What is Synchronization?

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Read this paper

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Sensorimotor synchronization: A review of the tapping literature

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Sensorimotor synchronization (SMS), the rhythmic coordination of perception and action, occurs in many contexts, but most conspicuously in music performance and dance. In the laboratory, it is most often studied in the form of finger tapping to a sequence of auditory stimuli. This review summarizes theories and empirical findings obtained with the tapping task. Its eight sections deal with the role of intention, rate limits, the negative mean asynchrony, variability, models of error correction, perturbation studies, neural correlates of SMS, and SMS in musical contexts. The central theoretical issue is considered to be how best to characterize the perceptual information and the internal processes that enable people to achieve and maintain SMS. Recent research suggests that SMS is controlled jointly by two error correction processes (phase correction and period correction) that differ in their degrees

Thank you for your kind attention

Stylistic Well-Formedness

Rhythmic understanding/grammaticality is dependent on musical enculturation:

What pulse is present here?

Outline of talk

1. Precis: rhythmic regularity, rhythmic ignorance, and rhythmic imperfection.
2. Two models of rhythmic timing: intervals and oscillators.
3. Testing synchronization: the tapping paradigm.
4. The limits of synchrony: The NMA and the subdivision benefit.
5. Who and what can synchronize.

1. Preliminaries

Presumption of Regularity

Synchronization, in one sense, obtains when two or more temporal processes are aligned in a lawful way.

Here is a temporal process:

Presumption of Regularity

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Here is a temporal process:

Here it is aligned with a second process:

Presumption of Regularity

Synchronization, in one sense, obtains when two or more temporal processes are aligned in a lawful way.

Here is a temporal process:

Here it is aligned with a second process:

→ Could <u>you</u> align with this rhythm? (probably not).

Presumption of Regularity

- So, there is more to synchronization, in the context of <u>synchronized behavior(s)</u> than just the lawful alignment of two or more temporal processes.
- In order for a "rhythmic agent" (e.g., a human) to synchronize with a rhythm, that rhythm has to be **regular enough** so that the agent can reliably predict future events (and thus target their own actions accordingly).

Presumption of Regularity

What is regular enough? Good question!

Presumption of Regularity

What is regular enough? Good question!

Long answer: Read my book, *Hearing in Time.*

Presumption of Regularity

What is regular enough? Good question!

Short answer: Having temporally periodic structure(s) in the temporal range accessible to human perception and cognition (i.e., 200-2000ms, or thereabouts).

Presumption of Ignorance

Synchronization does not depend on having prior knowledge of the temporal pattern to which one synchronizes.

- In other words, we can synchronize to rhythms we have not previously heard;
- At the same time familiarity can (and often does) improve synchronization.

Presumption of Imperfection

Human rhythmic behaviors are imperfect—we are neither perfect perceivers of temporal structure, nor are we perfect controllers of our own temporal behavior.

Therefore, in studying synchronization we must:

- Understand the nature of our (rhythmic) imperfection (this is not a moral question), and
- Understand the nature and mechanisms of <u>error correction</u>.

2. Models of Timing

Models of Timing

Timing can refer to perception of duration, prediction of location, control of a motor action, or all of the above . . . but the two principle approaches to timing are:

- Measure (and perhaps reproduce) a temporal <u>interval</u> via some internal clock.
- Resonate and reproduce <u>a pattern of beats</u> via some oscillatory process.

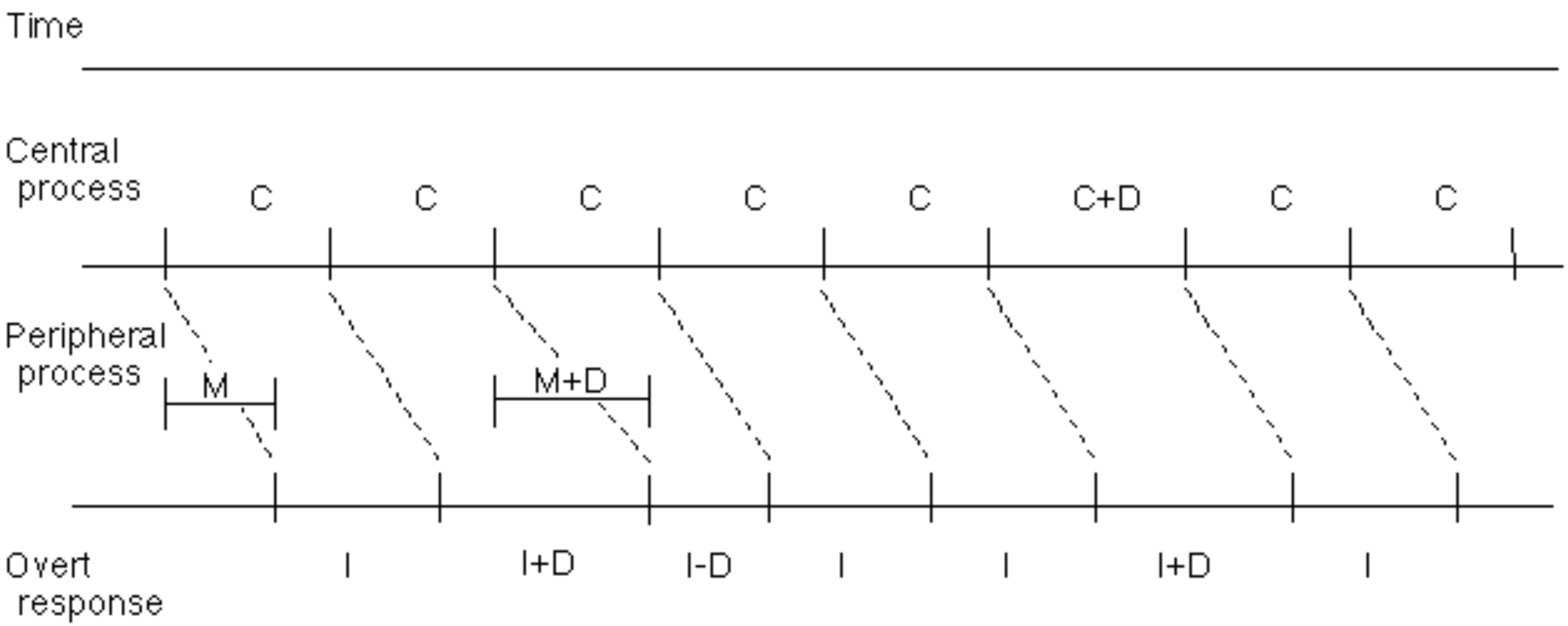
These are not mutually exclusive, and their application may depend on the task and context.

