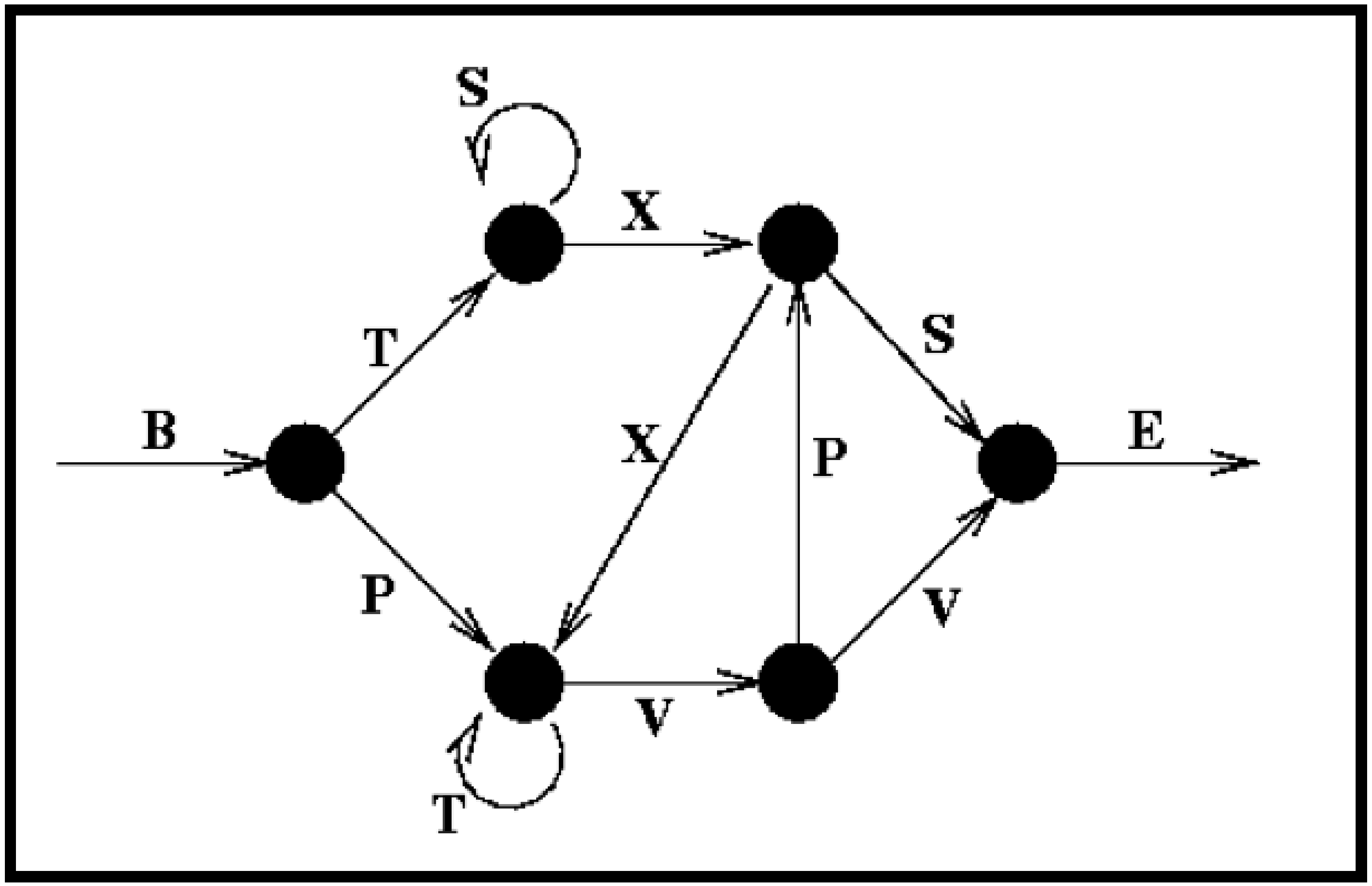
Exercise 3: Reber Grammar

