Synchronization in duet performance: Testing the two-person phase error correction model

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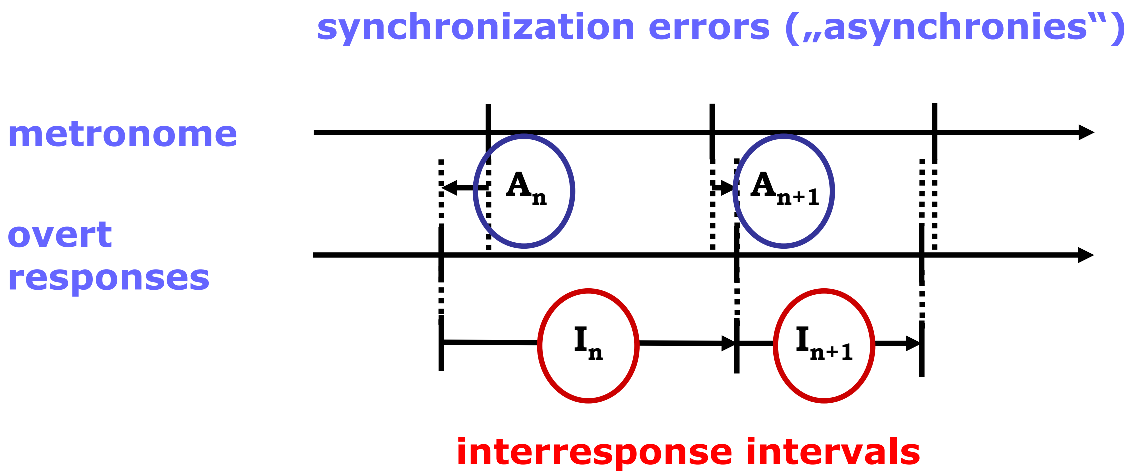
Overview

1. How do ensemble players manage to remain synchronized?
2. Sensorimotor synchronization, tapping along perfect metronome.
   → Synchronization is achieved by linear phase error correction.
3. Extend model to duet performance.
   → Major advantage: Use computer to simulate one of the duet partners.
4. Experimental study.
   → Preliminary data.

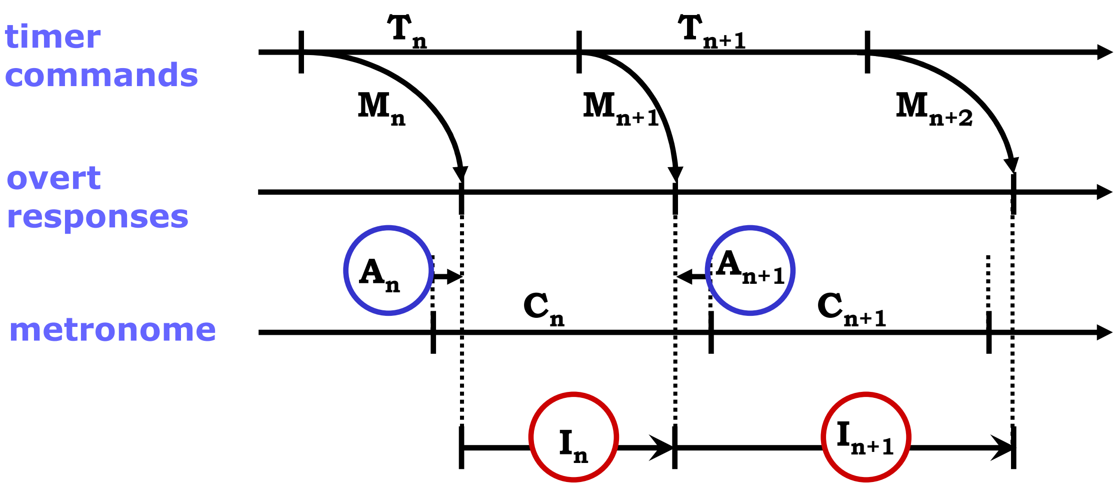
Definition of interresponse intervals and synchronization errors

task: tap in close synchrony with the metronome

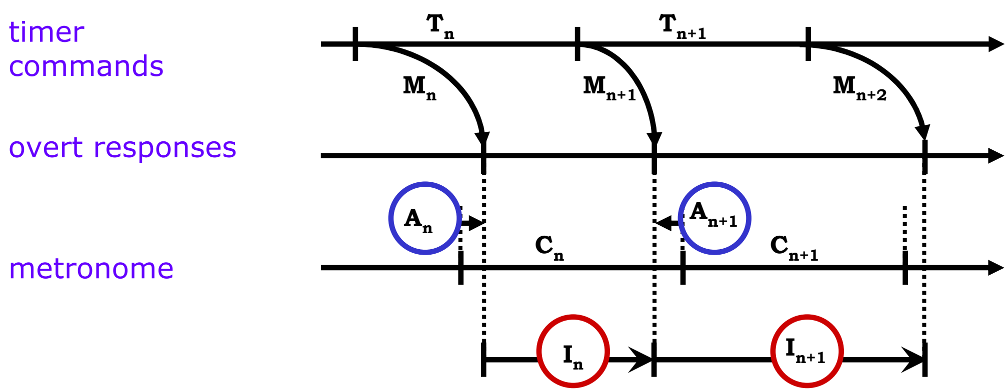


The phase-correction model

(Vorberg & Wing, 1994, 1996; Vorberg & Schulze, 2002; Schulze & Vorberg, 2003)