Interval models of timing

Interval based models (aka clock models) presume there is a central time keeper which generates successive intervals.

- Each interval onset triggers the start or end of a motor process.
- Initially developed in the study of the reproduction of single intervals.
- Synchronization involves successive reproduction of intervals, and correcting their alignment.

Wing & Kristofferson Model of Rhythmic Variance



Oscillator Models of Timing

- In contrast to time-discrete interval models of timing, oscillator or beat based models of timing are time continuous, and can be characterized as kind of “resonance” to a rhythmic stimulus.
- Oscillator models can be linear or non-linear, but non-linear oscillator models have been especially promising in modeling rhythmic behavior.

Oscillator Models of Timing

- Nonlinear oscillators are self-sustaining, and their behavior persists even in the absence of input.
- Nonlinear oscillators exhibit filtering behavior, responding maximally to stimuli near their own frequency.
- Oscillations arise at frequencies that are not present in the stimulus, due to nonlinear coupling.
- Nonlinear resonance predicts that metrical accent may arise even when no corresponding frequency is present in the stimulus.

Oscillator Models of Timing

"It is crucial to realize that neural resonance is not a computational model that adds mechanisms for entrainment and multi-frequency resonance to an underlying clock mechanism. The predictions [=behaviors] arise from the intrinsic physics of neural oscillation."

Edward Large (in Grondin 2008)

3. Testing Synchronization

Basic Tapping Paradigms

Stevens (1886-!) developed the basic synchronization-continuation paradigm: start tapping with a metronome, then continue on when it stops.

- Can measure stability of ITI with and without the pacing metronome.
- Can measure synchronization of tap with and without the pacer (latter relative to where metronome tap would have been).

Basic Tapping Paradigms

Continuation tapping . . .

- Is most accurate around 2hz/500ms;
  - Slower or faster rates tend to regress to 2hz
- Has a characteristic zig-zag pattern of variance (lag -1 autocorrelation);
- Longer sequences (hundreds of taps) show 1/*f* patterns characteristic of biological systems.

Basic Tapping Paradigms

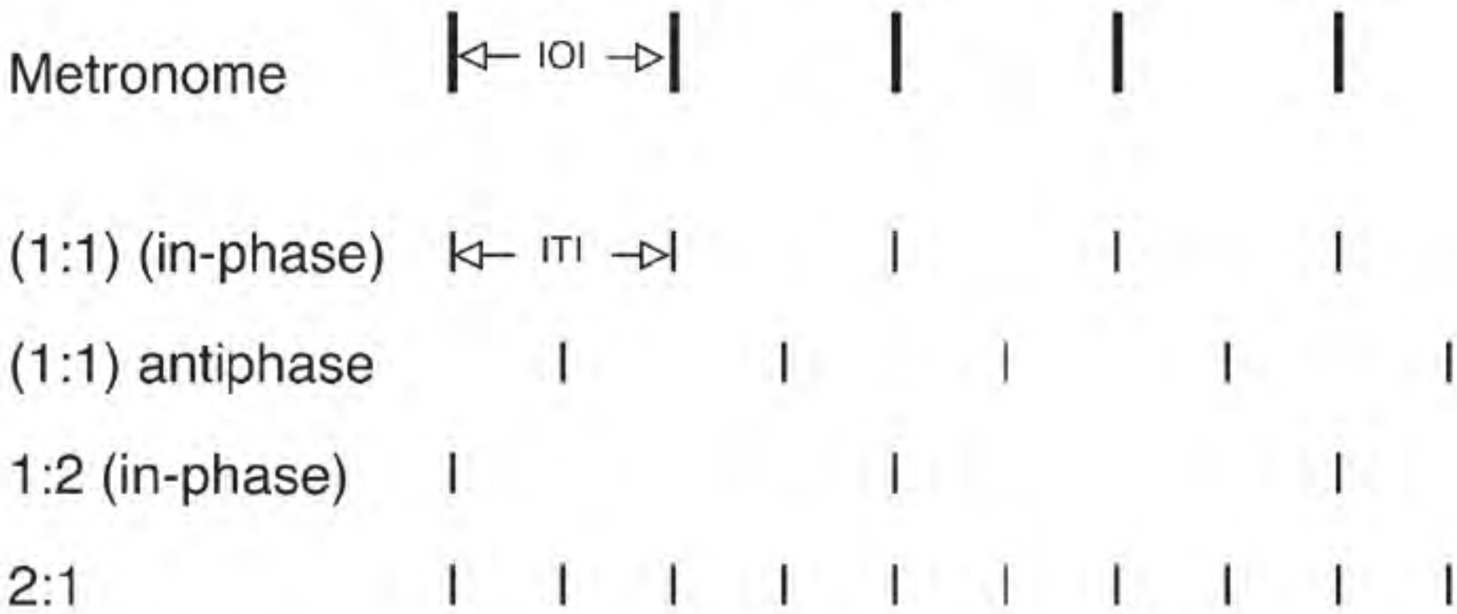
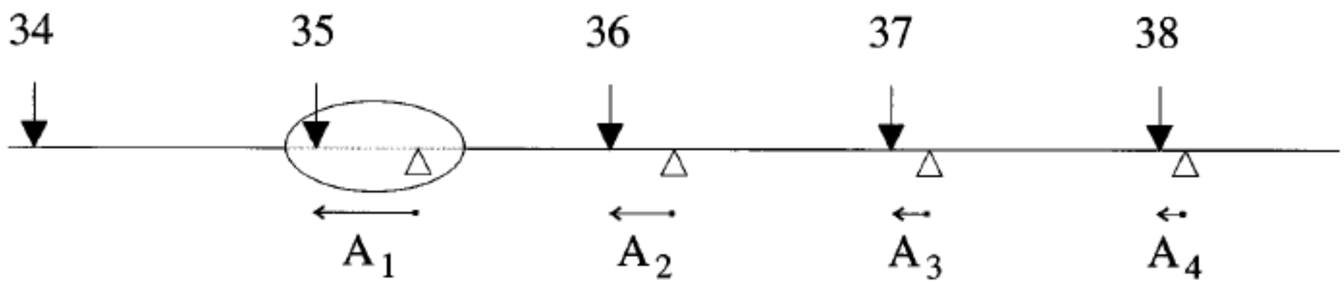
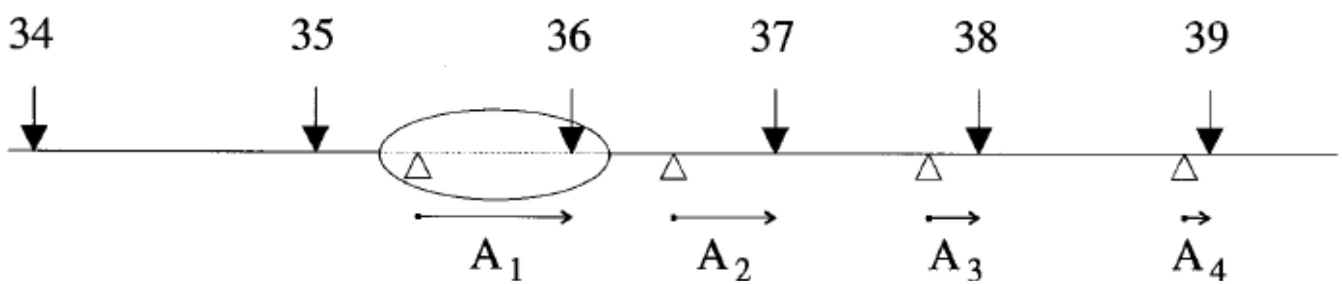


