Cross-frequency coupling explains preference for simple ratios in the relative phase of bimanual rhythmic tapping

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INTRO

Coordination and synchronization among individuals' movements and vocalizations is an important aspect of behavior. Within individuals, it is also vital for limb movements, muscle activations, and sensorimotor neural activity to be coordinated. In music, the biological and cultural origins of harmony and rhythm are oft-debated questions, with specific ratios playing an important role (Jacoby, McDermott, 2017). We studied whether bimanual tapping at different phases exhibits preferences that are reminiscent of simple ratios in rhythmic structures. We used cross-frequency coupling to account for the observed results.

Similar ideas have been advanced for pitch consonance and harmony, cross-culturally (Hannon & Trainor, 2007):

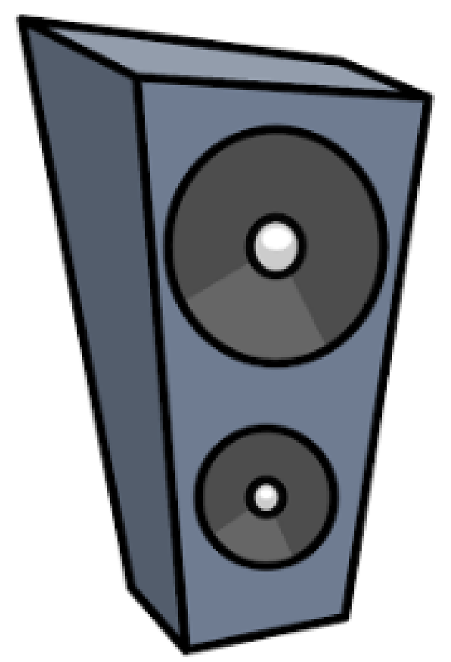
small vs. large integer ratios (2:1 vs. 45:32) => more positive affect

Although, some cultures use high complexity ratios in rhythms. Consider West African drumming experts (Polak & London, 2014).

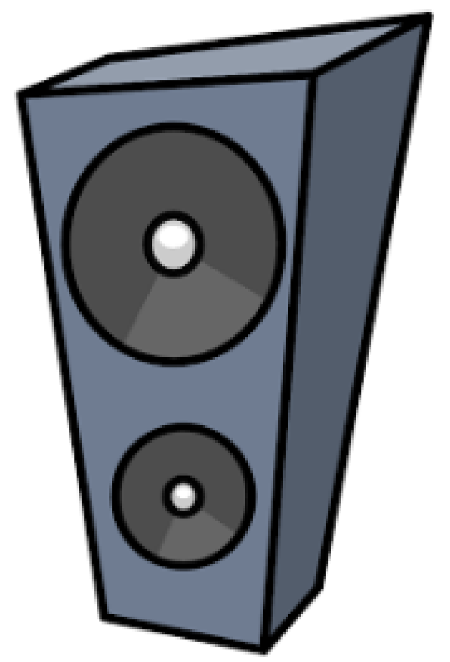
AIMS

To create an experimental paradigm revealing the difficulty of producing different ratios; to relate a metric for describing ratio complexity to the stability of rhythmic bimanual tapping; to hypothesize a neurally plausible explanation.

