Neural Entrainment during Musical Rhythm Perception

is correlated with Individual Differences in Temporal Prediction during Sensorimotor Synchronization

Peter Keller & Sylvie Nozaranadan
Sensorimotor Synchronization

- Coordinating movements with external rhythmic events
- Musical ensemble performance and dance
- Perception of temporal regularities in auditory rhythm
Regularity in Rhythm

**Beat:** Periodicity underlying rhythmic durations

**Meter:** Hierarchical levels of periodicity centred on the beat

**Tempo:** Musical speed (beat rate), which can vary

(200-1800 ms; preferred tempo ~500-600 ms)
Neural Entrainment to Beat & Meter

Induced EEG gamma band activity (20-60 Hz) reflects temporal expectancies to strong and weak beats

Zanto et al. (2006)

Beat-related MEG amplitude and coherence modulations beta oscillations (~20 Hz)  

Fujioka et al. (2012)
Neural Entrainment to Beat & Meter

A. Repeating rhythmic phrase: TT0 = \( \text{\textbullet} \text{\textbullet} \text{\textbullet} \)

B. Stimuli and Metrical Interpretation

- **Condition IB1**: imagine beat on 1st tone
- **Condition IB2**: imagine beat on 2nd tone

Induction sequence (beat is accented) vs. Identical test sequence (no accents)

---

**EEG Steady-state evoked potentials**

- Beta (20 - 30 Hz)
- Normalized Power over time

---

Iversen, Repp, & Patel (2009)

Nozaradan et al. (2011)
Exogenous & Endogenous Beat Finding

Unsyncopated: Tones present on all beats
Syncopated: Tone onsets not present on all beats

Rhythmic complexity

1.25 Hz beat rate (800 ms IBI)

Nozaranadan et al. (2012)
Exogenous & Endogenous Beat Finding

Unsyncopated

Syncopated

Processing steps
1. Time domain averaging
2. Fourier transform
3. Amplitude normalized via spectral baseline correction

Nozaradan et al. (2012)
Current Study

Research question

Functional significance of neural entrainment to the beat?

Hypotheses

• Facilitates accuracy of sensorimotor synchronization

• Endogenous component may enable temporal prediction: i.e. anticipation of upcoming event timing
Auditory Temporal Prediction

• Low asynchrony between musical ensemble performers (30-50 ms)
  
  (Keller & Appel, 2010; Ragert et al., 2013; Shaffer, 1984; Rasch, 1979)

• Negative mean asynchrony in paced finger-tapping tasks
  
  (Miyake, 1902; Repp, 2005; Woodrow, 1932)

• Synchronizing with tempo-changing sequences

Metronome
Finger Taps

Expressive timing in music performance

(Repp, 1999)
Predicting Tempo Changes

**Prediction Index:**
Tapping with tempo-changing pacing signal

(Pecenka & Keller, 2009, 2011; Rankin et al., 2009; Repp, 2002)

Prediction correlated with synchronization accuracy

Pecenka & Keller (2009)
1. Neural entrainment to beat:
EEG steady-state evoked potentials (SS-EPs)

2. Sensorimotor synchronization

3. Temporal prediction
Neural Entrainment: Methods

Participants: N=18, 2-26 years music training

Stimuli: 2 rhythm patterns (looped for 33 s) at 4 tempi

<table>
<thead>
<tr>
<th>Tempo</th>
<th>Inter-onset interval</th>
<th>Beat frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Slow)</td>
<td>400 ms</td>
<td>0.6 Hz (1600 ms)</td>
</tr>
<tr>
<td>2</td>
<td>200 ms</td>
<td>1.25 Hz (800 ms)</td>
</tr>
<tr>
<td>3</td>
<td>100 ms</td>
<td>2.5 Hz (400 ms)</td>
</tr>
<tr>
<td>4 (Fast)</td>
<td>66 ms</td>
<td>3.8 Hz (264 ms)</td>
</tr>
</tbody>
</table>

X = 1000 Hz pure tone (200 ms duration)  
. = silent interval

Procedure:

Listen to 10 trials (incl. 2 catch trials with tempo change) per condition; Tap the beat in trial 11

EEG recording: BioSemi 64 active electrodes, 10/20 system
Frequency (Hz)

Tempo

Unsyncopated

rhythmic pattern 1

sound envelope spectrum

EEG spectrum

Syncopated

rhythmic pattern 2

sound envelope spectrum

EEG spectrum

0.6 Hz

Slow

1.25 Hz

2.5 Hz

Fast

3.8 Hz
Effects of Rhythmic Complexity & Tempo on SS-EPs

Exogenously driven neural entrainment is stronger than endogenous entrainment, especially for slower beat frequencies (frequency tuning curve?)

SS-EPs at beat frequency

Amplitude normalized via spectral baseline subtraction
(as in Nozaradan et al., 2012)
SS-EP Amplitude & Synchronization Accuracy

Stronger neural entrainment to the beat is generally associated with asynchronies closer to zero.
Endogenous Entrainment & Prediction

Index of strength of endogenous beat generation:

**Syncopated** – **Unsyncopated** SS-EPs

Endogenous processes support temporal prediction
Conclusions

• SS-EP measures of neural entrainment to the beat reflect a mixture of exogenously and endogenously driven oscillatory processes.

• These covert processes generally facilitate overt sensorimotor synchronization with auditory rhythms.

• Endogenous mechanisms support temporal predictions that allow individuals to synchronize movements with complex temporal structures (1) lacking regular beat cues and (2) containing tempo changes.
Acknowledgements

Sylvie Nozaradan
Isabelle Peretz
Kerstin Traeger