Figure 1. Common coordination modes in sensorimotor synchronization experiments. Small vertical bars stand for taps. Interonset interval (IOI) and intertap interval (ITI) are indicated. Terms in parentheses are generally implied, when not mentioned explicitly.

Tapping Asynchronies





Tapping Asynchronies

Synchronization accuracy in tapping tests is measured in terms of:

- The average amount of asynchrony (mean of $|A_1|, |A_2|, |A_3| \ldots |A_n|$
  - N.B. best practice is to use circular statistics
- The sign (+ or -) of the average of A_1, A_2, A_3 . . . $|A_n|$
- The variance (SD) of A_1, A_2, A_3 . . . $|A_n|$

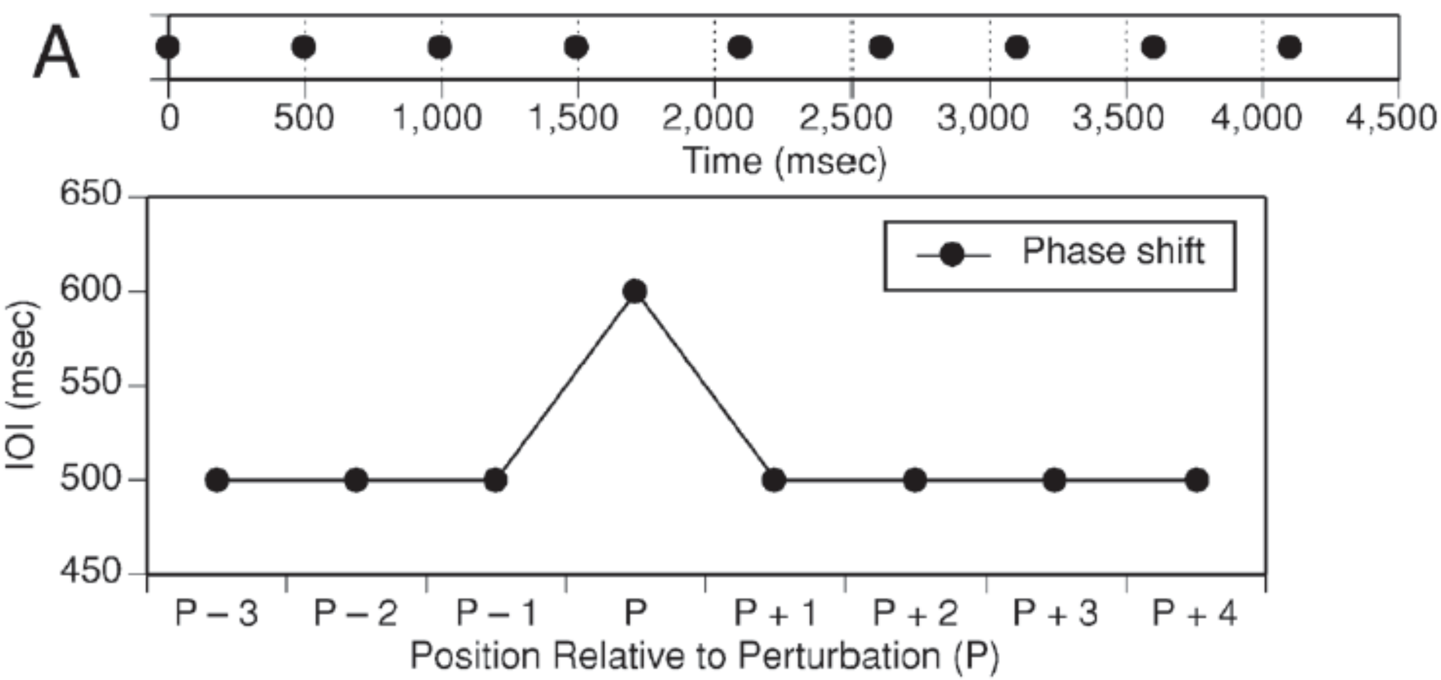
Perturbation Studies

While continuation studies reveal aspects of rhythm production, <u>perturbation</u> studies have shown key aspects of adaptive behavior required for synchronization.

– Perturbation tests demonstrate the presence of true entrainment, as it requires coupling between the rhythmic processes.
– Perturbation behaviors also can test different models of error correction.