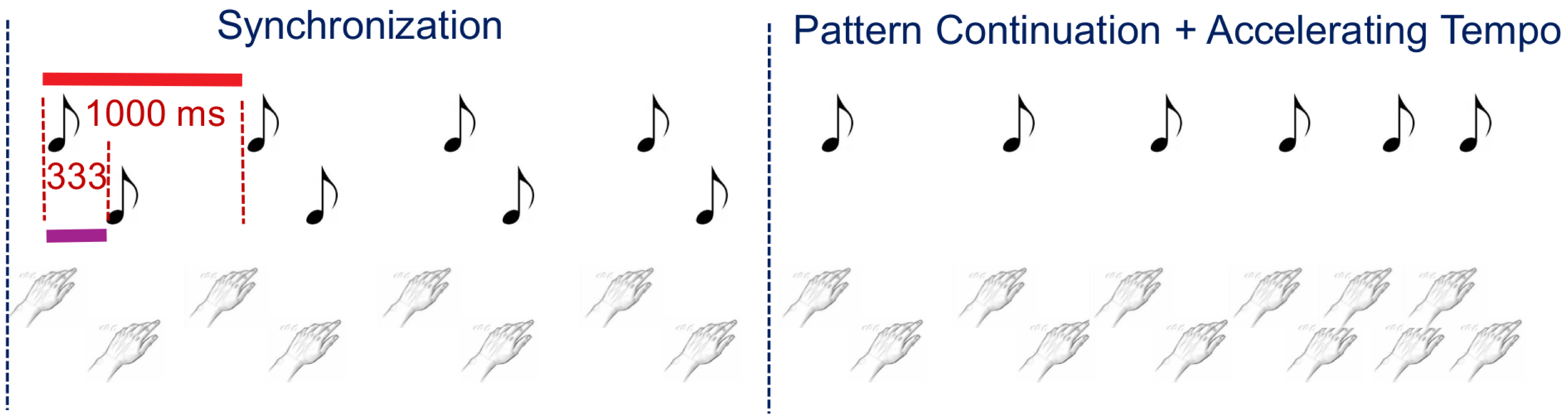
TASK: MAINTAIN AN INSTRUCTED BIMANUAL TAPPING PATTERN AS THE TEMPO INCREASES



Separate tones for stimulus and keystrokes



Each trial uses a different initial instructed phase in the range from 0 to 180 deg, randomly selected from the first 8 levels of ratio complexity.



p = 333.33 ms
q = 1000.00 ms

$$\frac{p}{q} = \frac{1}{3}$$

(p/q)*360 → 120°

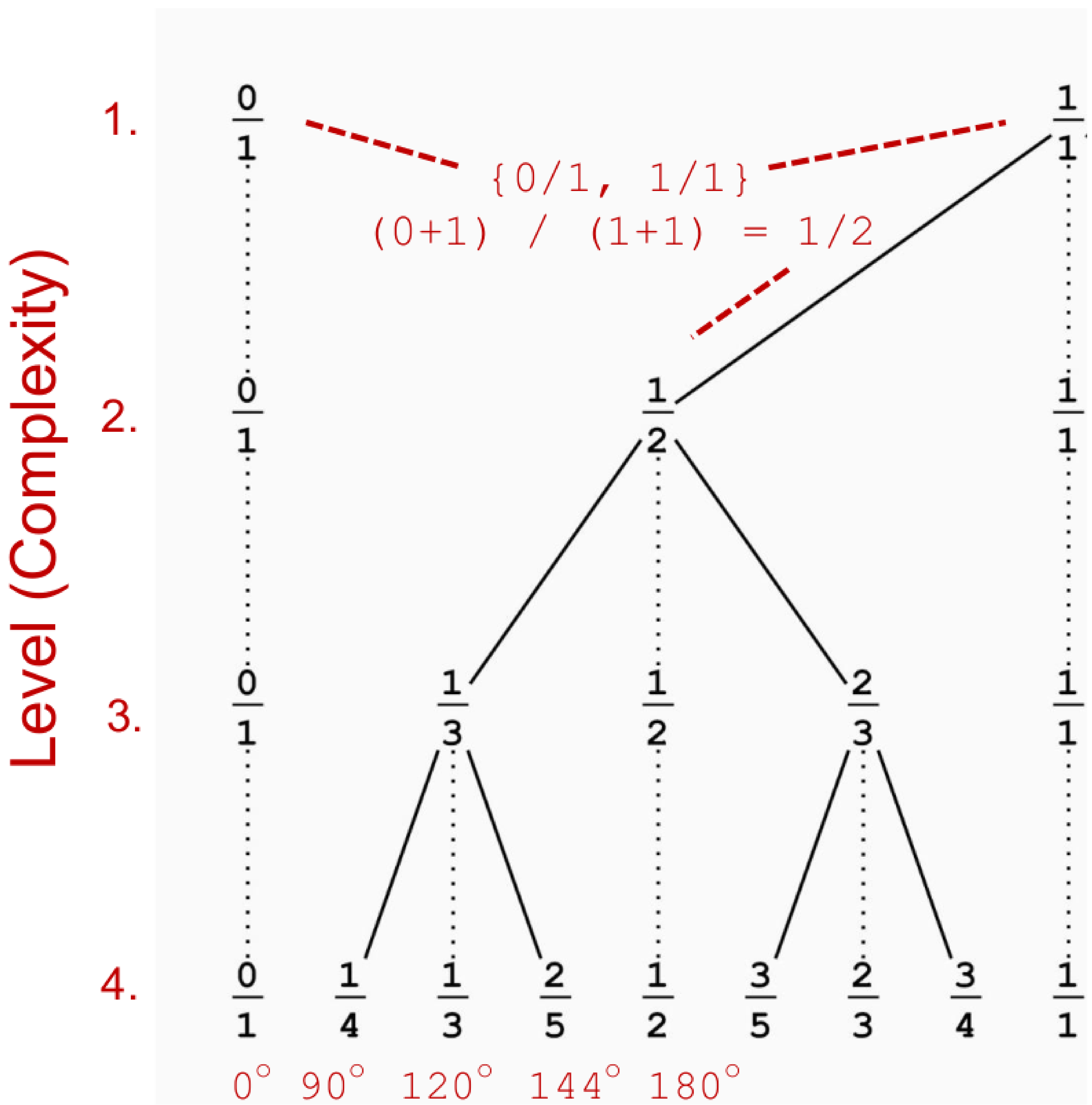
Important! This is not a task of polyrhythm or multifrequency tapping. Here the two hands are tapping at the same rate, just offset by a phase. We suspect that some phases are easier than others because they correspond to simple ratios of the whole tapping cycle.