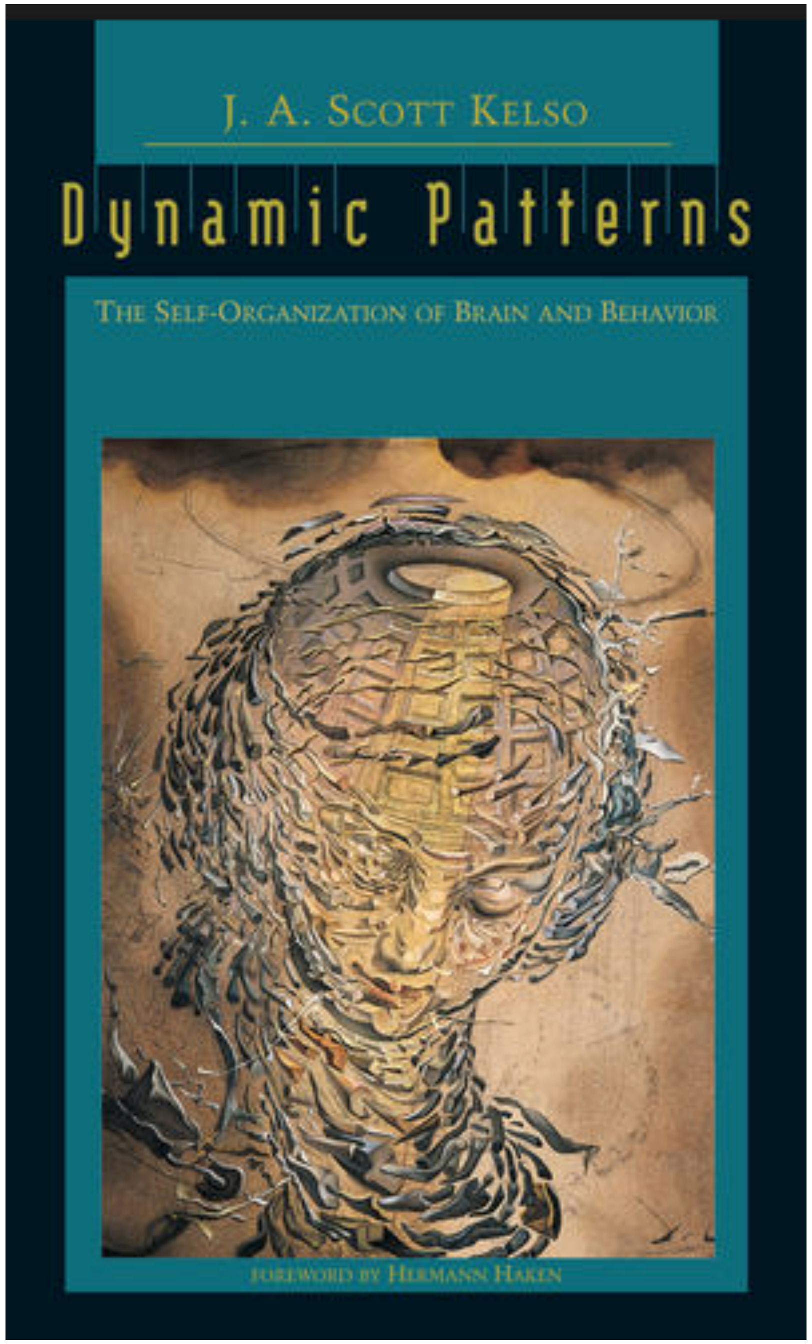


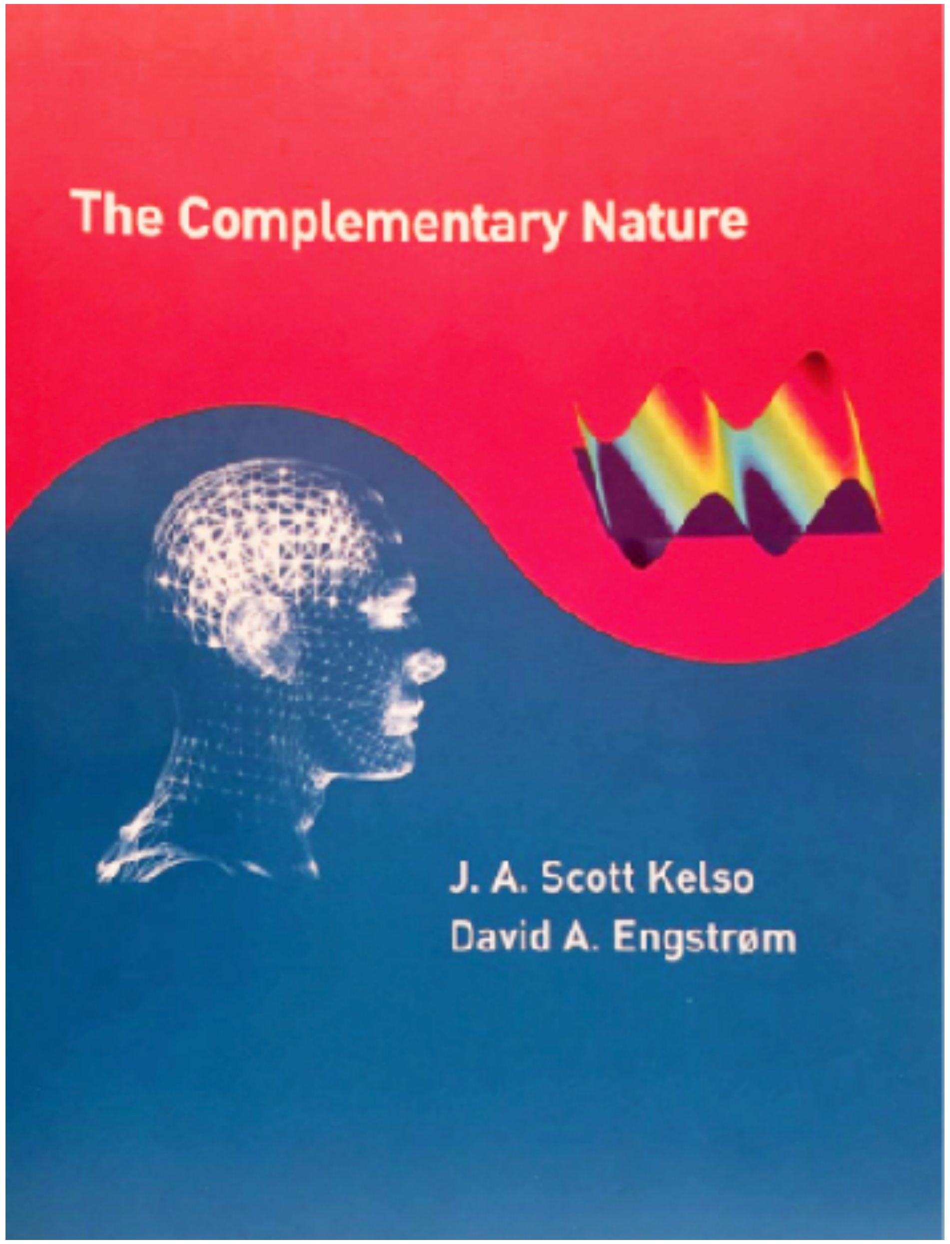
"Reber"	"Non-Reber"
BTSSXXTVVE	BTSSPXSE
BPVVE	BPTVVB
BTXXVPSE	BTXXVVSE
BPVPXVPXVPXVVE	BPVSPSE
BTSXXVPSE	BTSSSE