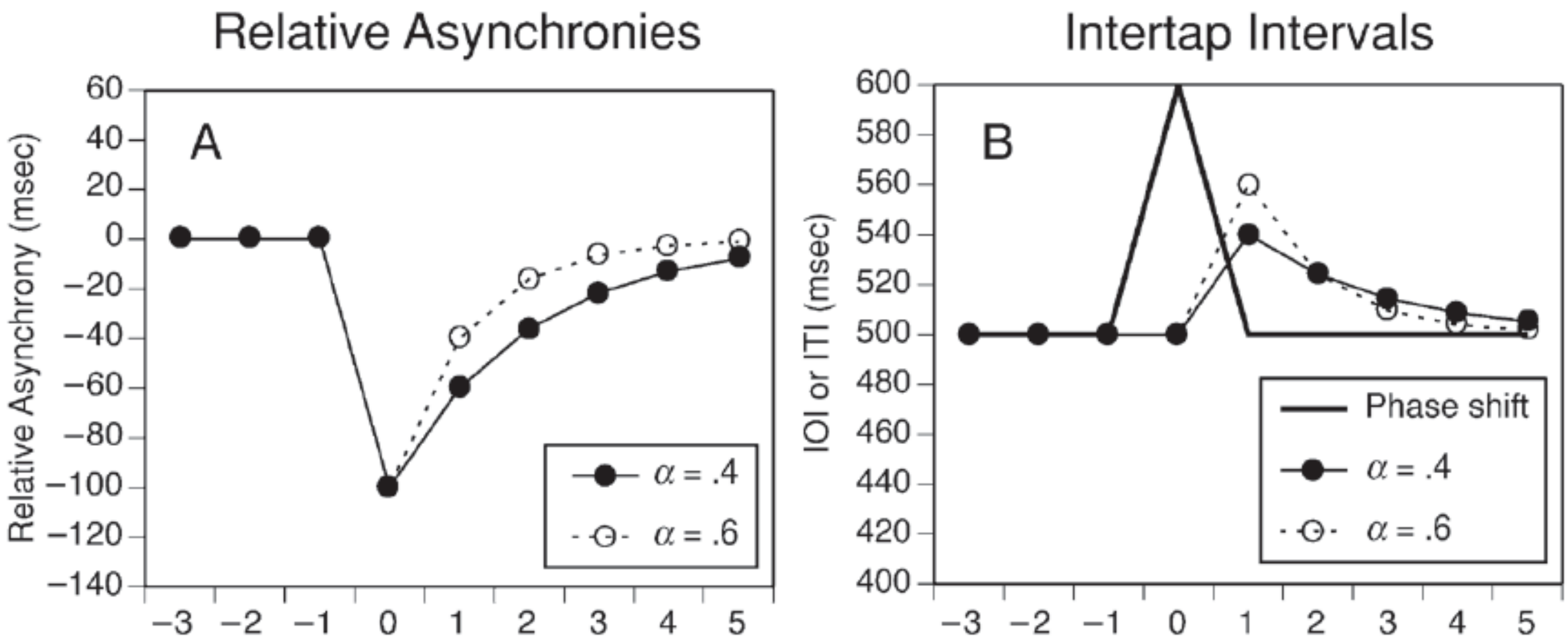
Perturbation Studies

Perturbation 1: Phase Shift



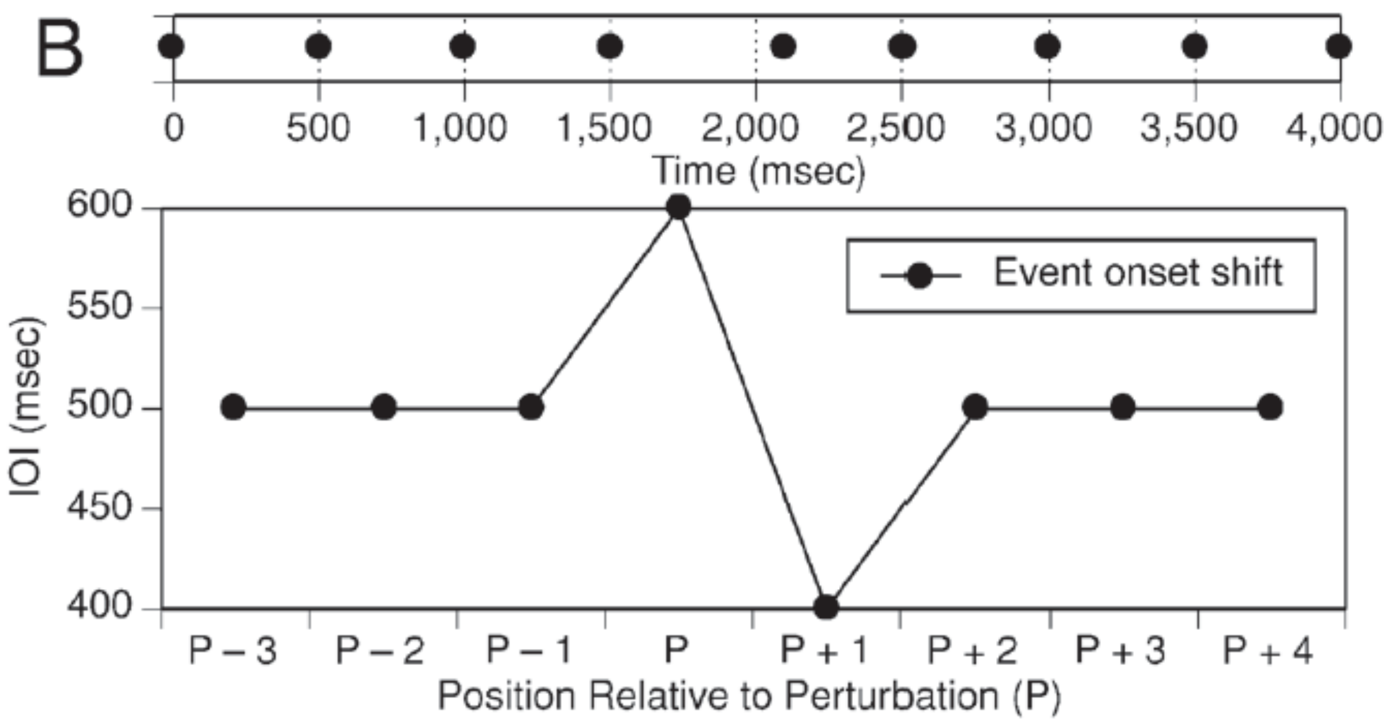
Perturbation Studies

Perturbation 1: Phase Shift



Perturbation Studies