RHYTHMIC STRUCTURE AND RATIO TREES

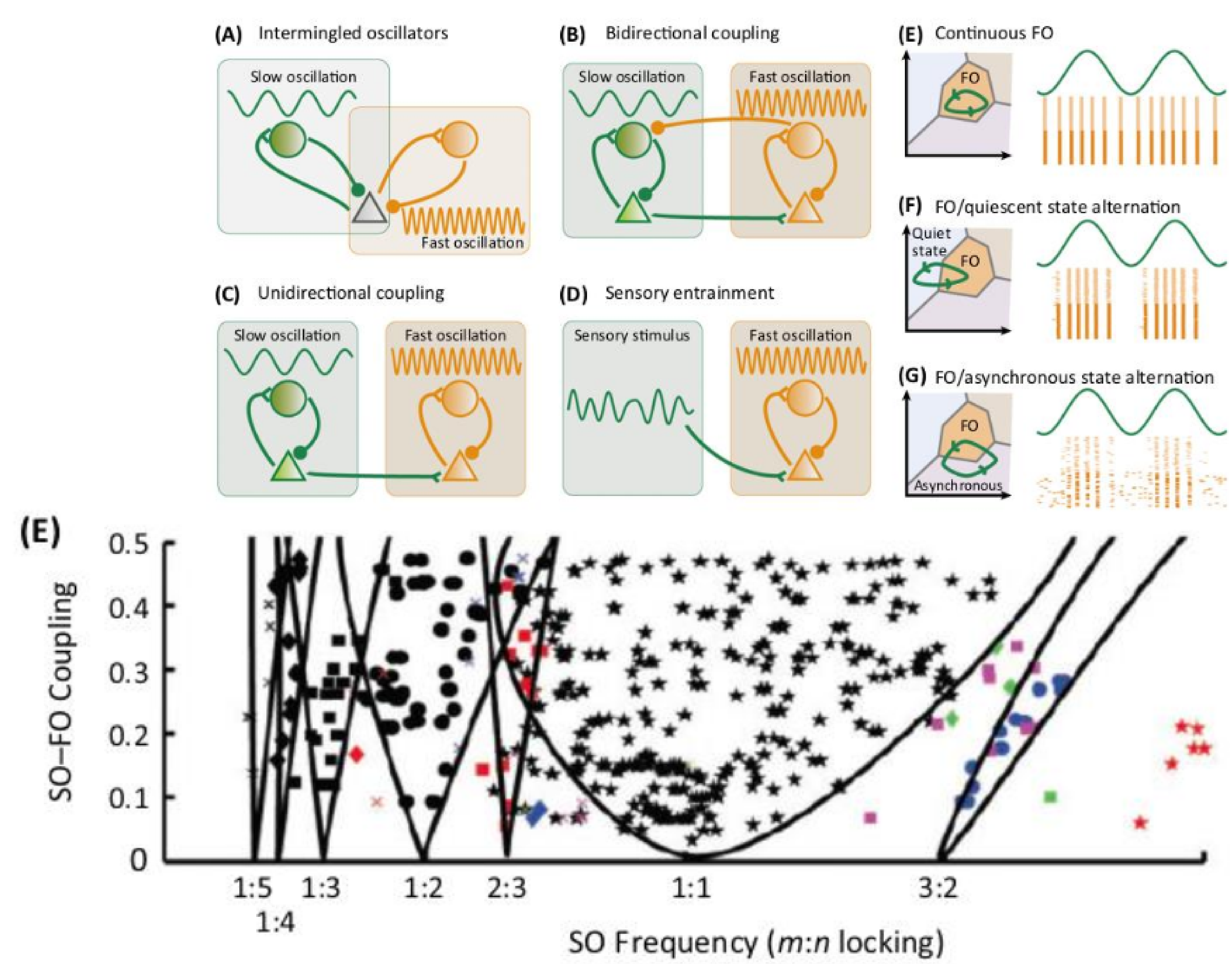
Express phase as a subdivision of a beat cycle. In this way, 90 degrees corresponds to the second hand tapping at the quarter of the leading hand cycle (1/4), 120 degrees to the third (1/3), 144 to two fifths (2/5), etc..