A more extensive worked example

Coordination Dynamics

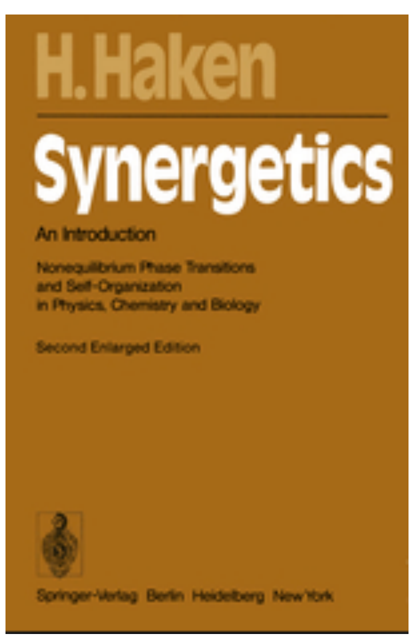
J. Scott Kelso





J. Scott Kelso

Many others



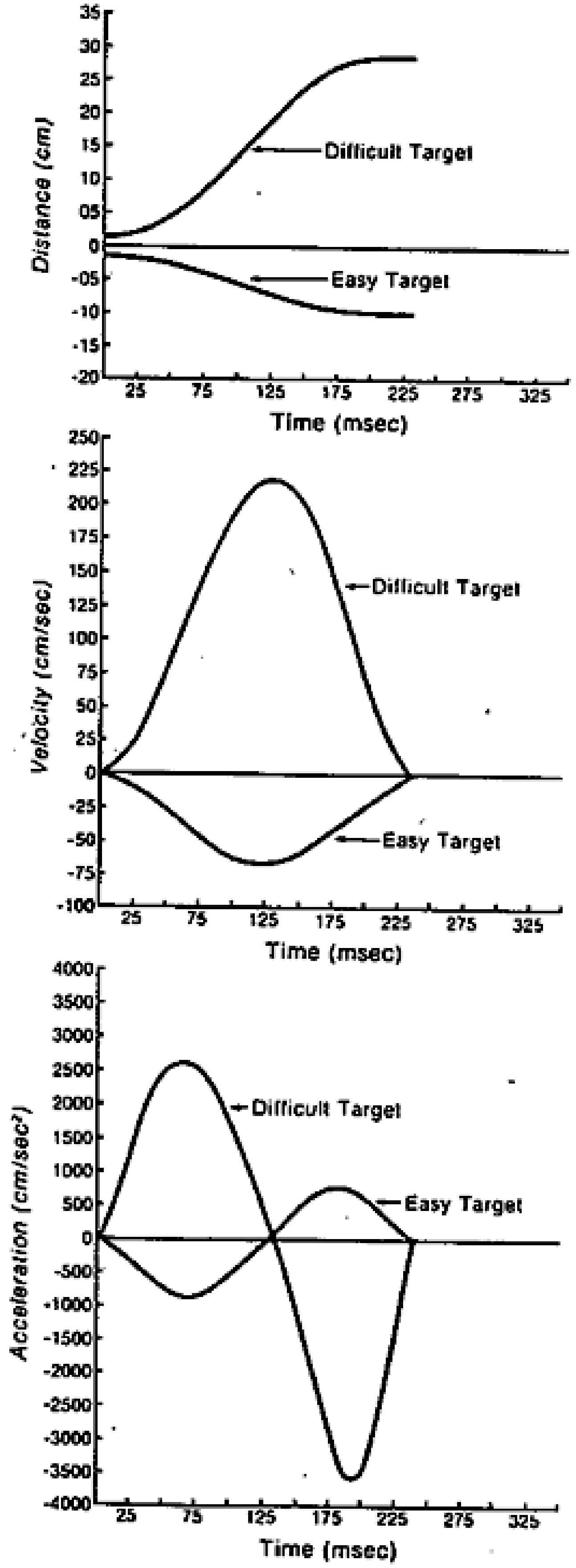
Herman Haken

Science, 1979: On the Nature of Human Interlimb Coordination (Scott Kelso)

Total Response Time	Movement Time	Reaction Time	Left Target	Home Keys	Right Target	Reaction Time	Movement Time	Total Response Time
				• •	1	218	159	377
371	151	220	2	• •				
287	82	205	4	• •				
				• •	3	218	78	296
308	89	219	6	• •	5	224	85	309
403	166	237	8	• •	7	240	169	409
393	155	238	10	• •	9	246	133	379
383	140	243	12	• •	11	240	158	398

Fig. 1. Mean reaction time, movement time, and total response times for single- and two-handed movements varying in amplitude and precision requirements.