Perturbation 2: Event Onset Shift



Perturbation Studies

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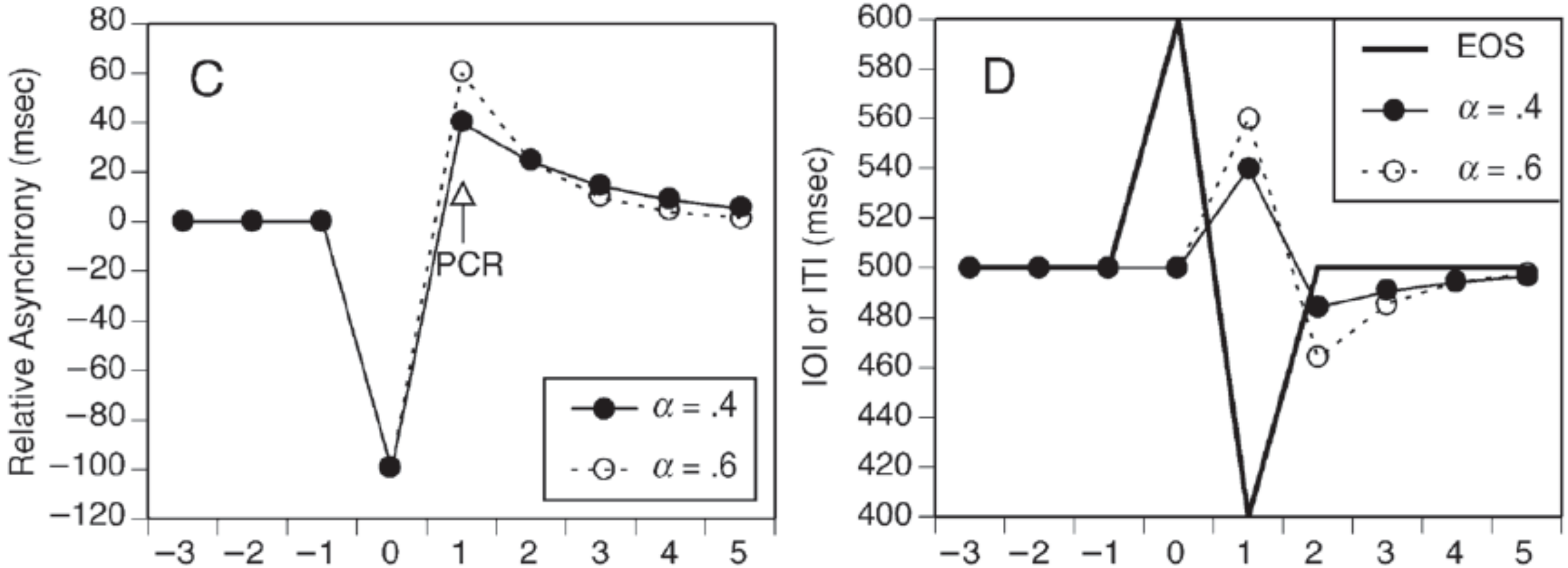
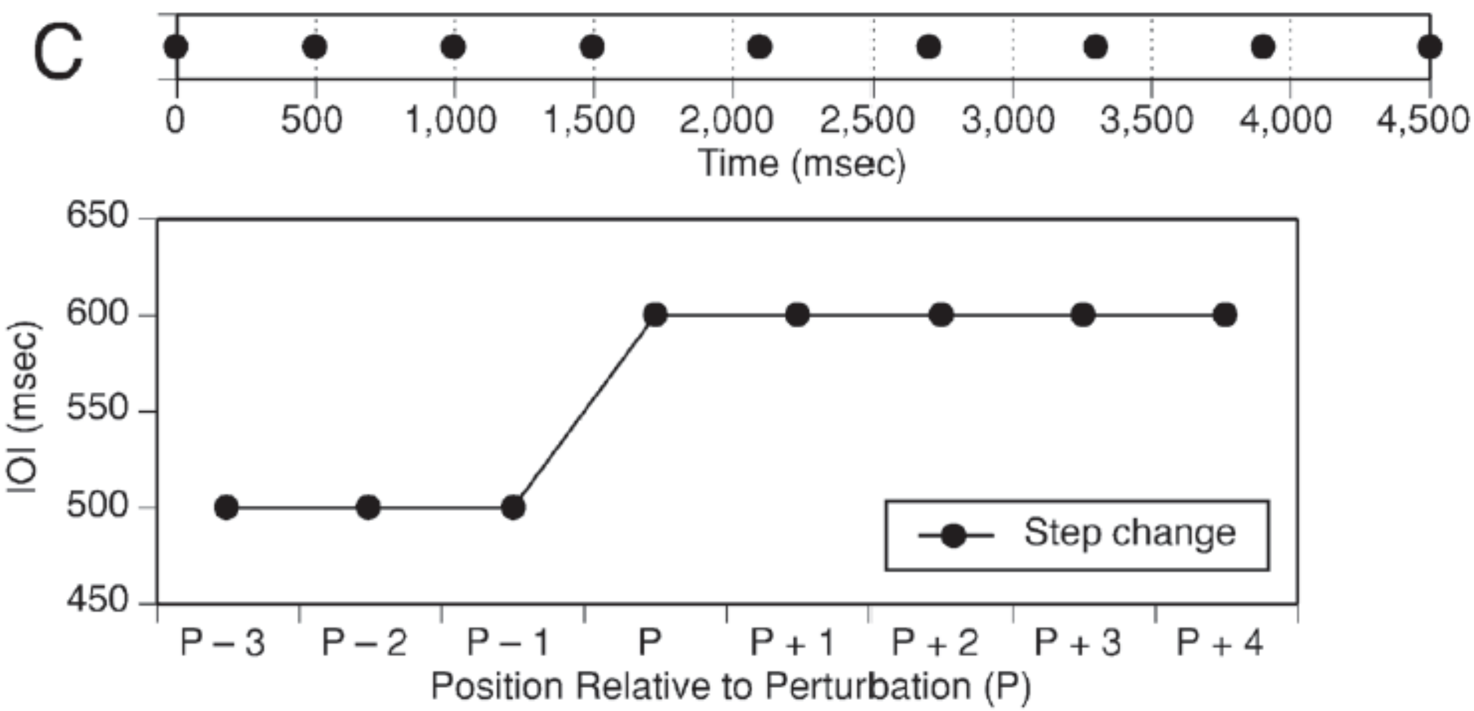