How to express ratio complexity (i.e. compare 1/4 to 2/3)?
Does ratio complexity (and by implication phase complexity) correspond to the difficulty of drumming patterns?

The Stern-Brocot and Farey trees are iterative procedures for generating ratios.



Compare to models of neuronal cross-frequency coupling [Hyafil et al., 2015]

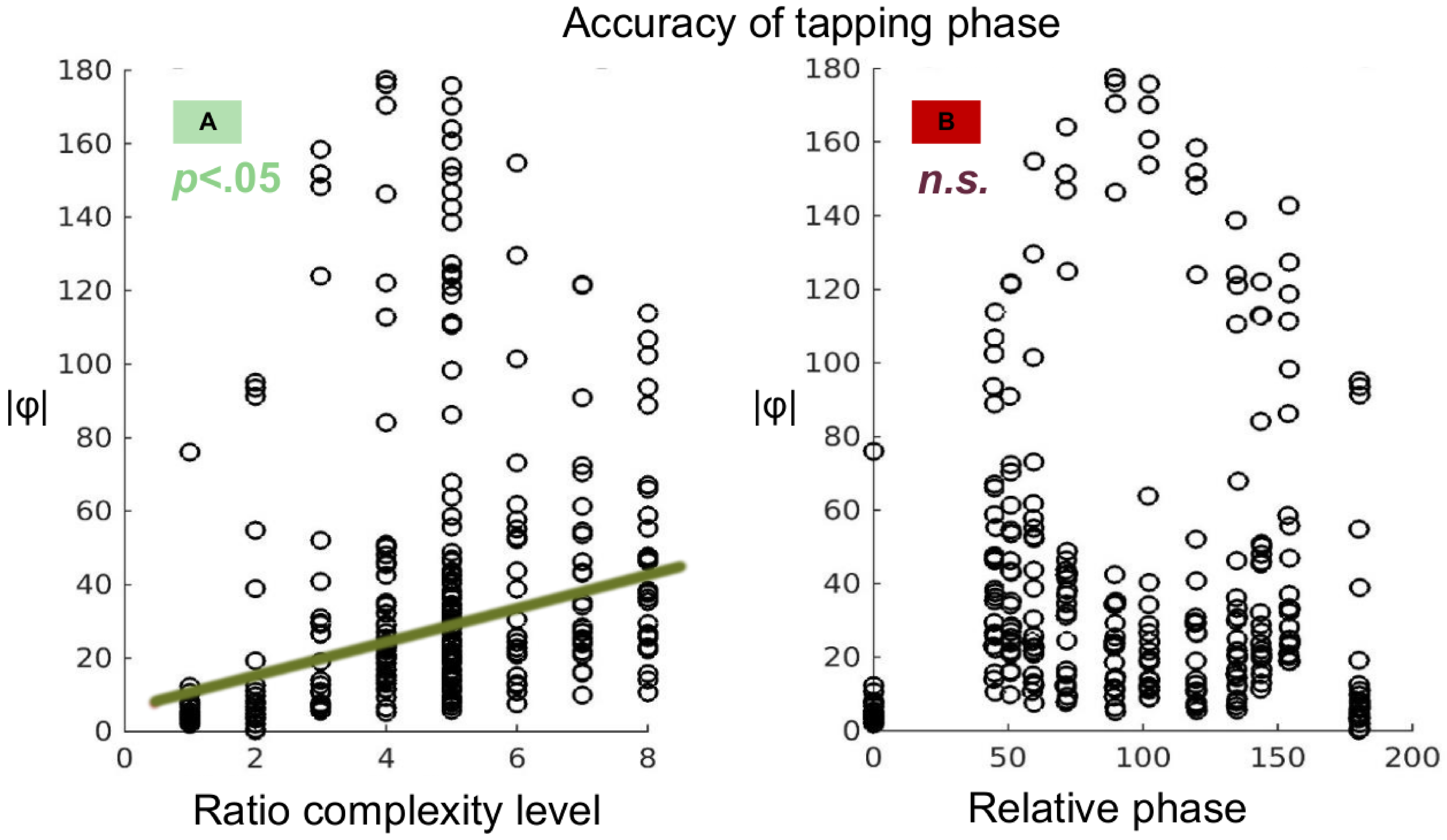


