Modeling synchronization and learning in musical duets

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Introduction

How do people learn to synchronize movement with sound?

- Individuals often coordinate the timing of their actions with external sound (Bégel et al., 2022)
- Musicians often practice with a recording or metronome (unidirectional influence) when preparing to perform with others (bidirectional influence) (Brandler & Peynircioglu, 2015)

Can learning to synchronize with an auditory recording improve synchrony with a partner?

- Presence of a partner can influence synchronization with a steady cue (Bégel et al., 2022; Zamm et al., 2016)
- Musically trained individuals can synchronize flexibly across rates (Scheurich et al., 2018)

Can a model with coupled oscillators capture synchrony between partners?

- According to the strong anticipation framework, synchronization relies on anticipatory behavior based on time-delayed feedback (Voss, 2000; Stepp & Turvey, 2010)
- Delay-coupled models capture unidirectional coupling with a metronome (Bégel et al., 2022)
- These models also capture bidirectional synchrony between partners (Demos et al., 2019)

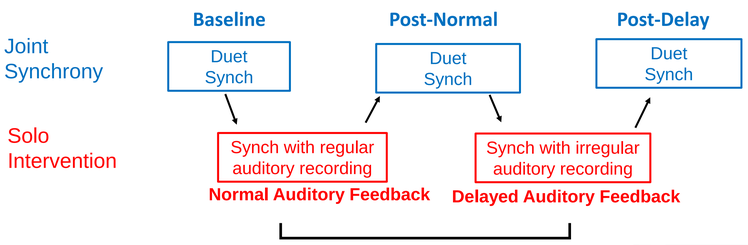
$$\dot{\theta}_1 = \omega_1 + k_1(\theta_2 - \theta_{1\tau}) \quad \text{Partner 1}$$
$$\dot{\theta}_2 = \omega_2 + k_2(\theta_1 - \theta_{2\tau}) \quad \text{Partner 2}$$

Intrinsic Frequency — Coupling strength — Time delay (neural transmission)

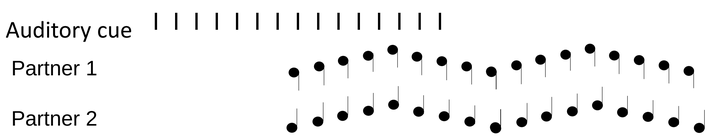
Methods

Participants: N = 50 adults (age range: 18-33 years, M = 22.3)
50 Musically Trained (training range: 6-16 years, M= 10.2)

All tasks performed by all partners (within-subject design):

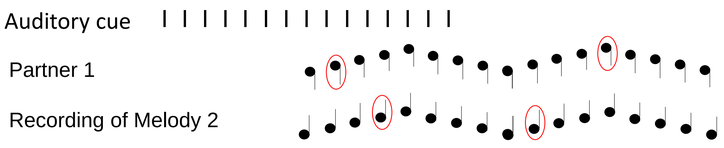


1. Joint Synchrony:
Partners synchronize their melodies



2. Solo Intervention: Individuals synchronize with a recording of their partner's melody:

a) Normal auditory feedback
b) Delayed feedback: 25% of tones randomly delayed by 30-70 ms

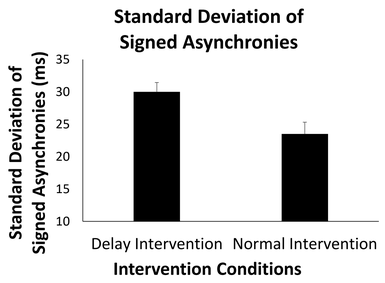


Modeling Joint Synchrony:

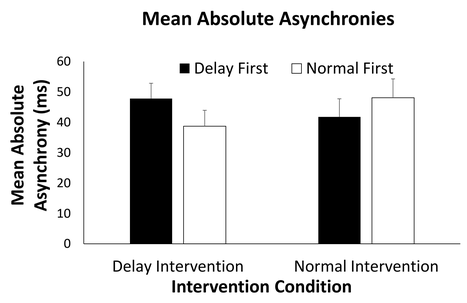
- 10 model fits / trial to average asynchrony at each melody position
- Model parameter boundaries (kappa = 0-49; omega-diff = 299 to -299)
- Tau chosen from best-fitting model (lowest RMSE) per trial
- Model fits repeated with tau fixed to median value: τ = 19.7 ms