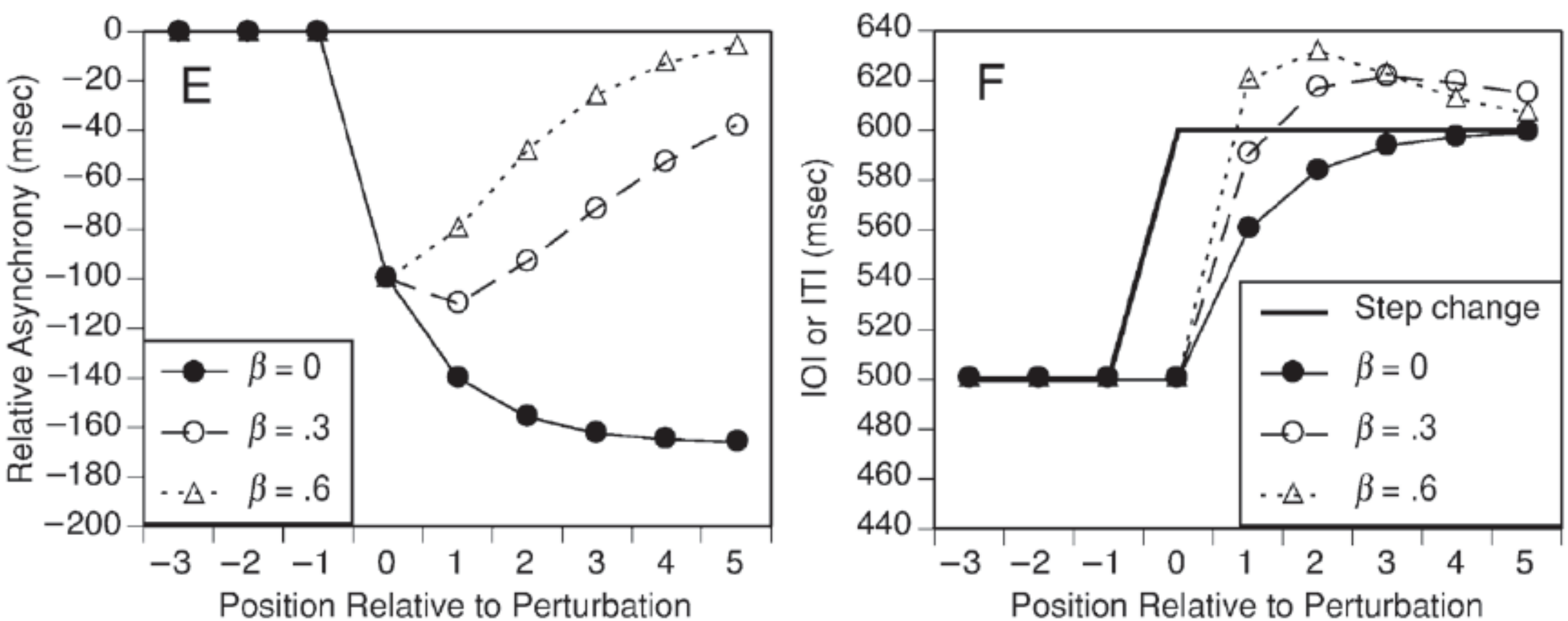
Perturbation Studies

Perturbation 3: Period Shift



Perturbation Studies

Perturbation 3: Period Shift



Perturbation Summary

- Different perturbations engage different error correction mechanisms (phase vs. period).
- Human responses to perturbations can show our sensitivity to errors, and be used in the development of error correction models.
  - PCRs evident even for subliminal perturbations(!)
- Once larger patterns of a timing sequence are learned, they can give rise to predictive behavior.

Perturbation Studies

- Phase correction is rapid and automatic, period correction is slow and volitional.
- Implications for our sense of interaction and coordination:
  - Keeping together once a tempo is established is an automatic process—maintaining an alignment.
  - Changing tempo while still keeping together requires awareness and negotiation—changing alignment.

4. Constant Errors

Negative Mean Asynchrony

"NMA" is the tendency to tap ahead of the beat by ≈20-40ms. It occurs:

- When tapping to a metronome/"stationary rhythm";
- At a moderate rate (but not at slower rates);
- Is absent when tapping to real music;
- Is diminished or absent for musician tappers;
- It can be eliminated with visual feedback.

Negative Mean Asynchrony

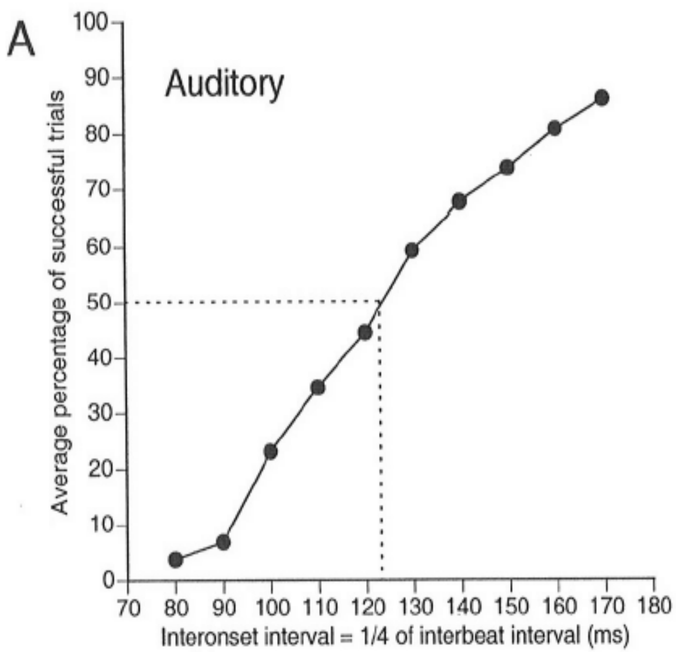
- With NMA the points of objective synchrony and subjective synchrony generally do not coincide, at least for nonmusicians—they feel they are “tapping late” to eliminate the asynchrony.
- Do you have NMA? Let’s find out(!)

The Subdivision Limit

Repp (2003) found the <u>rate limit</u> for synchronization in a n:1 tapping test.

