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Neural Entrainment during Musical Rhythm Perception

is correlated with

Individual Differences in Temporal Prediction during Sensorimotor Synchronization

Peter Keller & Sylvie Nozaradan

Sensorimotor Synchronization

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

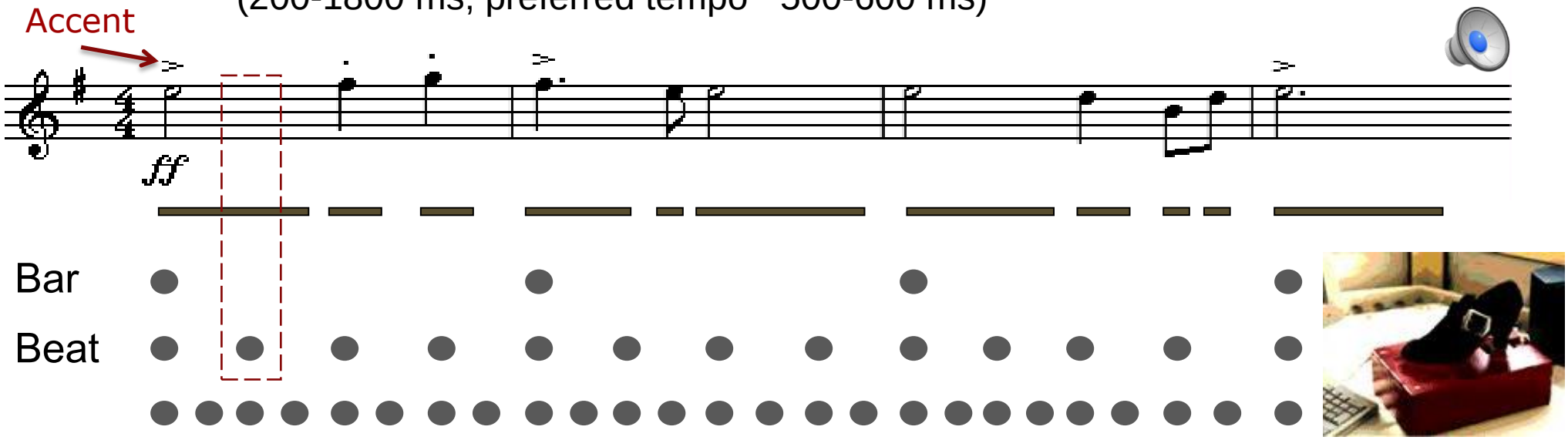
Regularity in Rhythm

Beat: Periodicity underlying rhythmic durations

Meter: Hierarchical levels of periodicity centred on the beat

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

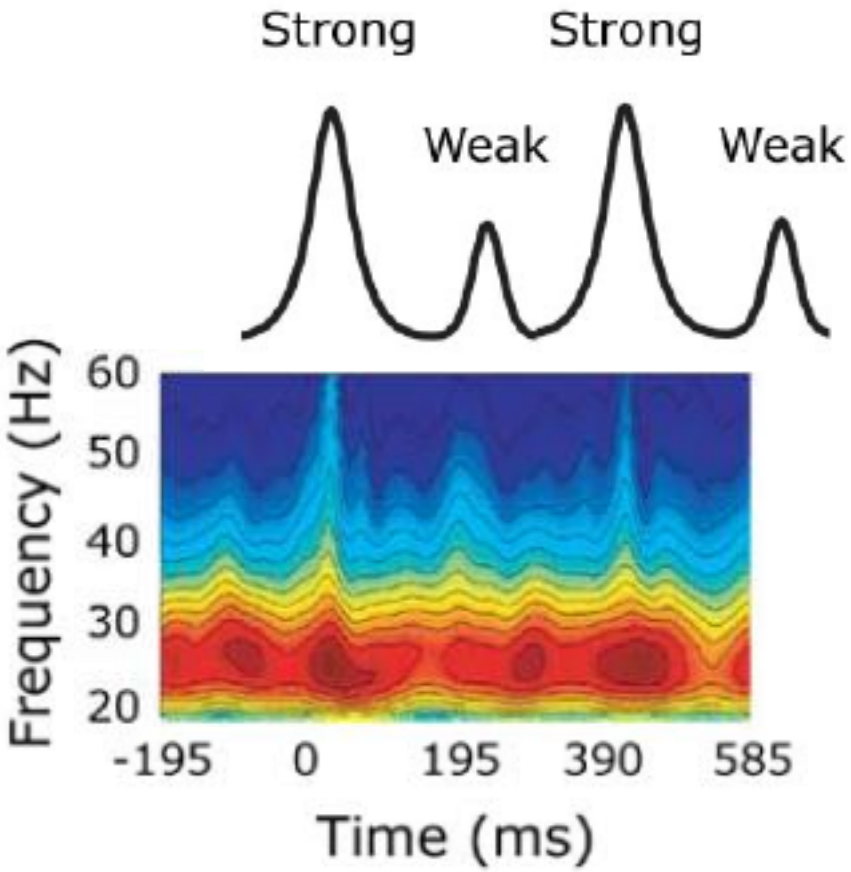
(200-1800 ms; preferred tempo ~500-600 ms)