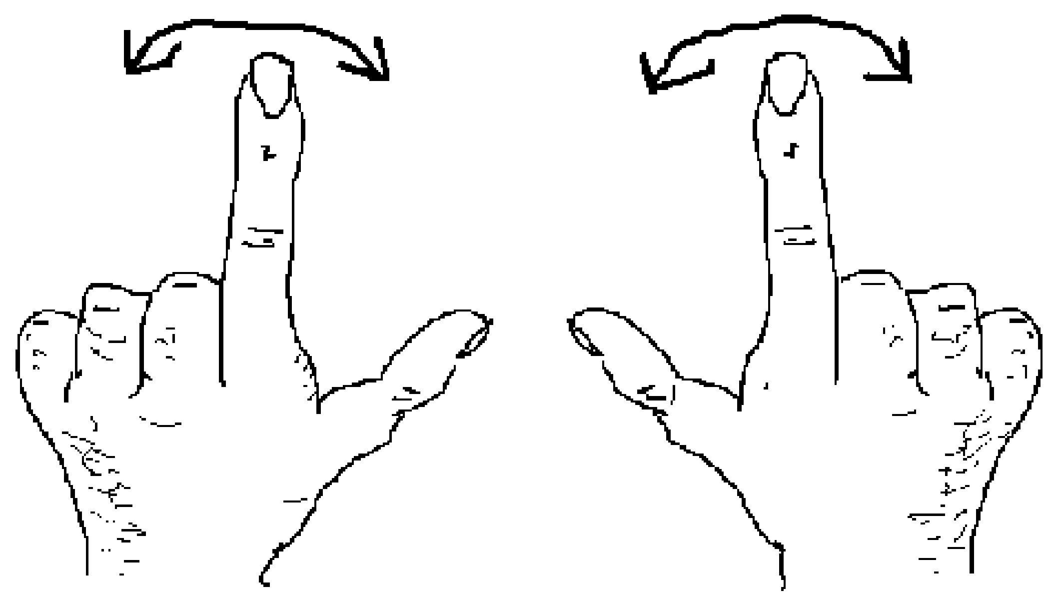
Each row corresponds to one experimental task. Subjects are asked to move, after a signal, from the midline to one or two targets.



..the brain produces simultaneity of action not by controlling each limb independently, but by **organizing** functional groupings of muscles that are **constrained** to act as a single unit

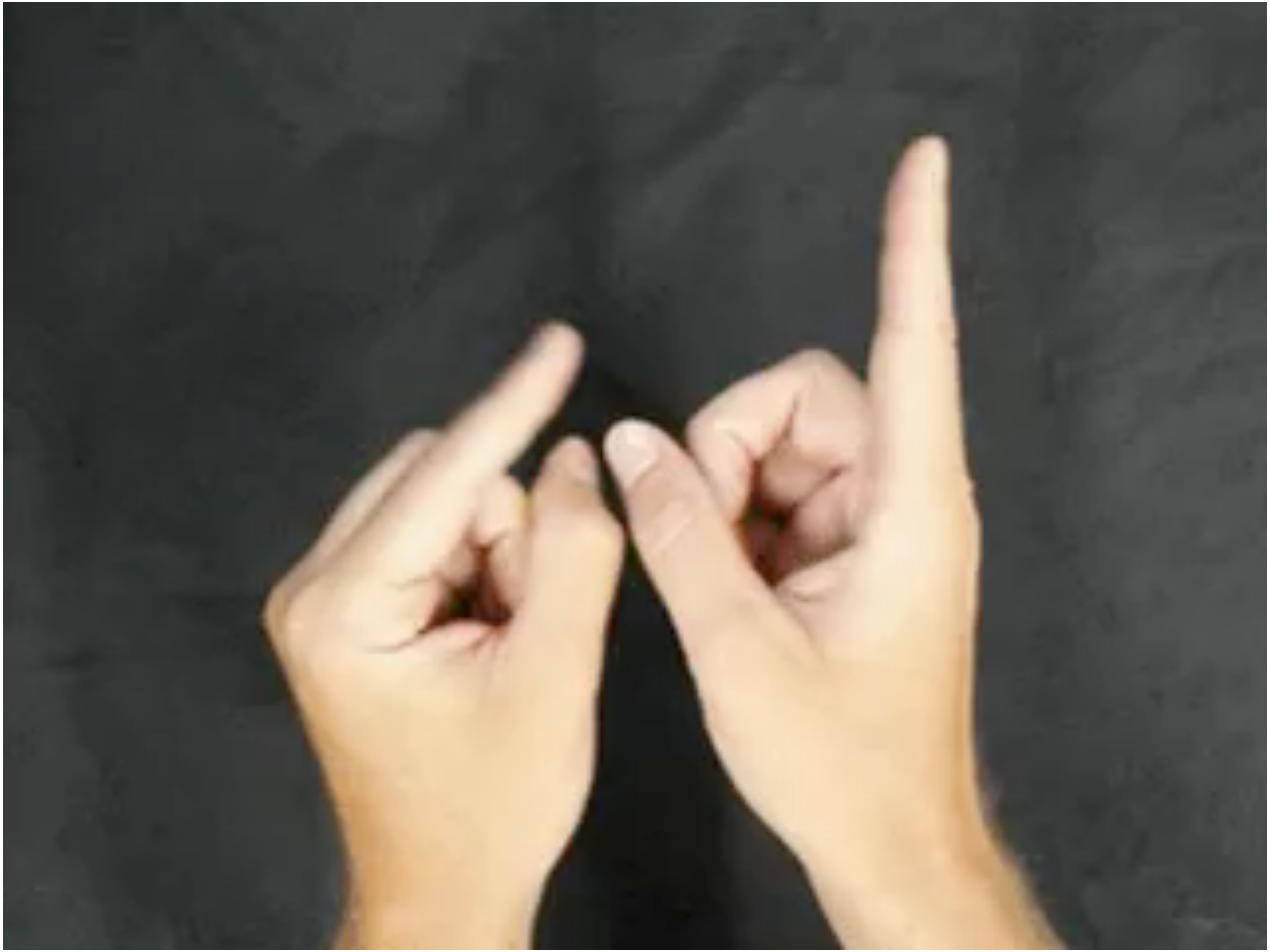
Coordination Dynamics: Scott Kelso and co-workers

