

# Delay-coupling models of auditory-motor synchronization

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## Introduction

### 1. Synchronization in a social context:

- Synchronization is fostered by a social (group) context (Kirschner & Tomasello, 2009)

### 2. Spontaneous Production Rates (SPR):

- SPR = Natural, consistent rate at which individuals produce a familiar musical sequence (Zamm et al, 2016; Scheurich et al., 2018)
- SPR differences between individuals reduce synchronization accuracy in group coordination (Palmer et al, 2019; Zamm et al., 2016)

### 3. Delay-coupling models:

- Coupled nonlinear dynamical systems can capture anticipatory synchronization (Voss, 2000; Stepp & Turvey, 2010)
- Coupling strength and time delay can capture properties of solo and group synchronization (Demos et al., 2019)

$$\begin{aligned} \dot{\theta}_1 &= \omega_1 && \text{Driver oscillator (metronome)} \\ \dot{\theta}_2 &= \omega_2 + k_2(\theta_1 - \theta_2, \tau_2) && \text{Driven oscillator (tapper)} \end{aligned}$$

↖ Intrinsic frequency      ↖ Coupling strength      ↖ Time delay

### 4. Hypotheses:

#### Behavior

- Synchronization will be higher when tapping at cued rate = Self-SPR than = partner-SPR
- Synchronization will be higher when participants tap in the joint (group) condition than in solo condition

#### Model

- Natural frequency  $\omega_2$  will change when cued rate does not match tapper's  $\omega$ .  $k_2$  and  $\tau_2$  will increase when cued rate does not match tapper's  $\omega$ , to aid synchrony.

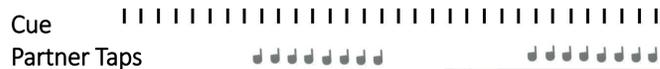
## Method

**Participants:** 24 adults, normal hearing, range of musical experience

### 3 Tasks:

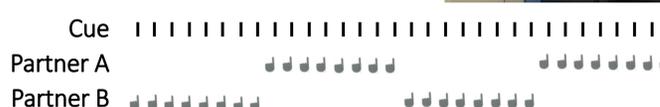
**1) Spontaneous rate (SPR):** Participant taps melody at steady (uncued) rate

**2) Solo Synchronization:** Participant taps melody with metronome cue (tap 8 beats, wait 8 beats)



### 3) Joint Turn-taking:

Participants face each other, take turns synchronizing with metronome cue (Tap 8 beats, wait 8 beats)



Cued Rates = Partner A's Solo SPR, Partner B's Solo SPR

### Data Analysis:

#### 1) Behavioral analyses:

Mean Asynchronies (ms) = [Metronome – Tap], examined by Condition (Solo, Joint) and Tempo (Cue=PartnerA rate, Cue= PartnerB rate)

#### 2) Delay-coupling model fits:

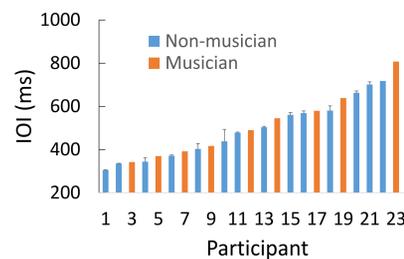
Fit the model to asynchronies from individual participants' trials

## Results

### 1. Large Individual Differences in Spontaneous Rates

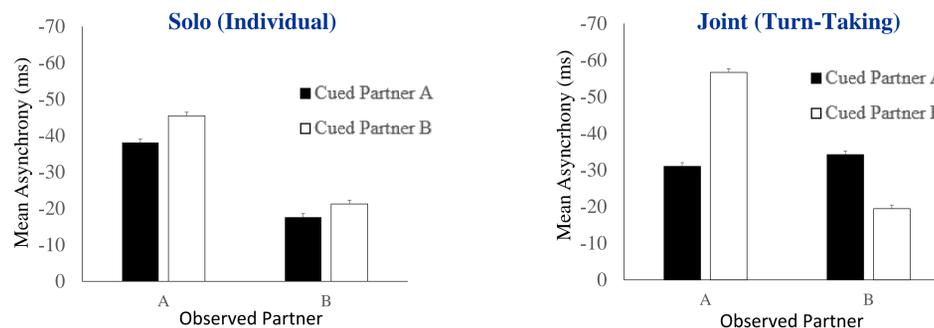
Individuals consistent across trials

No significant differences between Musicians and Non-musicians (t-test,  $p > .05$ )