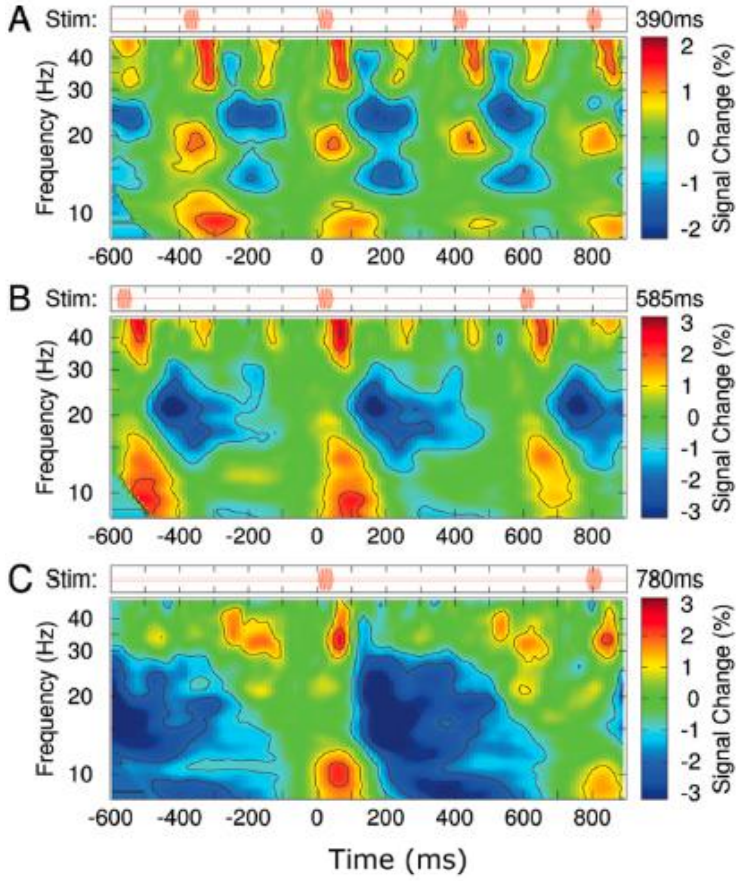
Neural Entrainment to Beat & Meter

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

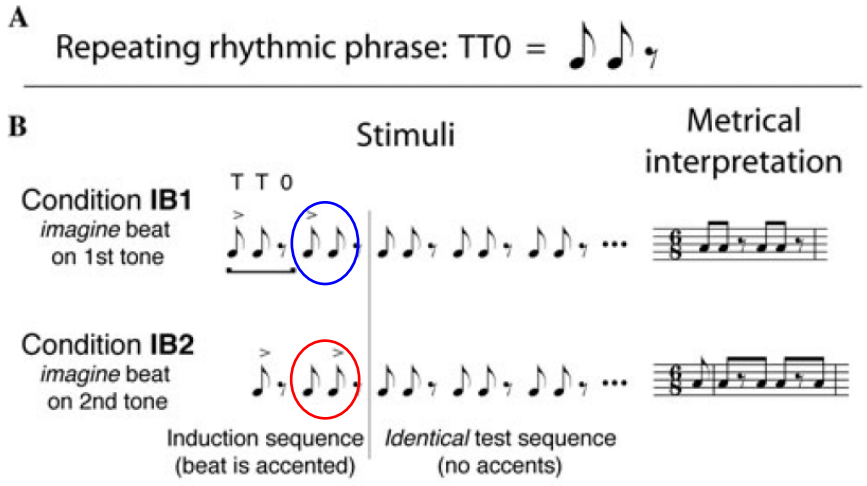
Zanto et al. (2006)



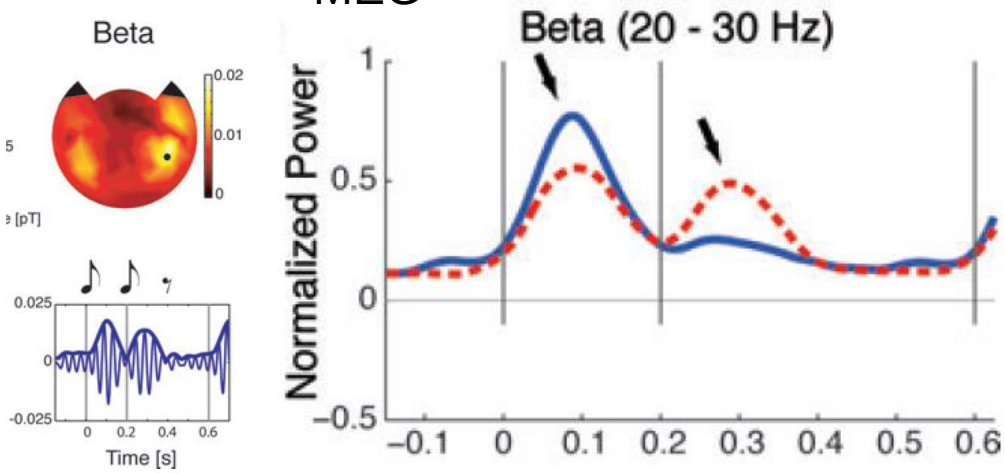
Beat-related MEG amplitude and coherence modulations beta oscillations (~20 Hz) *Fujioka et al. (2012)*