The two-level timing model augmented by phase error correction



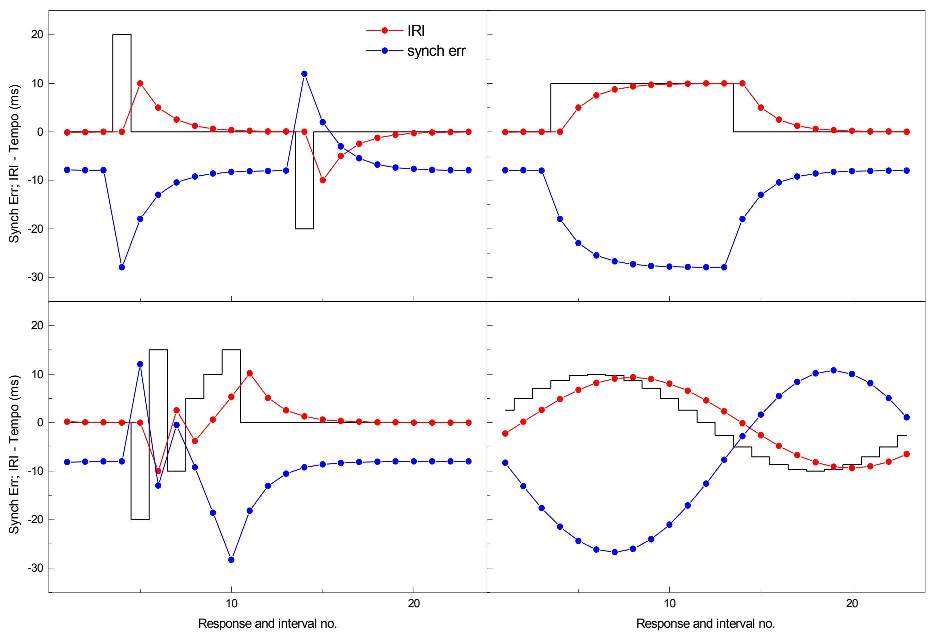
1. **basic assumption:**

$$T_n^* = T_n + (1-\alpha)A_n$$

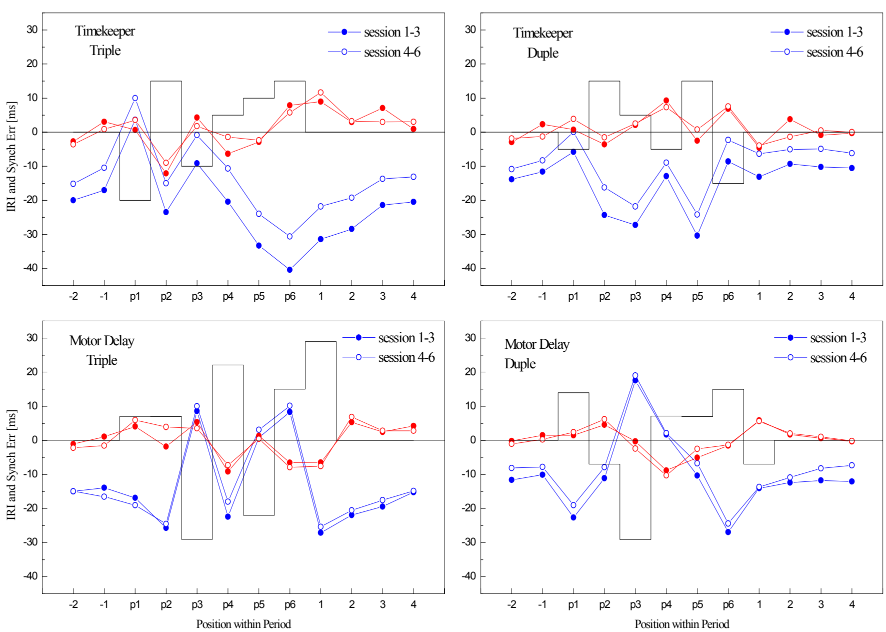
1. **testable consequence:**

$$A_{n+1} = (1-\alpha)A_n + (T_n+M_{n+1}-M_n) - C_n$$

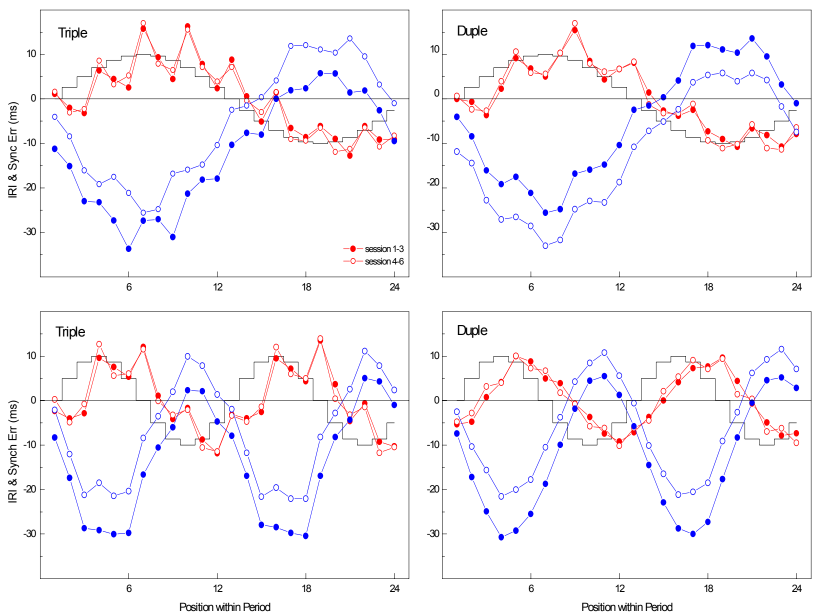
Model predictions I:
response to experimental perturbations



Results (Antje Fuchs, 2003)



Results (Antje Fuchs, 2003)



Model predictions II:
serial or auto-covariance function (acvf)

serial variance = acvf at lag 0 = acvf(0)

A_1	A_2	A_3	...	A_{i-1}	A_i	A_{i+1}	...	...	A_{n-1}	A_n

Auto-covariance function (acvf)

lag 1 auto-covariance = acvf(1)

A_1	A_2	A_3	...	A_{i-1}	A_i	A_{i+1}	..	..	A_{n-1}	A_n	
	A_1	A_2	A_3	...	A_{i-1}	A_i	A_{i+1}	..	..	A_{n-1}	A_n

Auto-covariance function (acvf)

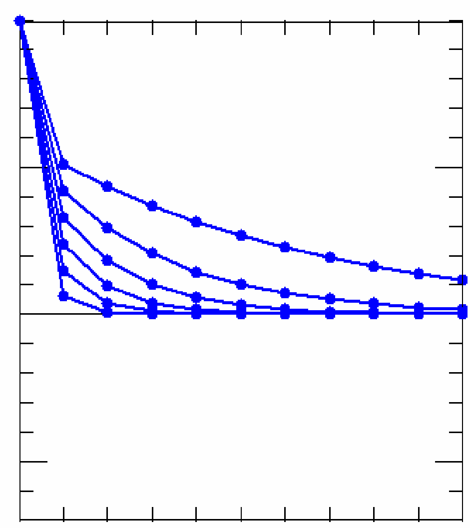
lag 2 auto-covariance = acvf(2)