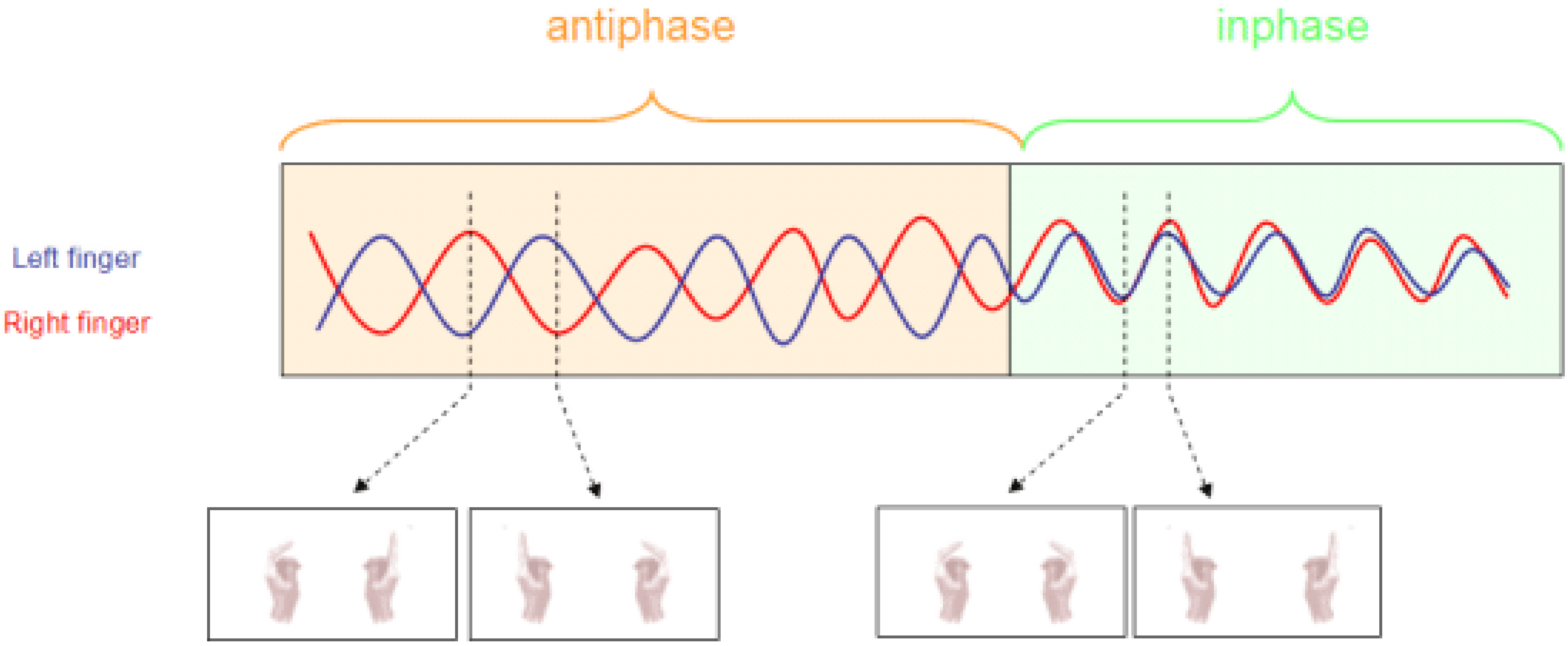
A **model system** for studying coordination