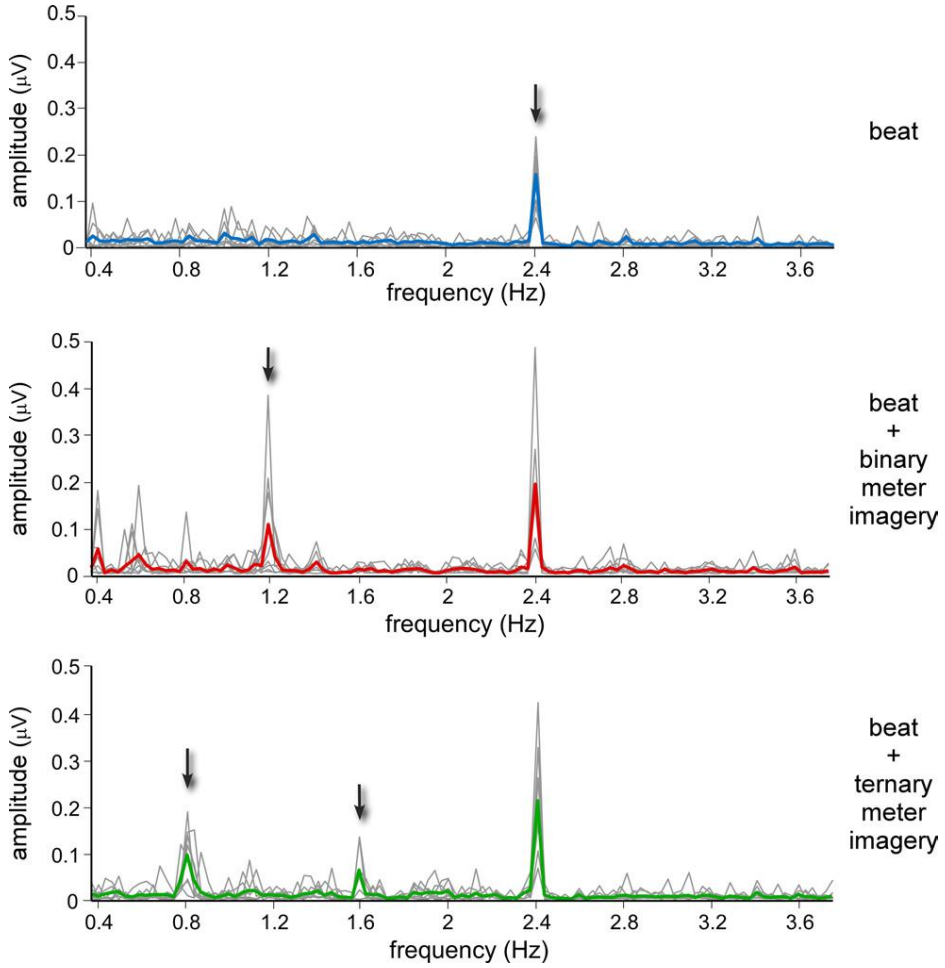
Neural Entrainment to Beat & Meter



MEG



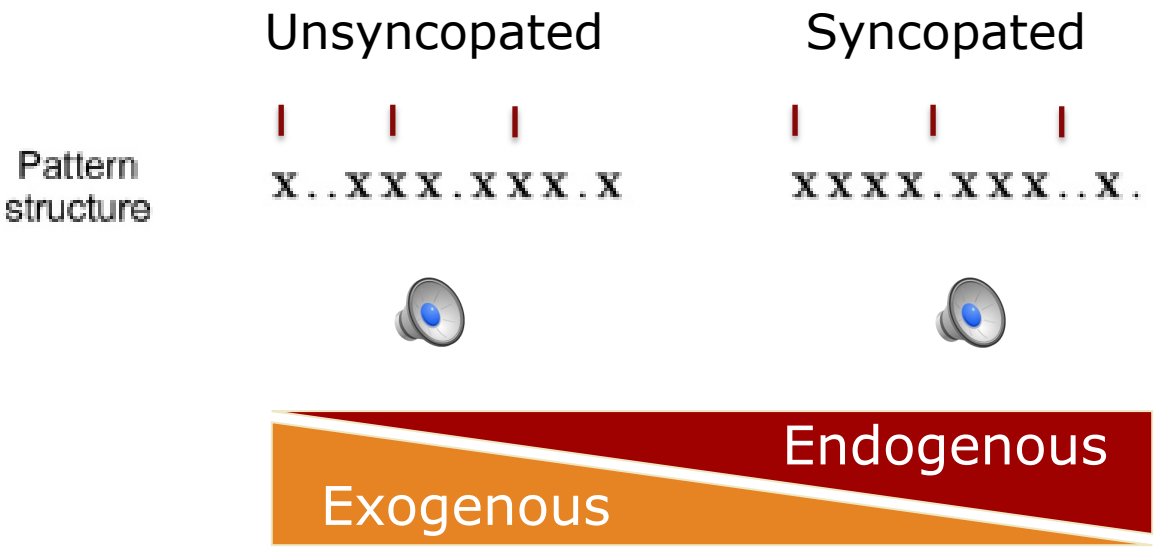
EEG Steady-state evoked potentials



Iversen, Repp, & Patel (2009)

Nozaradan et al. (2011)

Exogenous & Endogenous Beat Finding



1.25 Hz beat rate

(800 ms IBI)