A_1	A_2	A_3	...	A_{i-1}	A_i	A_{i+1}	..	..	A_{n-1}	A_n	
		A_1	A_2	A_3	...	A_{i-1}	A_i	A_{i+1}	..	A_{n-2}	A_{n-1}

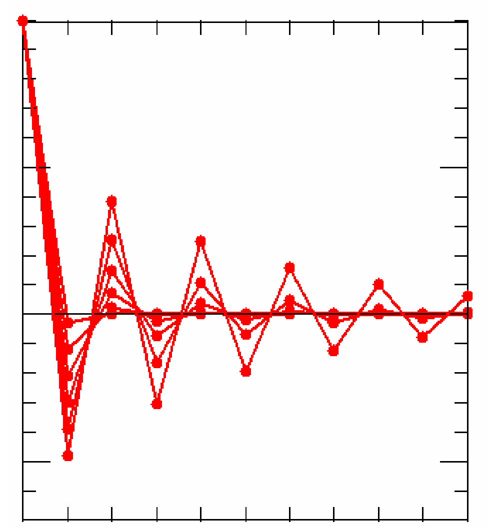
auto-correlation function acf(lag) = acvf(lag) / acvf(0)

Predicted asynchrony acf (as a function of lag)

0 < α < 1



1 < α < 2



Note:

Synchronization performance is *unstable* if α outside this range.

Extension of the model to duet performance

Basic assumption: **Each player serves as metronome for the other one.**

Parameters:

Player A (subject)

timekeeper variance	σ_T^2
motor variance	σ_M^2
error correction	α

Player B (metronome)

timekeeper variance	σ_U^2
motor variance	σ_N^2
error correction	β

Two-person phase synchronization model: Main result

Predicted 2-person asynchrony acvf

$$\mathrm{var}(A) = [(\sigma_T^2+\sigma_U^2)+2(\alpha+\beta)(\sigma_M^2+\sigma_N^2)] \;/\; [1-(1-(\alpha+\beta))^2]$$

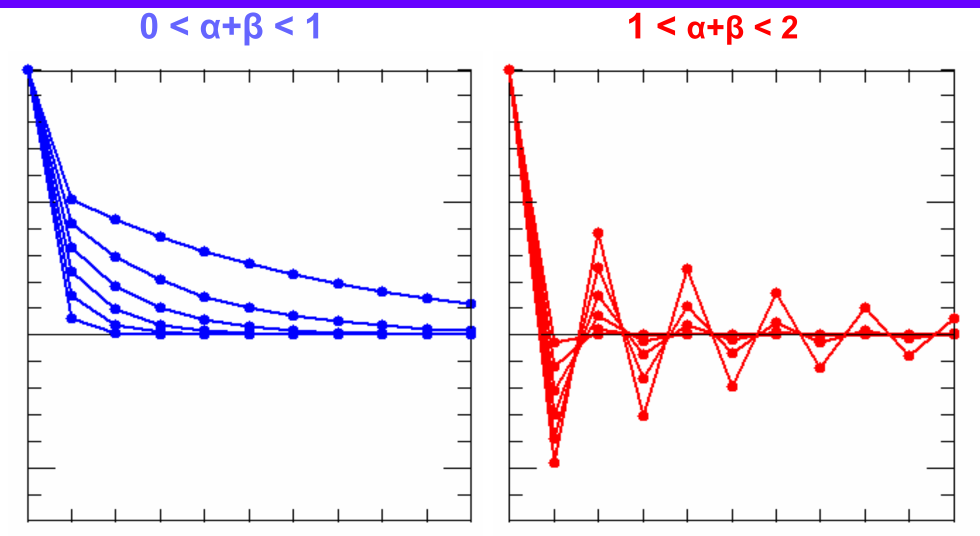
$$\mathrm{cov}(A_n,A_{n+k}) = [1-(\alpha+\beta)]^{k-1}[\mathrm{var}(A)(1-(\alpha+\beta)) - (\sigma_M^2+\sigma_N^2)]$$

Predicted 1-person asynchrony acvf

$$\mathrm{var}(A) = [(\sigma_T^2) + 2(\alpha)(\sigma_M^2)] \;/\; [1-(1-(\alpha))^2]$$

$$\mathrm{cov}(A_n,A_{n+k}) = [1-(\alpha)]^{k-1}[\mathrm{var}(A)(1-(\alpha)) - (\sigma_M^2)]$$

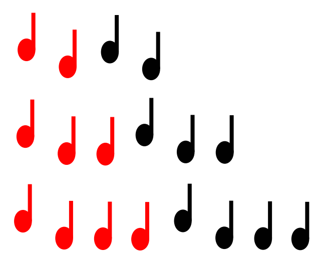
Predicted asynchrony acf for two-person model:



1. Synchronization performance is unstable if α+β outside this range.
2. **Predictions**:
   - Stable but **oscillatory acf** for β positive .
   - **Unstable** synchronization for β negative.

Experiment: Conditions

1. tempo
   - IOI=450 ms / 300 ms
2. meter
   - duple / triple / quadruple
3. metronome gain factor
   - $\beta=0$
   - $\beta=.4$ / .8
   - $\beta=-.25$ / -.50
4. seven subjects
   - 6 one hour sessions
   - 18 sequences/condition