- 10hz/100ms Inter-Tap interval (ITI) is about the limit for rhythmic behavior.
- Too fast for 1:1 synchronization . . .
- . . . but we can synchronize with rapid stimuli if we ourselves do not have to produce that interval.

The Subdivision Limit



Here is the averaged data from a 4:1 tapping test; synchronization was above chance (50%) for IOIs ≥ 120ms/8hz

This is for both musician and non-musician tappers. Musicians—esp. percussionists—do better (100ms).

The Subdivision Benefit

- Repp also found that for slower IOIs (metronome up to about 200ms), the presence of the metronome taps in a 2:1 or 3:1 tapping task <u>improved</u> synchronization.
- Subsequently found that this is true even if the subdivisions are irregularly timed.
- Let's try this out . . . (!)

5. Who and What can Synchronize?

What Can Synchronize?

A great debate in evolutionary biology is ongoing regarding what creatures are capable of synchronization.

What Can Synchronize?

Fireflies can:

What Can Synchronize?

Some have claimed that birds can:

Figure 1. Snowball
Snowball, a male sulphur-crested cockatoo (*Cacatua galerita eleonora*) investigated in the current study.

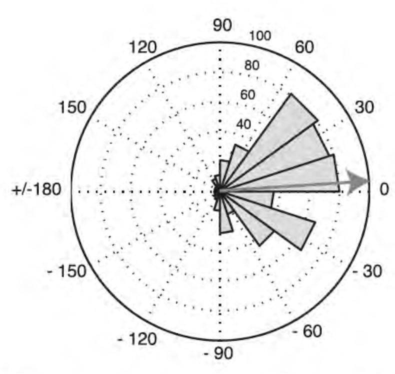
What Can Synchronize?

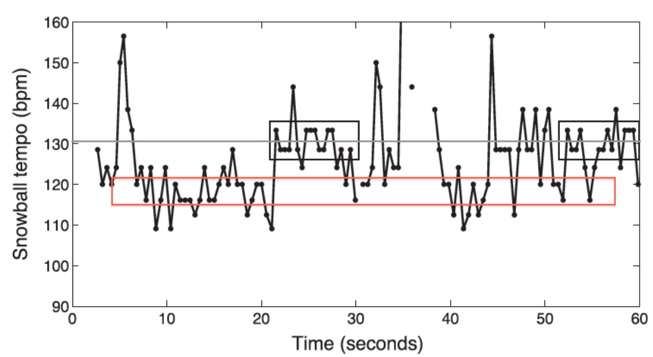
Why Birds? The <u>vocal learning hypothesis:</u>

- Vocal learning is the ability to imitate novel sounds, evidenced by birds (learning songs) and humans (learning language)
- Timing control is important in learning and reproducing novel sound sequences
- Birds and humans have neural circuits that connect auditory perception, vocal production, and sensorimotor rhythms.
- Therefore, vocal learning species may also have a capacity for synchronization.

What Can Synchronize?

. . . . but there are doubters (including JML). While snowball can produce rhythmic behavior within a certain range, it is not clear if he is truly synchronized.





What Can Synchronize?

Then there is Ronan, the seal:

https://www.youtube.com/watch?v=sYisjieeKK8

"A California Sea Lion (Zalophus californianus) Can Keep the Beat: Motor Entrainment to Rhythmic Auditory Stimuli in a Non Vocal Mimic"

Cook, et. al (2013), Jour. of Comparative Psychology

What Can Synchronize?