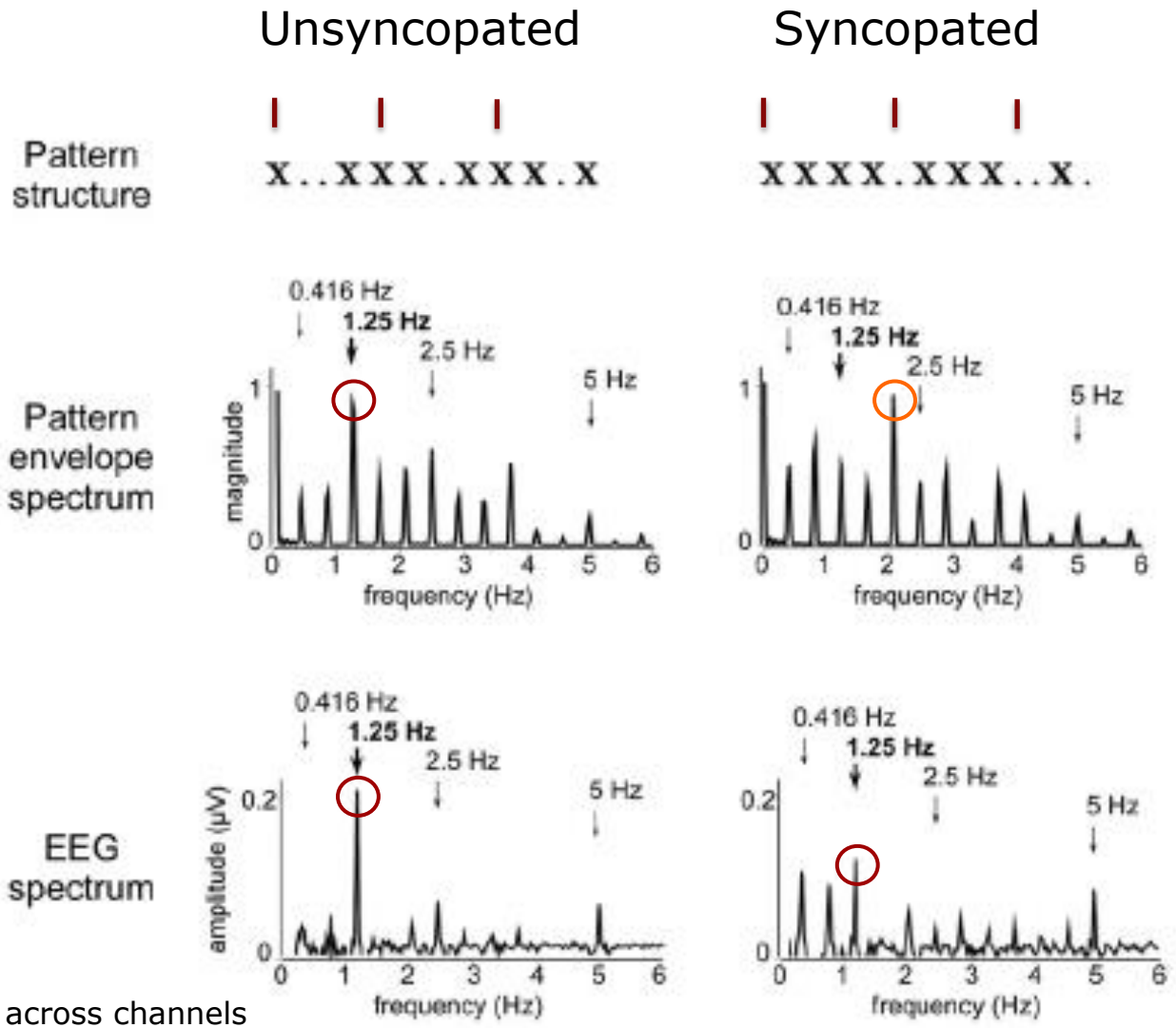
Rhythmic complexity

Unsyncopated: Tones present on all beats

Syncopated: Tone onsets not present on all beats

Nozaradan et al. (2012)

Exogenous & Endogenous Beat Finding



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

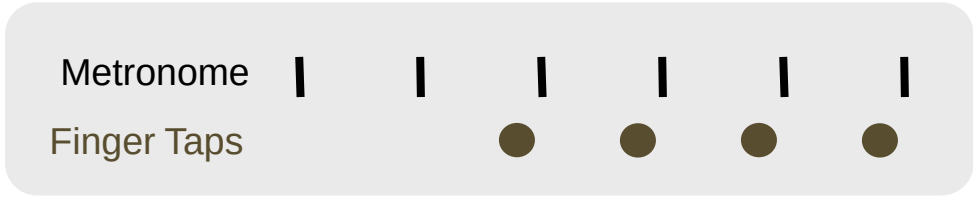
Auditory Temporal Prediction

- Low asynchrony between musical ensemble performers (30-50 ms)