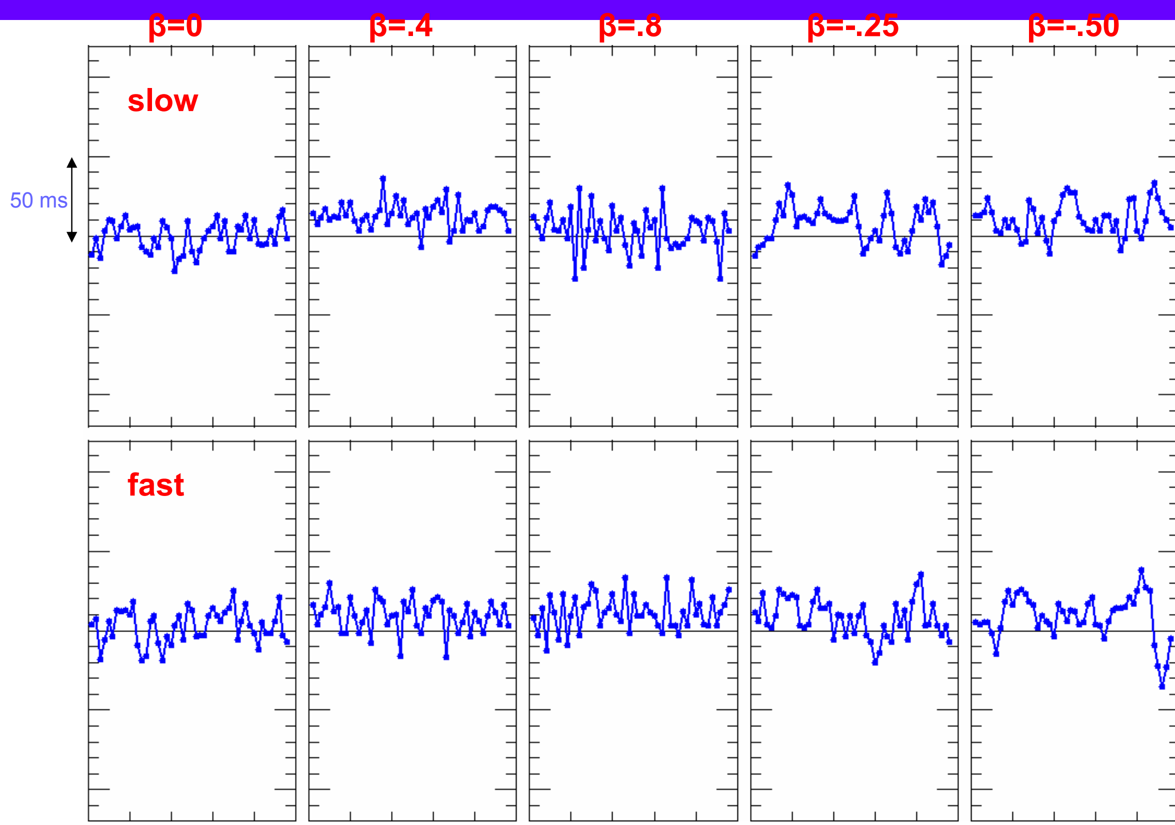


Results

1. Exemplary time series after six hours of practice
   - asynchronies
   - interresponse intervals, IRI (subject)
   - interonset intervals, IOI (metronome)
2. Auto-correlation functions, acf

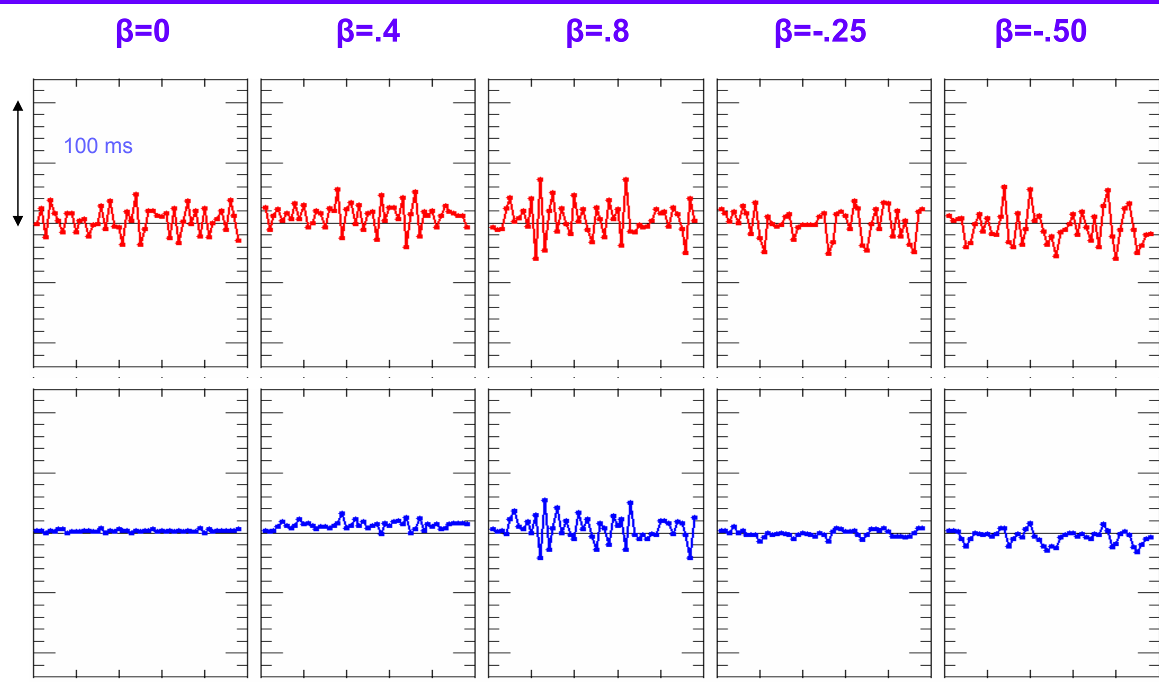
subject an: asynchronies

(x-axis: tap no. 1 – 48; y-axis: tap-metronome asynchrony in ms)