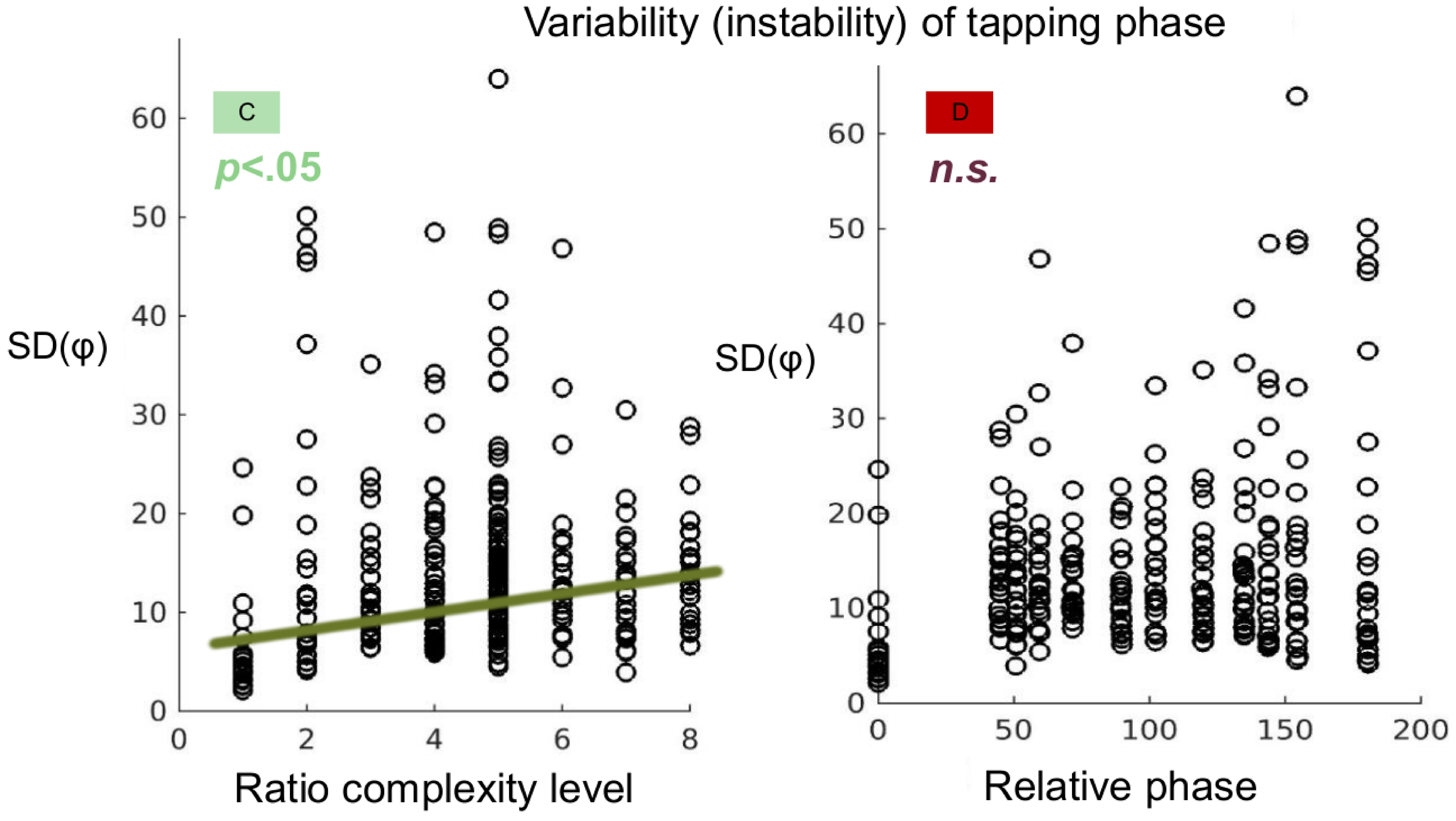
RESULTS: PREFERENCE FOR SIMPLE RATIOS IN BIMANUAL TAPPING

Ratio complexity predicted the variability and accuracy of performed phase better than existing theories of motor coordination.

Significant linear regressions between instructed ratio complexity and accuracy (A), and variability (C).