in phase

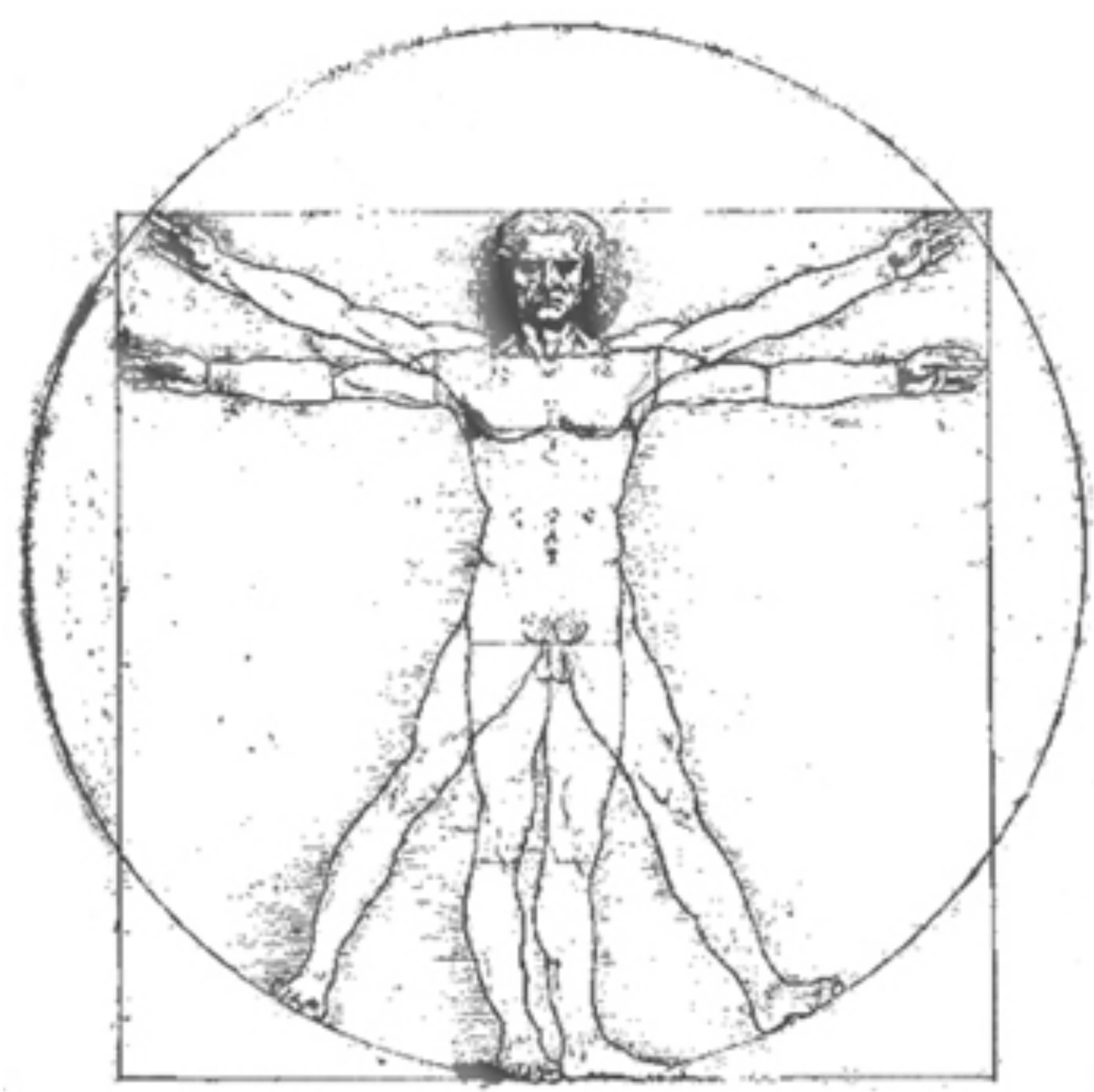
antiphase




antiphase
inphase
Left finger
Right finger

- Two stable modes at moderate speed: in phase, and anti-phase
- transition to a single mode (in phase) at fast rate
- No comparable transition as rate is reduced
- Increase in variability shortly before the transition (critical fluctuations)
- Model system for studying coordination

Notice how “in phase” and “anti-phase” have been defined with respect to the bilateral symmetry of the body.



The switch between patterns occurs when we start at a low frequency (anti-phase, say 1 Hz), and gradually speed up. Resisting the switch causes instability that destroys the coordination.

I confess I am still unsure about the relative importance of the use of homologous muscle groups vs orientation w.r.t. the body’s symmetry in defining these patterns.