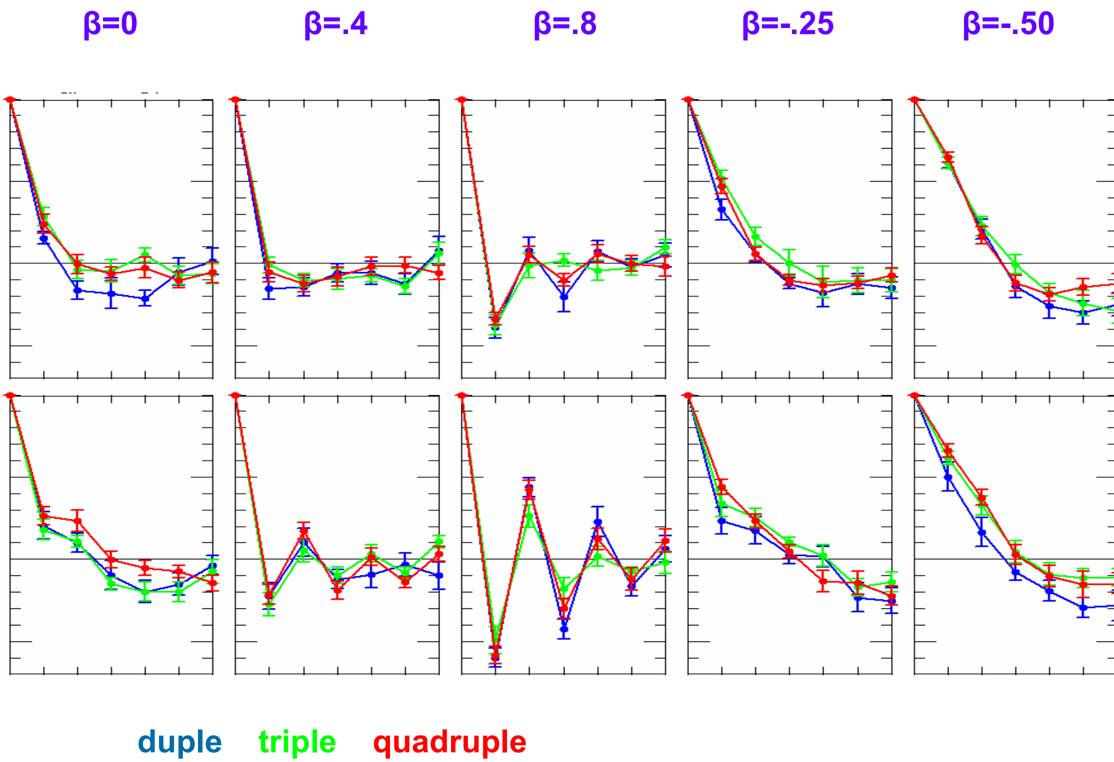
subject an: IRIs (top) and IOIs (bottom)

(x-axis: tap no. 1 – 48; y-axis: deviation from nominal IOI, in ms)

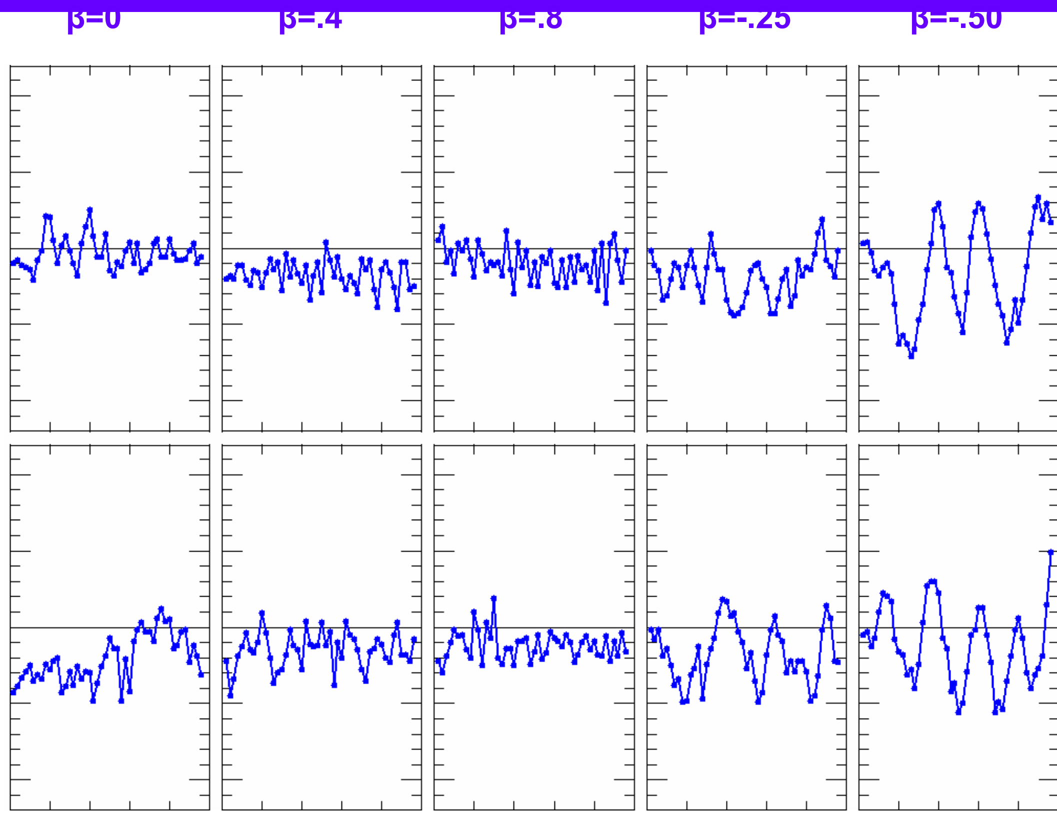


subject an: acf.s for slow (top) and fast tempi (bottom)

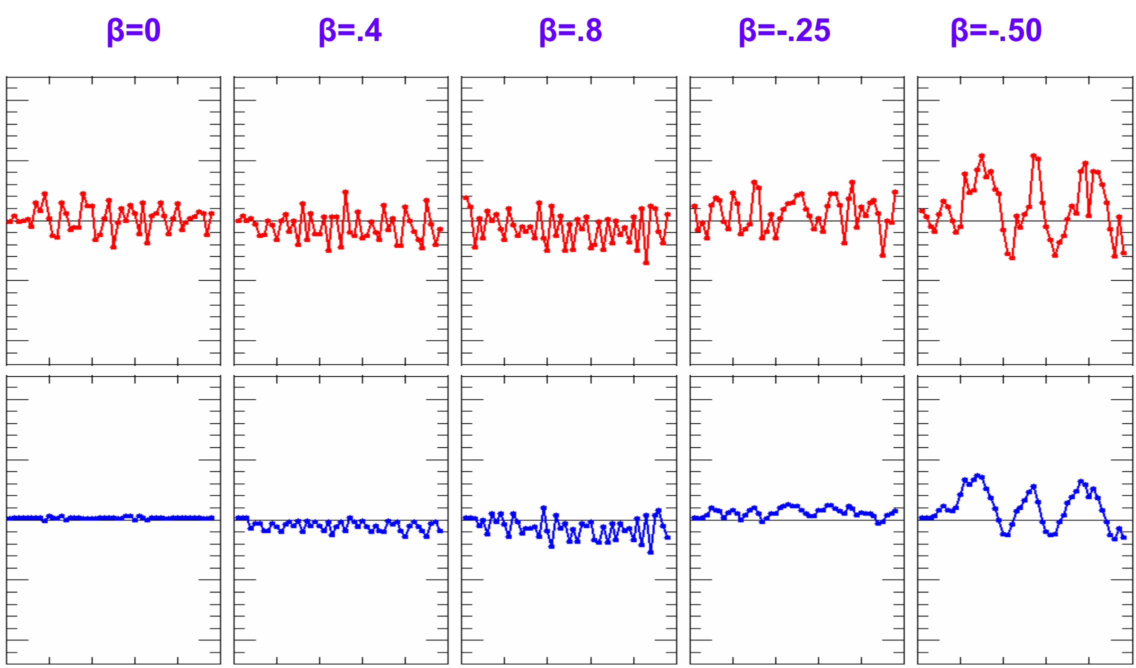
(x-axis: lag 0 to 6; y-axis: correlation size)