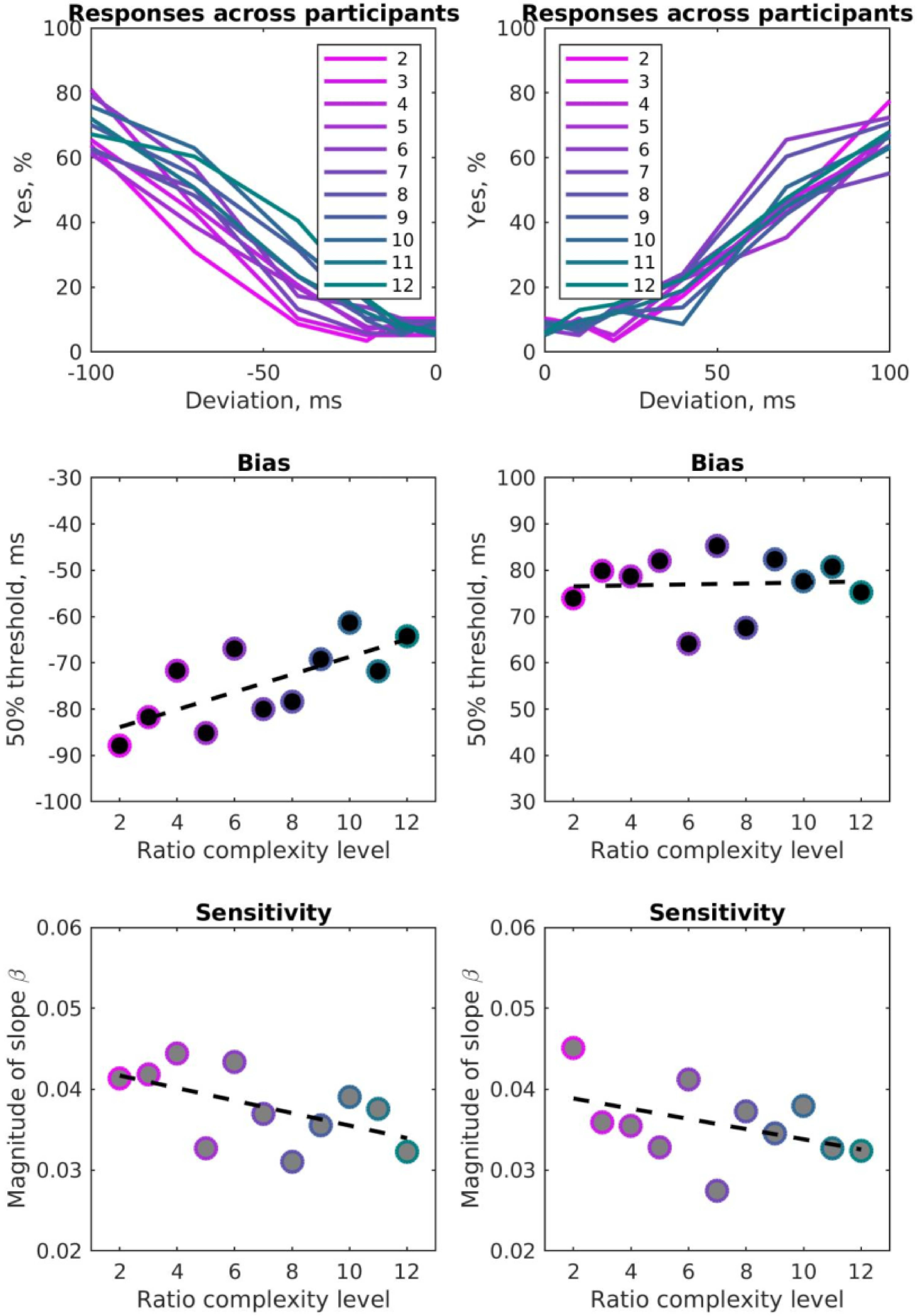
In contrast, the correlations between the same variables and required phase are poor (B and D).