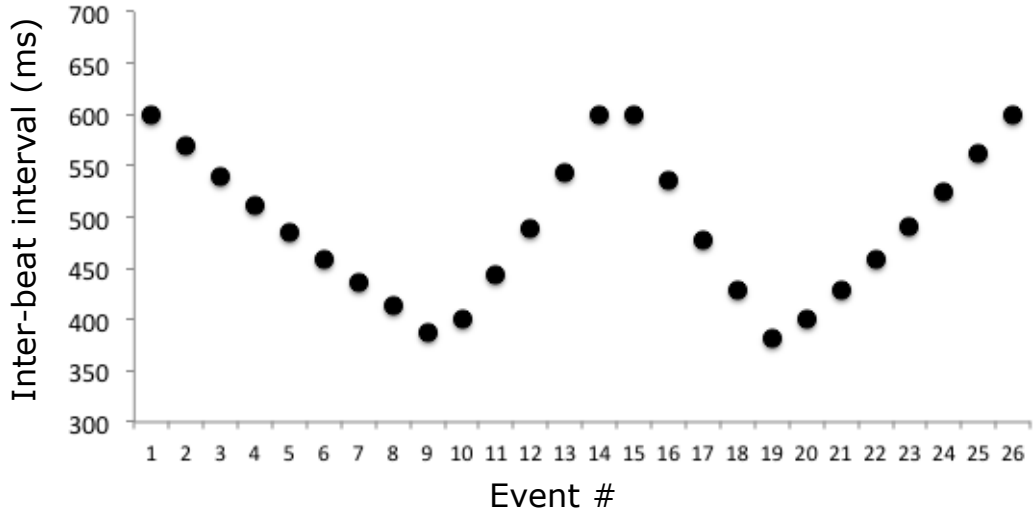
  (Keller & Appel, 2010; Ragert et al., 2013; Shaffer, 1984; Rasch, 1979)

- Negative mean asynchrony in paced finger-tapping tasks

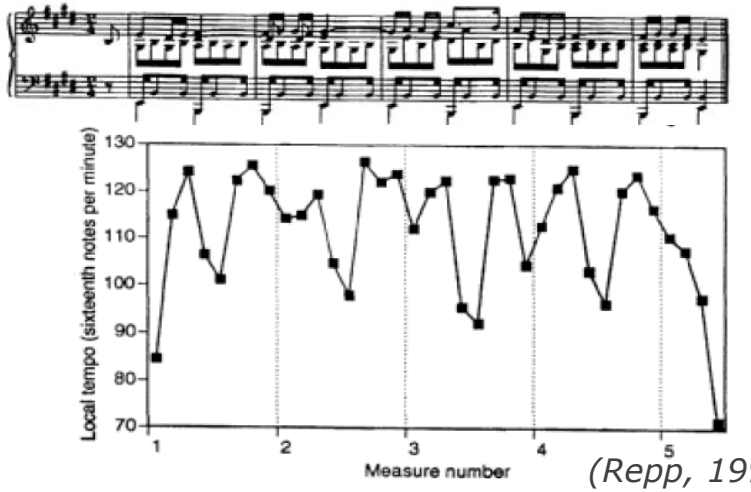
  (Miyake, 1902; Repp, 2005; Woodrow, 1932)



- Synchronizing with tempo-changing sequences



Expressive timing in music performance



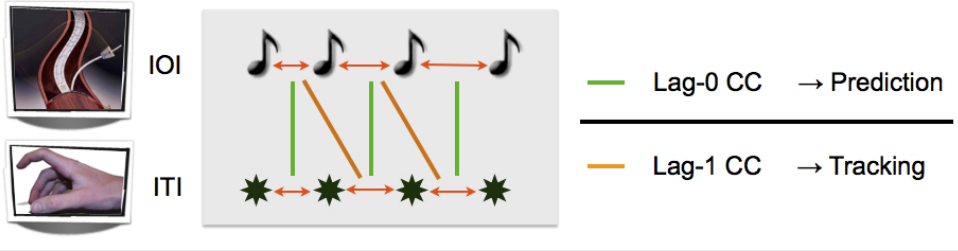
(Repp, 1999)

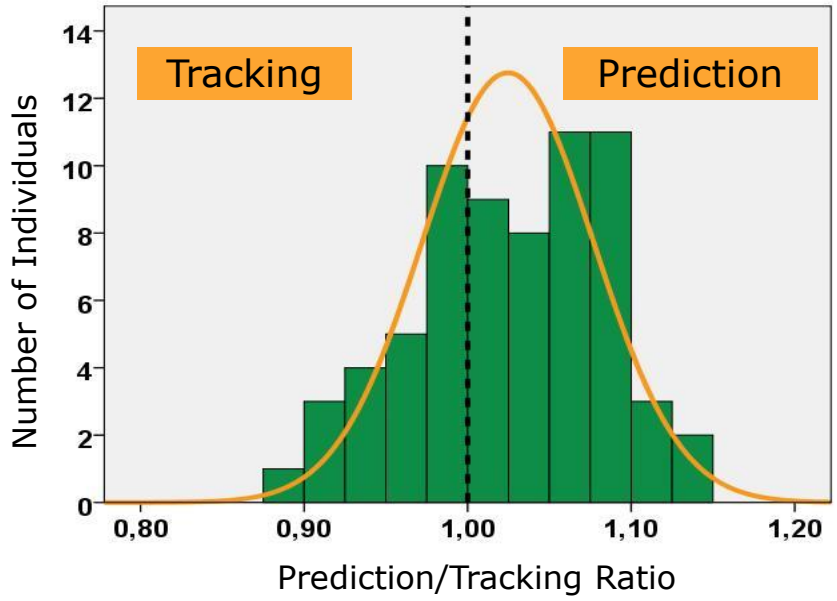
Predicting Tempo Changes

Prediction Index:

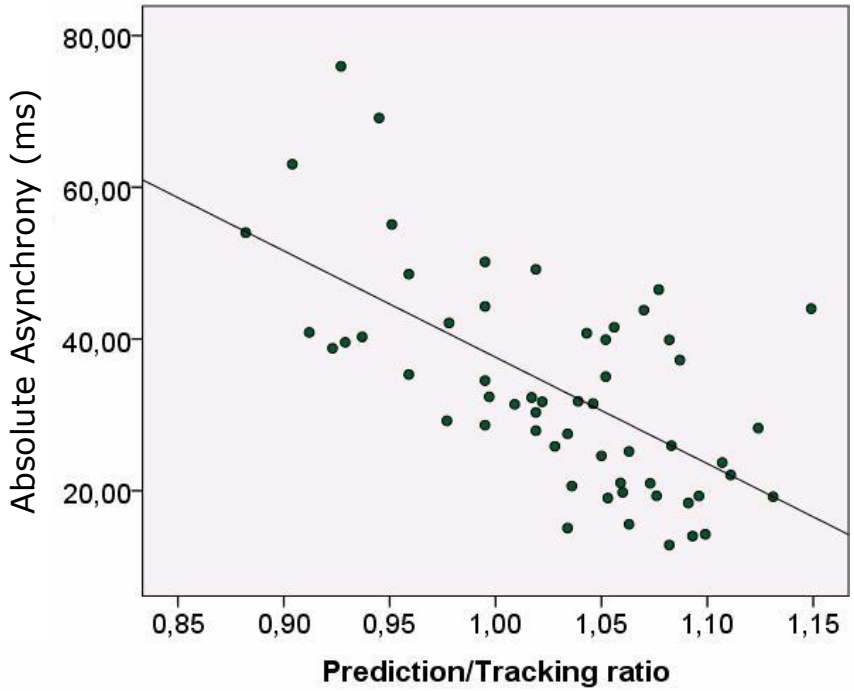
Tapping with tempo-changing pacing signal

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





Prediction correlated with synchronization accuracy



Pecenka & Keller (2009)

Current Study Design

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

Unsyncopated

x..xxx.xxx.x

Syncopated

xxxx.xxx..x.

Endogenous

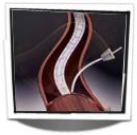
Exogenous

2. Sensorimotor synchronization

x..xxx.xxx.x

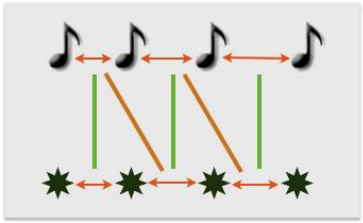
xxxx.xxx..x.

3. Temporal prediction



IOI

ITI



Neural Entrainment: Methods

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

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

```
|     |     |
X . . XXX . XXX . X
|     |     |
XXXX . XXX . . X .
```

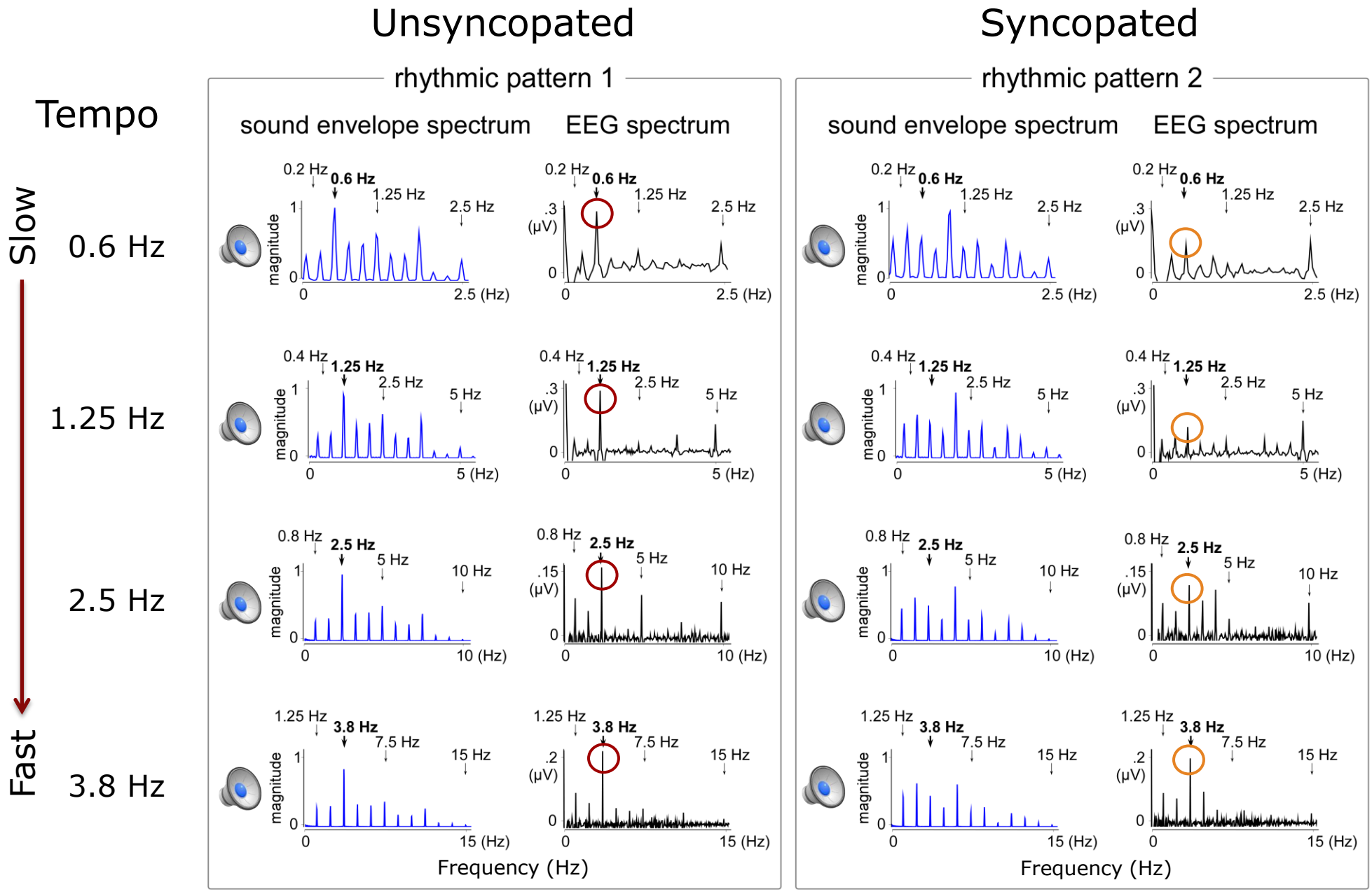
X = 1000 Hz pure tone (200 ms duration)
. = silent interval