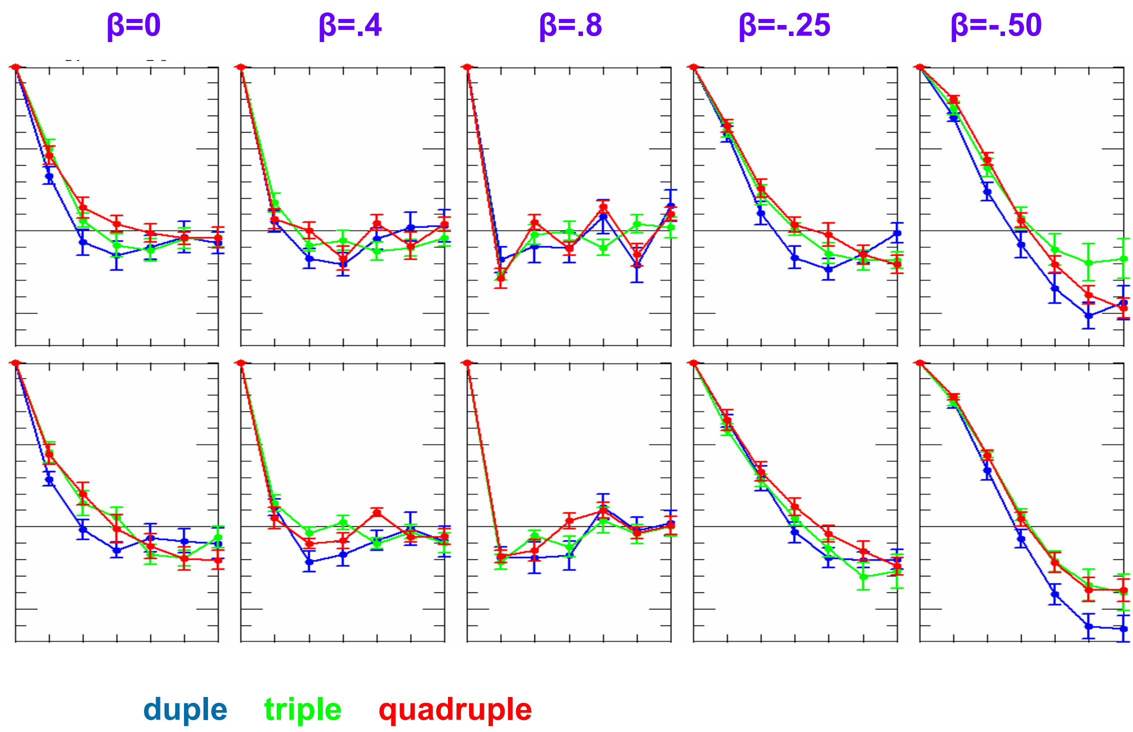
subject bv: asynchronies slow (top) and fast (bottom)



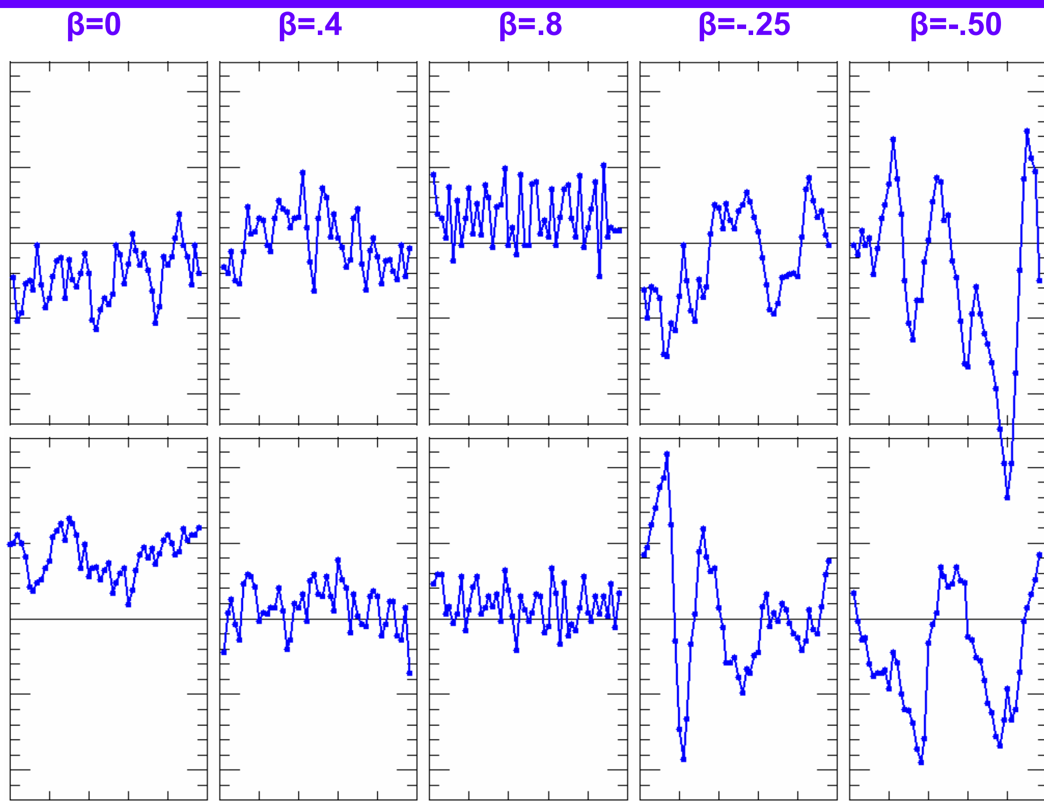
subject bv: IRIs (top) and IOIs (bottom)