AUDITORY PATTERN DEVIATION 2AFC

COVID-19 Update



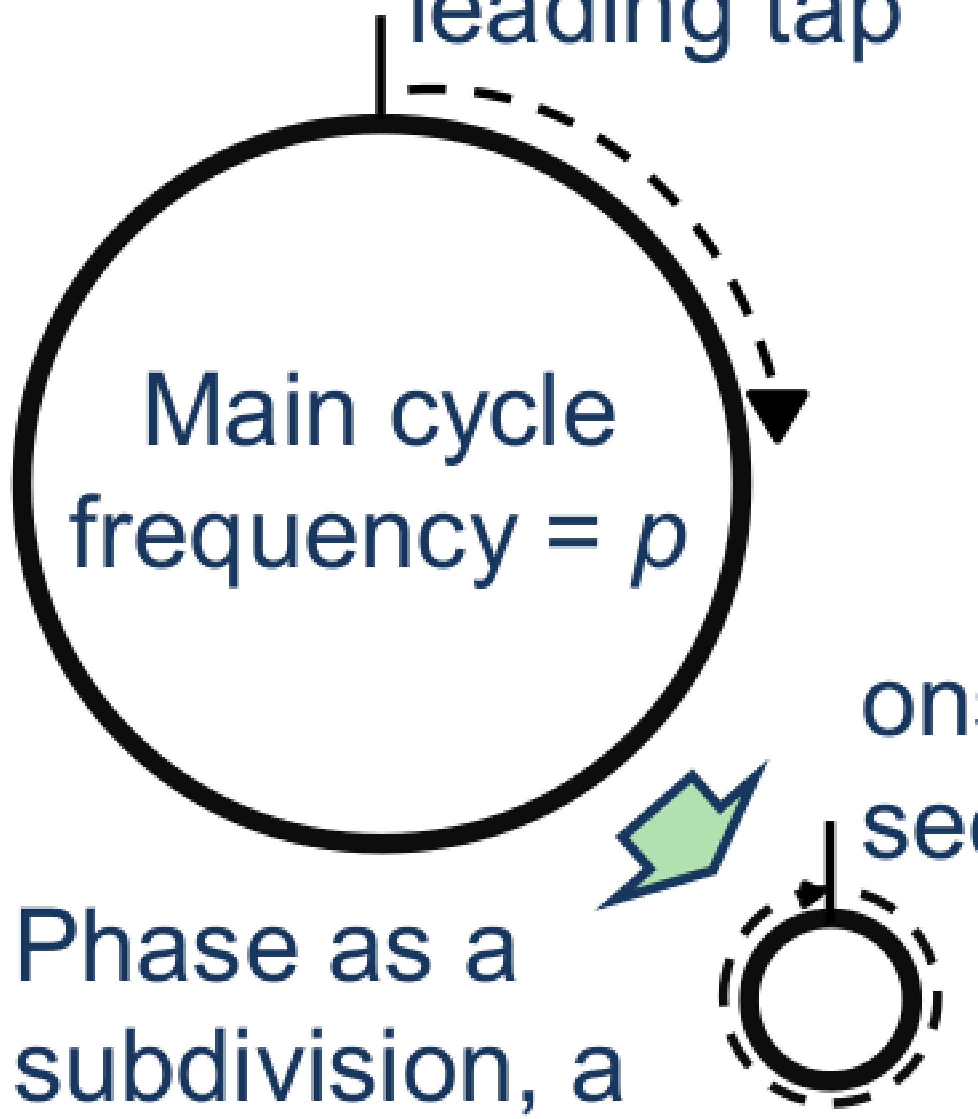
Online, www-based study
jspsych + pavlovia.org + Matlab-made stimuli + our department's pool of students who don't have many options for earning extra credit.

Participants (*N*=58) detected time deviations (2AFC) in the last tone of a two-tone rhythmic pattern. The rhythms were the same as the stimuli in the synchronization phase of the tapping study.

In the preliminary analysis we found decreasing sensitivity with increasing ratio complexity, R^2=0.2351, $F(1,20)$=6.1462, p=0.0222, and tendency for longer RT.

Try our study!
https://run.pavlovia.org/dodo_bird/phase_perceptual/

HOW COULD THIS WORK?