Tempo	Inter-onset interval	Beat frequency
1 (Slow)	400 ms	0.6 Hz (1600 ms)
2	200 ms	1.25 Hz (800 ms)
3	100 ms	2.5 Hz (400 ms)
4 (Fast)	66 ms	3.8 Hz (264 ms)

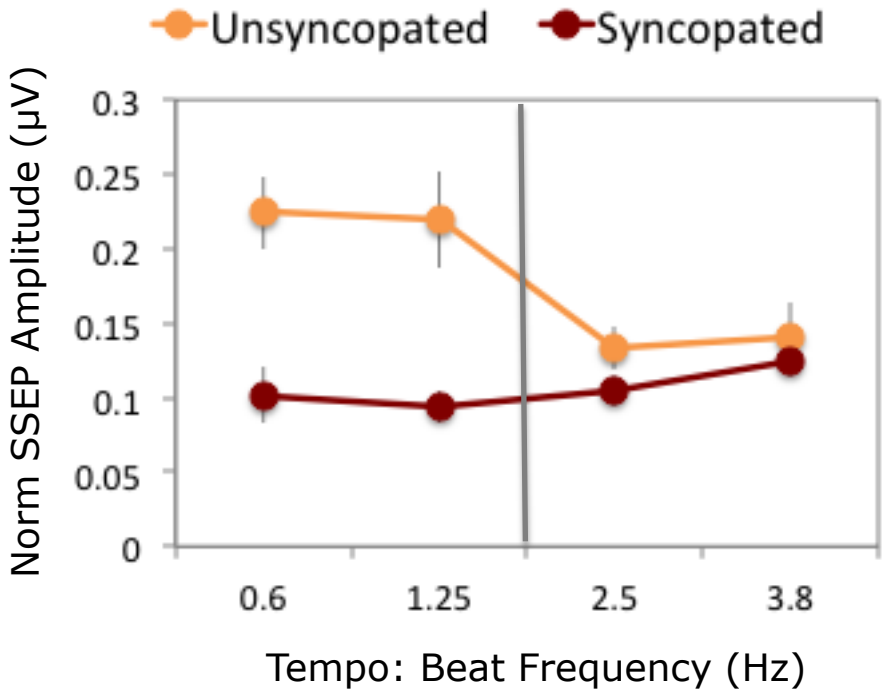
Procedure:

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


Unsyncopated
Syncopated
Tempo
Slow
Fast
0.6 Hz
1.25 Hz
2.5 Hz
3.8 Hz
rhythmic pattern 1
rhythmic pattern 2
sound envelope spectrum
EEG spectrum
magnitude
(μV)
Frequency (Hz)