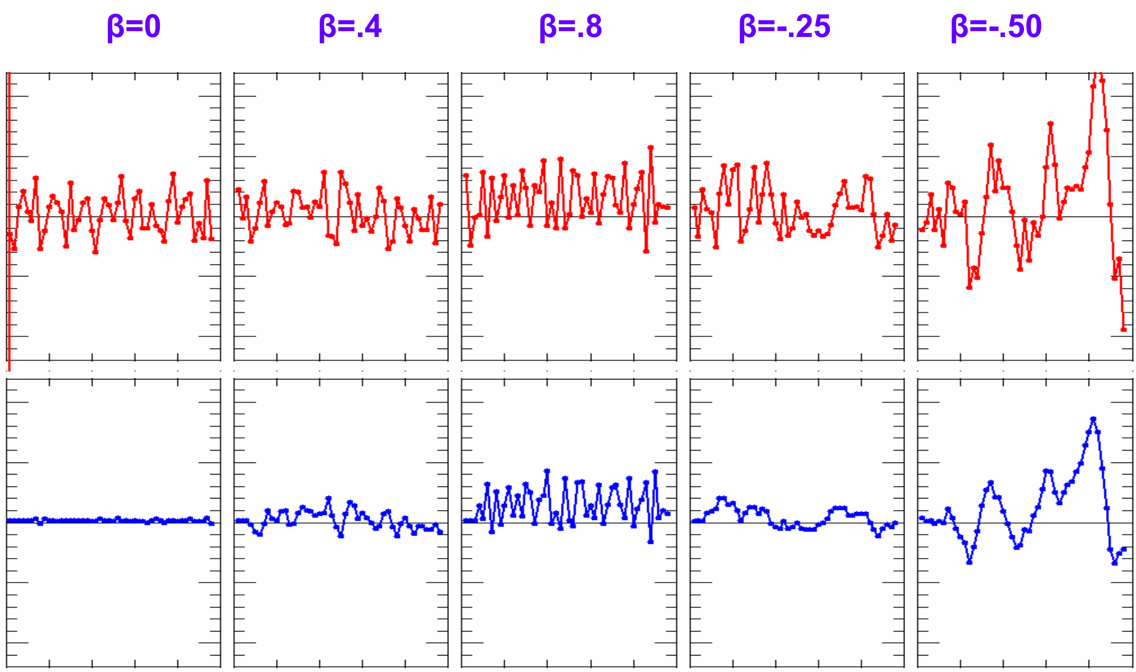
subject bv: acf.s for slow (top) and fast (bottom) tempi



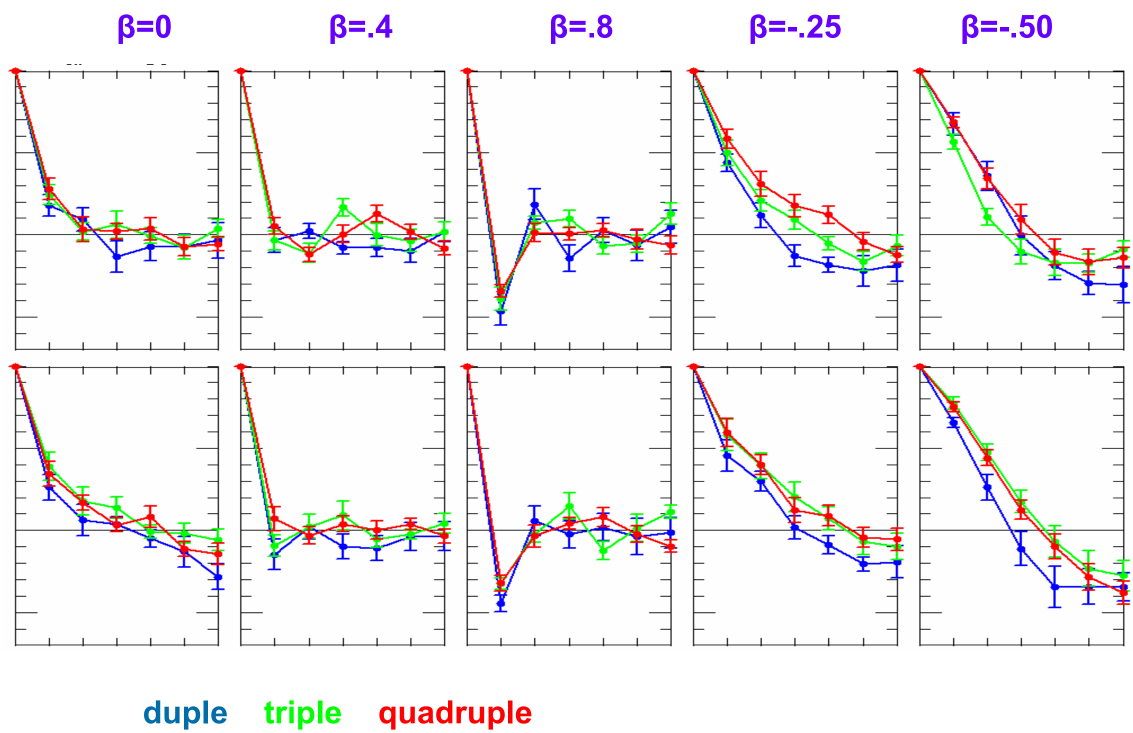
subject eh: asynchronies, slow (top) and fast (bottom)