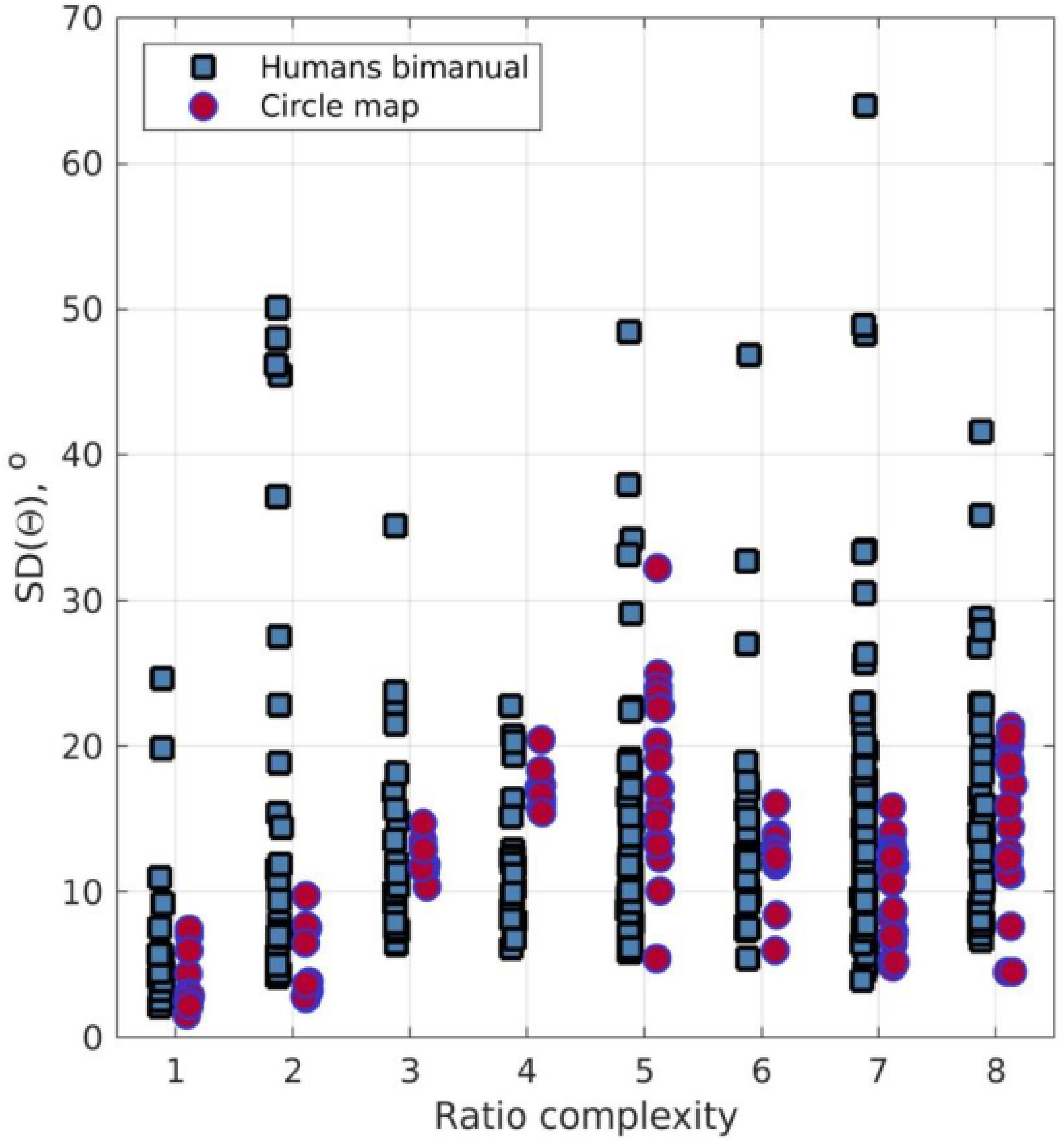
-- Assume a hierarchical network of oscillators with different frequencies.
-- Bimanual tapping at a given phase expressed as the ratio p/q becomes a problem of p:q multifrequency synchronization.

=> cross-frequency hierarchical coupling in neural oscillations [Lakatos et al., 2008, 2019] or single neuron-neuron couplings [Zhang, Bose, Nadim, 2009]

$$\Theta_{n+1} = \Omega - (K/2\pi)\,(1 + A\cos(2\pi\Theta_n))\sin(2\pi\Theta_n)$$

$$\Omega = p/q \qquad \Theta_n = \Theta_n\ (modulo\ 1)$$

The phase-attractive circle map (deGuzman et al., 1991)



CONCLUSION

1. A hierarchy of oscillatory units with distinct frequencies (Lakatos, 2008), rather than two parallel isochronous oscillators, explains complex coordination.
2. This data suggests biological constraints contribute to the range of musical rhythms found across cultures.
3. The model can be extended to account for ratios obtained in iterated tapping tasks, suggesting how cross-frequency coupling could constrain some of the priors for rhythm discussed in previous literature (Jacoby, McDermott, 2017).
4. Relevance to basic motor control. Existing theory showing how dynamic constraints enable patterns of coordination need to be extended beyond in-phase (0^{o}) and anti-phase (180^{o}), as was done recently (Avitabile, Slowinski, Bardy, & Tsaneva-Atanasova, 2016), but in a way that accounts for a hierarchy of phases (ratios).

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