Results

Impact of Solo Interventions

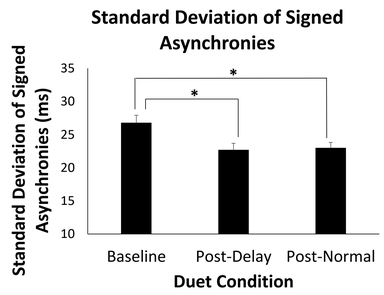


More variable asynchronies:
Delayed feedback > Normal feedback
p < .05, η_G^2 = .075

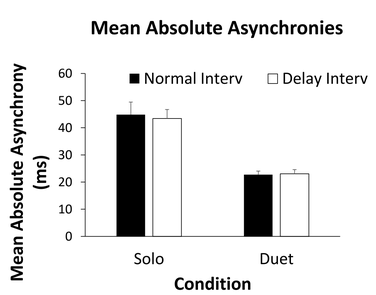


Interaction: Intervention condition X Order
Larger asynchronies in first intervention
$p < .05$, η_G^2 = .019

Impact of Solo Interventions on Duet Synchronization

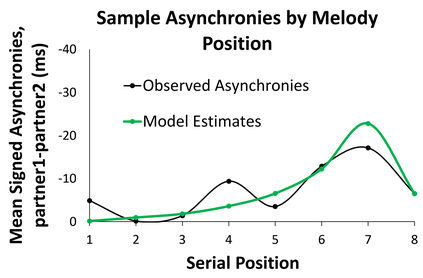


Synchrony improves following interventions
$p < .05$, η_G^2 = . 136



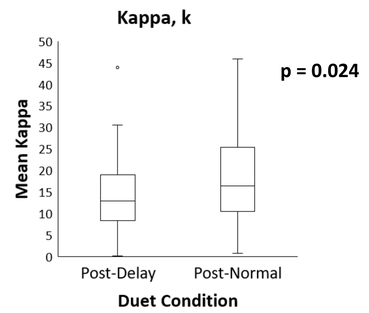
Duet asynchronies < Solo asynchronies
$p < .001$, η_G^2 =.340
No interaction with intervention

Delay-Coupled Model Fits to Duet Synchrony



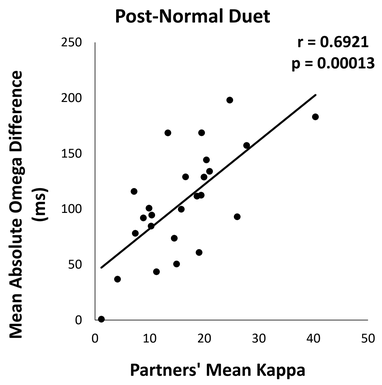
- Best model fits chosen based on smallest RMSE

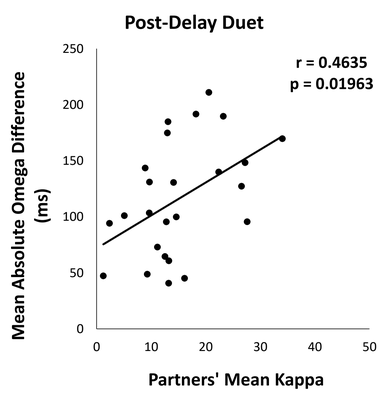
Prior Interventions Impact Partners' Coupling in Duet Synchrony



Greater coupling following Normal Intervention
Post-Normal > Post-Delay

Coupling and Intrinsic Frequency Parameters Increase Together in Duet Performances





- Greater differences in partners' intrinsic frequencies require greater coupling
- Kappa + Omega Difference parameters are positively correlated (no tradeoff)
  No significant Omega differences across Duet conditions

Discussion

How do people learn to synchronize?

- Solo practice (interventions) improved duet synchrony with a partner
- Regular auditory feedback improved Solo synchrony with a metronome more than irregular feedback

Can learning to synchronize with a partner be modelled with coupled oscillators?

- Duet coupling (model parameter) is lower following solo practice with an irregular recording than a regular recording
- Extended delay-coupled models to capture impact of solo practice on duet synchrony (Bégel et al., 2022)
- Model suggests partners need greater coupling as difference in partners' intrinsic frequencies increases (Zamm et al., 2016)

Final Points

- Study shows more accurate synchrony in the post-Solo Duet performances than in the Solo interventions
- Coupling parameter in model is sensitive to disruptions in Solo practice that impact subsequent Duet synchrony
- Effects of altered feedback on coupling behavior are temporary for musicians (Demos et al., 2019; Bégel et al., 2022)

Future directions

- Examine whether interventions and model parameters differ with musical training
- Test whether elapsed time (allowing memory consolidation) improves duet synchrony (Duke et al., 2009; Simmons, 2011)
- Compare delay-coupling with other models for bidirectional synchrony
- Model unidirectional synchronization in Solo conditions (during Interventions)

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