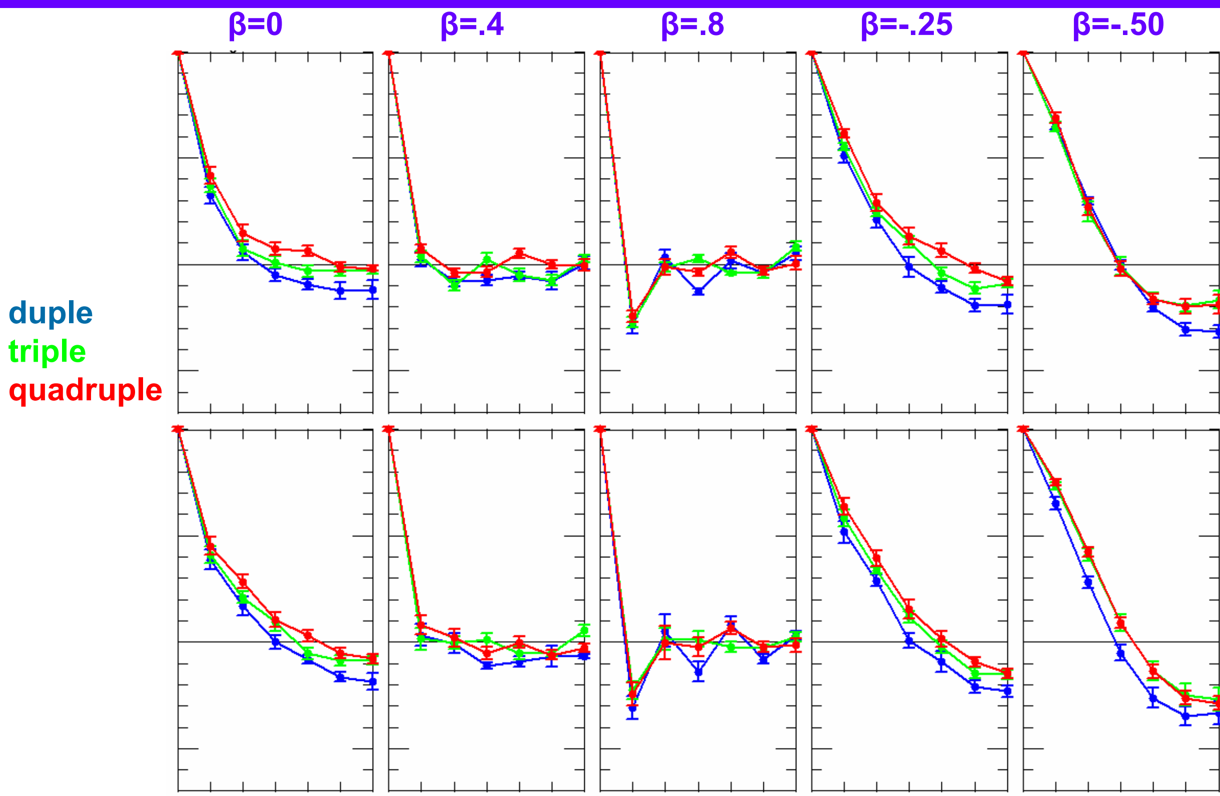
subject eh: IRIs (top) and IOIs (bottom)



subject eh: acf.s for slow (top) and fast (bottom) tempi

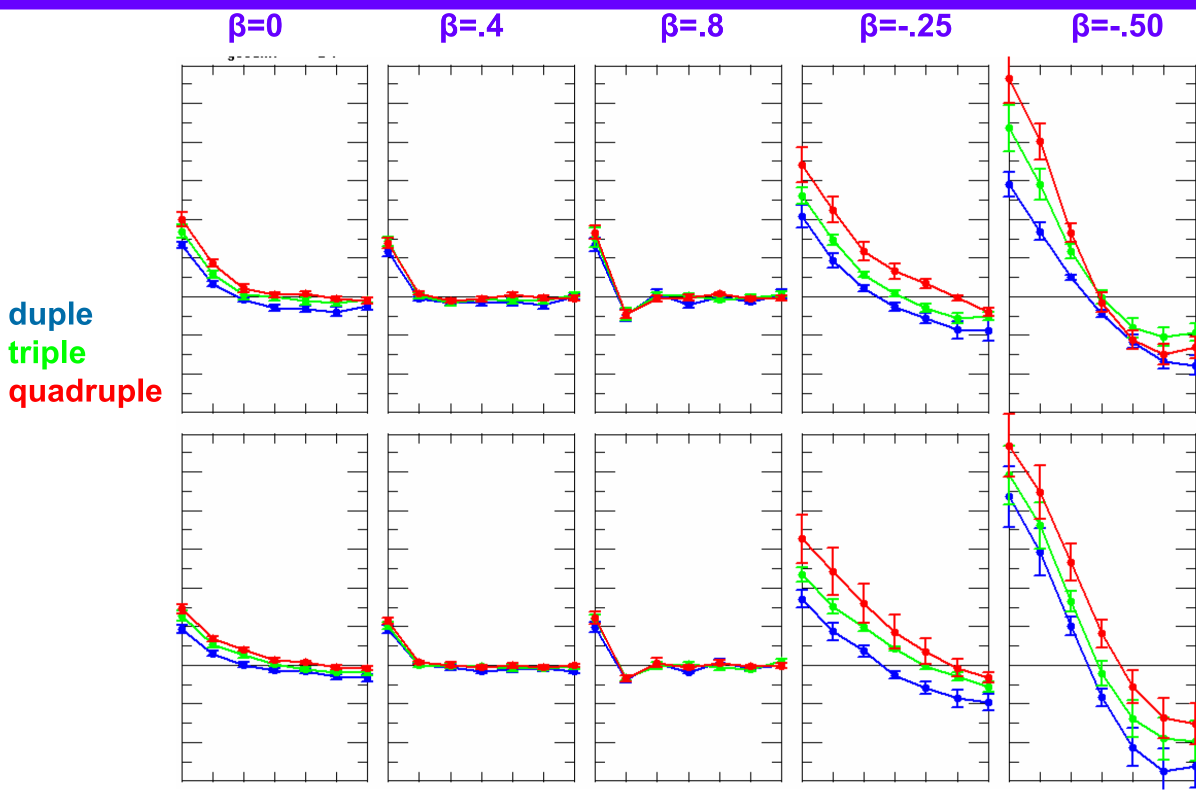


Empirical asynchrony acf.s (all subjects)



Empirical asynchrony acvf.s (average across subjects)

(x-axis: lag 0 to 6; y-axis: autocovariance at lag k)



Summary and conclusions

1. Two-person model is in qualitative agreement with observations.
   → As predicted, *acf* becomes oscillatory as metronome gain **β** increases.
   → For negative gain **β**, performance is unstable for most subjects.
2. Subjects can to adapt their phase-correction strategy to that of the duet partner.
3. **Next step: Quantitative model fit.**
4. Model-based experimental paradigm is a promising tool for studying duet synchronization. The model is easily extended to musically more challenging conditions.