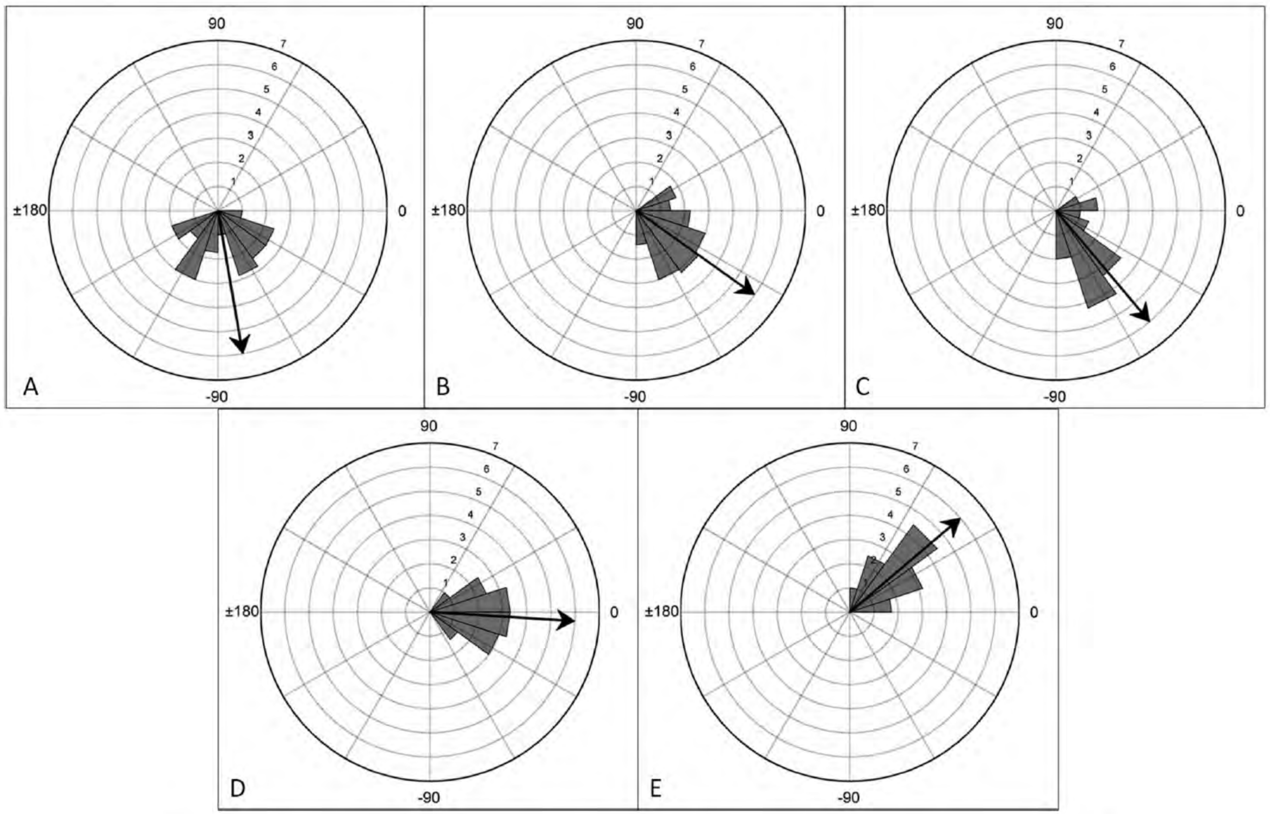
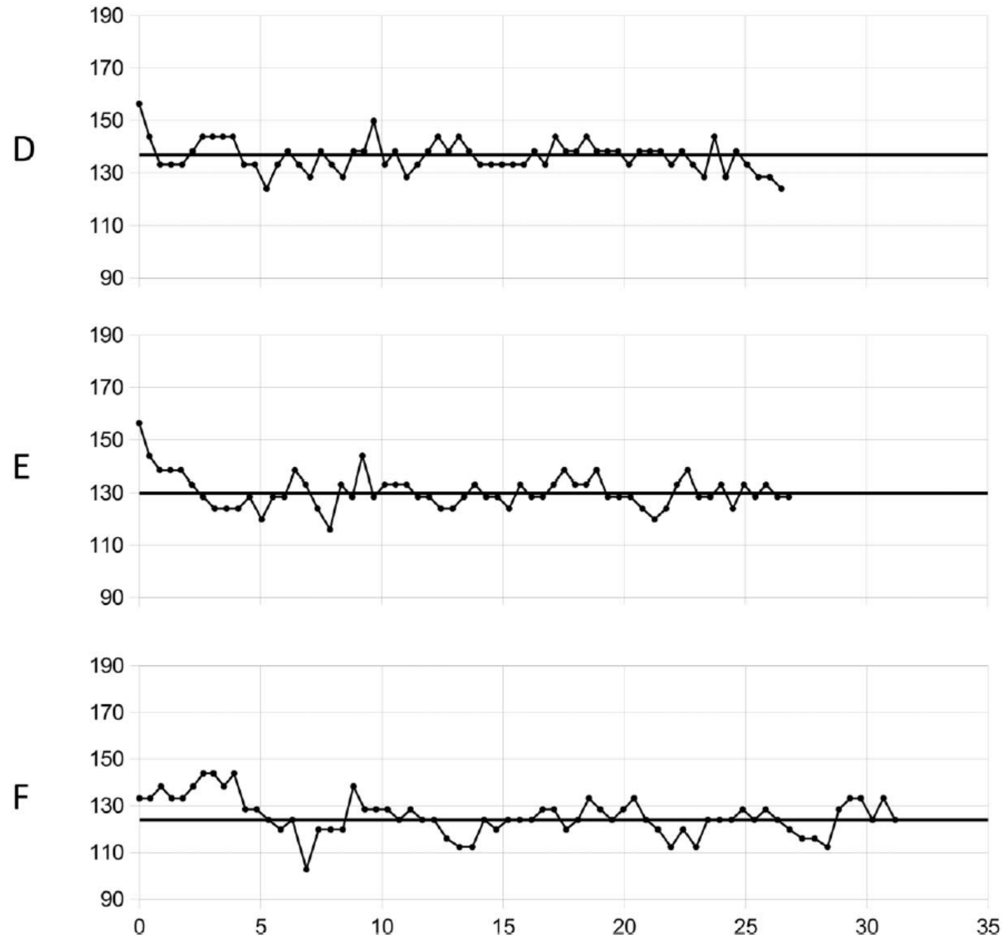


Figure 2. The cumulative angular distribution of Ronan's phase angles on her first two exposure trials to 5 frequency-modulated stimuli at the novel rates of (A) 72 beats per minute (bpm), (B) 88 bpm, (C) 96 bpm, (D) 108 bpm, and (E) 132 bpm. These tests made up Experiment 2.

What Can Synchronize?



What Can Synchronize?

Can primates other than homo sapiens synchronize?

What Can Synchronize?

The most nuanced account of primate rhythmic behavior is that of Merchant and Honing (2014) who propose a Gradual Audio-Motor Evolution Hypothesis:

- Humans fully share interval-based timing with other primates, but only partially share synchronization ability.
- Non-human primates are like humans in interval reproduction, categorization, and interception tasks . . .
- . . . but show differences in entrainment, synchronization, and continuation tasks.

Summary

- Synchronization presumes a regular rhythm or as the target/framework for synchronizing behavior.
- Synchronization requires adaptive behaviors, since neither we nor our target rhythms are error free.
- Synchronization involves matching the phase and period:
  - Phase correction is rapid, pre-cognitive and involuntary.
  - Period correction is slower, cognitive, and volitional.

Summary

- The limits of synchronization are slower than that of rhythm production.
- Some aspects of synchronization – most especially phase correction, and period flexibility – seem to be uniquely human.
- In rare cases humans lack this ability.

End of Lecture #2

Teaser

Musical synchronization, as opposed to metronome synchronization, shows aspects of temporal coordination that are <u>socially grounded.</u>

→ Thus synchronization needs to be studied and understood in terms of its natural context and function, which is bound up with social interaction . . . (stay tuned for next lecture!)

Beat Deafness

Amusia is the congenital absence of basic auditory capacities needed for music perception.

- According to Honing (2011) the two basic capacities are (a) hearing relative pitch, and (b) beat induction (i.e., entrainment).
- Peretz & colleagues have developed the *Montreal Battery of Evaluation of Amusia* (MBEA) to test for their presence/absence.

Beat Deafness

Amusia is not very common (perhaps 2% of the population have it to some degree).

- Most cases involve deficits in pitch perception and/or production (“tone deafness”)
- Rhythm deficits are extremely rare, but recently a few have been found . . .

Beat Deafness

Mathieu is a (now) 26 year old (post?) university student with no language deficits and no other apparent learning or social disorders.

- M. is “out of time” when he (attempts to) synchronize his movements with most music—he produces a periodic behavior, but at the wrong period and phase.
- M. cannot detect whether someone else is moving in time with the music.
- But M. *can* tap along with a metronome, and at different tempi.

Mathieu & the Merengue