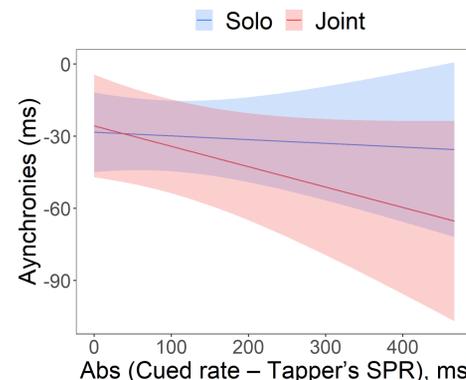


### 2. Asynchronies Tapping with Metronome Differ by Social Context

ANOVA: significant Observed Tapper X Cued Rate X Condition interaction ( $p < .05$ )



Linear Mixed Model: Significant interaction of Abs[Cued rate – Tapper's Rate] X Condition ( $p < .05$ )



**Tapper's asynchrony increases (more anticipatory) as cued rate deviates from Tapper's Spontaneous rate**

- More so in Joint Condition

### 3. Delay-coupling model applied to individual trials:

**Participant S03:**

**"Match" condition:**

SPR (initial frequency) = 545ms

Cued rate = 545 ms (S03's SPR)

**"Mismatch" condition:**

Cued rate = 343 ms (Partner's SPR)

#### Asynchronies:

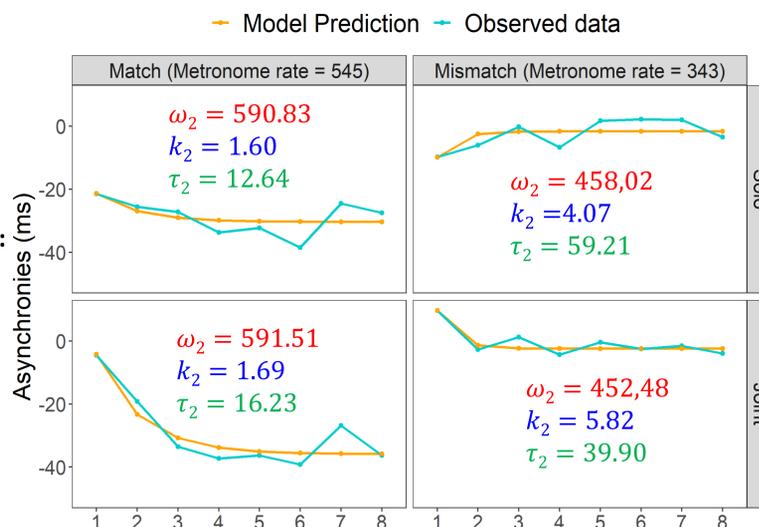
Anticipatory in Match only

#### Coupling strength ( $k$ ):

Mismatch > Match

#### Delay ( $\tau$ ):

Mismatch > Match



## Discussion

### 1. Spontaneous Rates affect Synchronization

- Participants exhibit consistent differences in spontaneous rates of producing melodies
- Those spontaneous rates influence synchronization in both Solo and Joint tasks
- Smaller asynchronies for partners when Cued rate = partners' Natural rate (Match)

### 2. Effect of Social Context

- Large differences between partners' SPRs are associated with larger asynchronies in the Joint condition
- Possible social influence of partner
- The farther the cued rate is from the participant's SPR, the more negative the asynchronies in the Joint condition

### 3. Delay-coupling model Predicts Anticipation

- Delay-coupling models can capture synchronization:
  - in Solo and Joint conditions (with/without social context)
  - At Matched and Mismatched rates (coupling parameter)
- Intrinsic frequency ( $\omega$ ) closer to the cued frequency in the Match condition
- Tapping at a rate very different from their intrinsic frequency (Mismatch) showed expected changes:
  - Time delay ( $\tau$ ) increased, suggesting participants anticipate more to maintain synchrony
  - Coupling strength ( $k$ ) increased, in order to maintain synchrony

### 4. Limits and future directions

- How to avoid local minima in parameter-fitting
- Test effects of interindividual differences on Solo/Joint synchronization:
  - Faster / slower partners, less / more variable tappers

## References

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