Effects of Rhythmic Complexity & Tempo on SS-EPs



SS-EPs at beat frequency

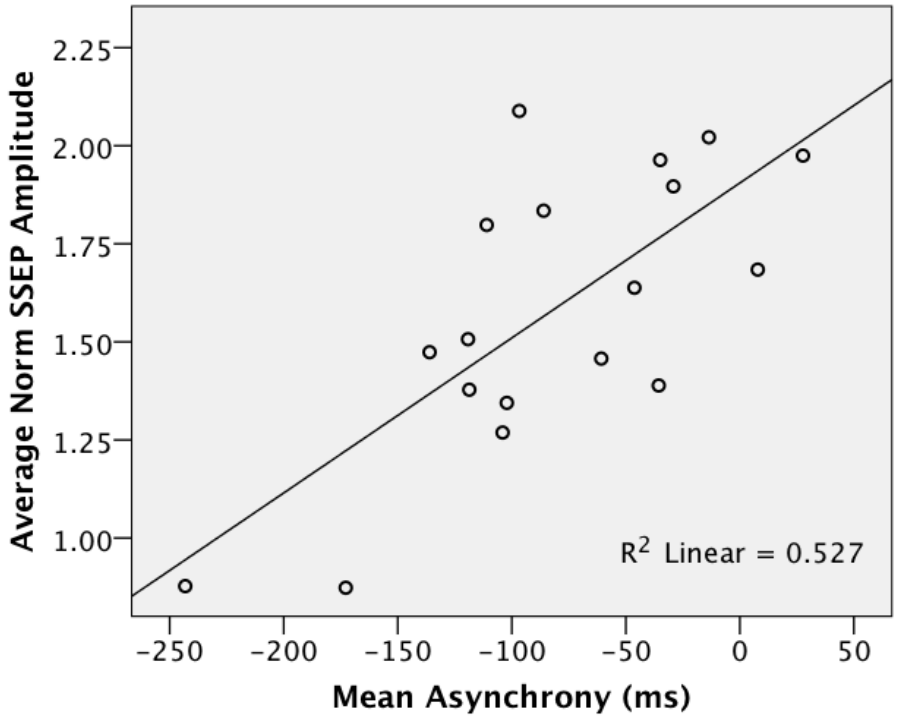
Amplitude normalized via spectral baseline subtraction

(as in Nozaradan et al., 2012)

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

SS-EP Amplitude & Synchronization Accuracy

Z score representing amplitude at beat frequency relative to other metric levels



x..xxx.xxx.x

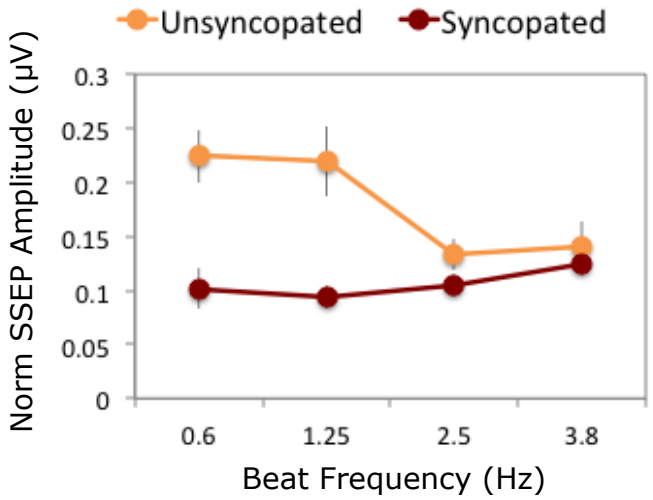
xxxx.xxx..x.

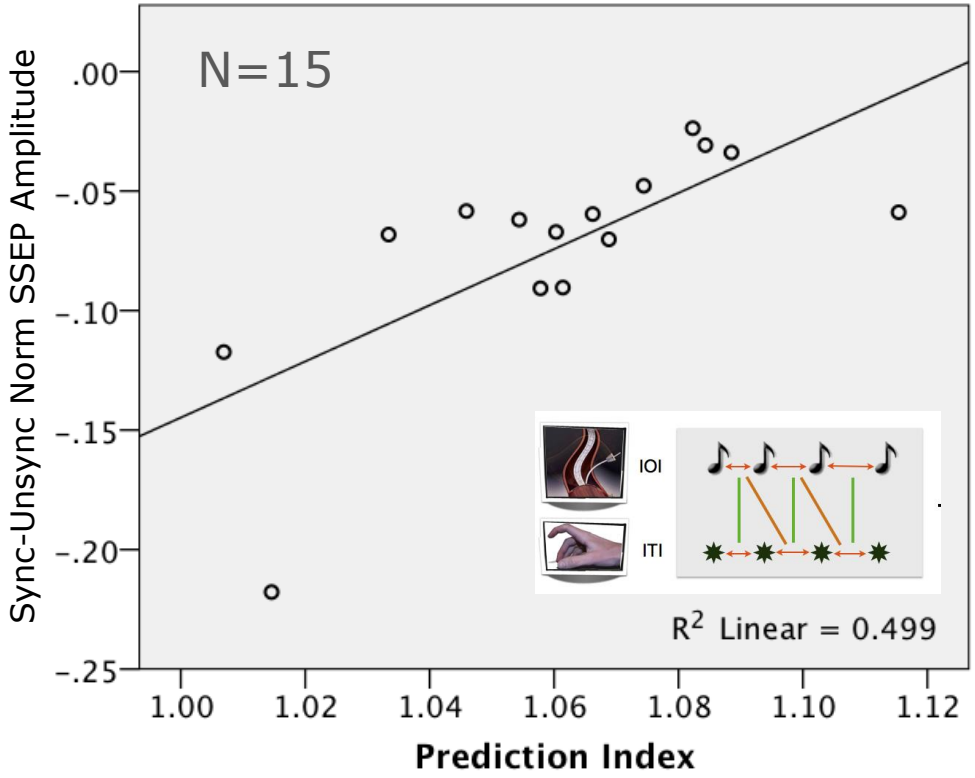
Stronger neural entrainment to the beat is generally associated with asynchronies closer to zero

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

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