord progressions

**10s of minutes - hours**
- Musical structures and compositions

**Accurate synchrony and integration**

**Amongst players, too**
Research Questions

1) Does ability to pay attention correlate with ability to synchronize in a group setting?

2) Is this correlation, if it exists, solely due to differences in attentional allocation or do underlying differences in time processing also exist?

3) Since it is possible to improve one’s ability to synchronize through group music practice, can such improvements translate into measurable improvements in attentional performance?
The Gamelan Project – preliminary study

Does ability to pay attention correlate with ability to synchronize in a group setting?
Experimental instrument: aluminum keys with piezoelectric film elements
Temporal Dynamics of Learning

Time and Space

Audio recording data
Examples of good and poor synchronizers using vector strength analysis.

[Graph showing phase plots for good and poor synchronizers]
Other measures

Swann teacher ratings

Psychometric tests

Results

A significant correlation was found across all measures

\[ p < 0.0025 \]
The individual system and the system of others must achieve integrated **temporal and spatial scales for both:**
- brain systems,
- social systems
for optimal learning and social interactions.