What if the hands belonged to two people? Let’s try!

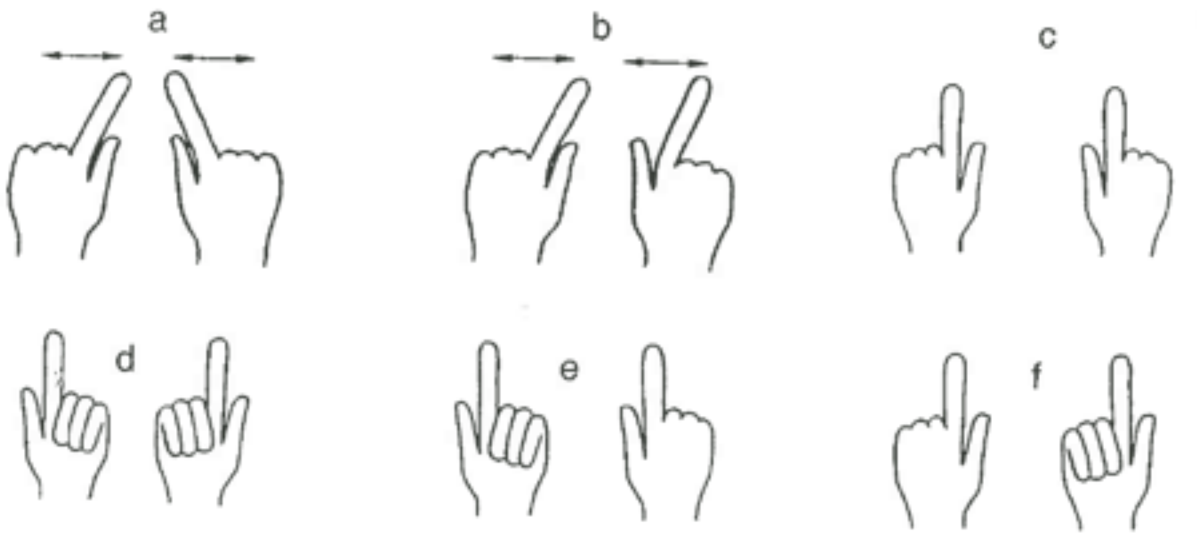


Fig. 1. Instructed synchronous finger oscillation patterns, and hand positions. a, Symmetrical movement. b, Parallel movement. c, d, Congruous positions with both palms up or both palms down. e, f, Incongruous positions with one palm up and the other palm down

Mechsner, F., & Prinz, W. (2003). What is coordinated in bimanual coordination?. *The Dynamical Systems Approach to Cognition: Concepts and Empirical Paradigms Based on Self-Organization, Embodiment, and Coordination Dynamics. Edited by TSCHACHER WOLFGANG & DAUWALDER JEAN-PIERRE. Published by World Scientific Publishing Co. Pte. Ltd., 2003. ISBN# 9789812564399, pp. 71-91*, 71-91.

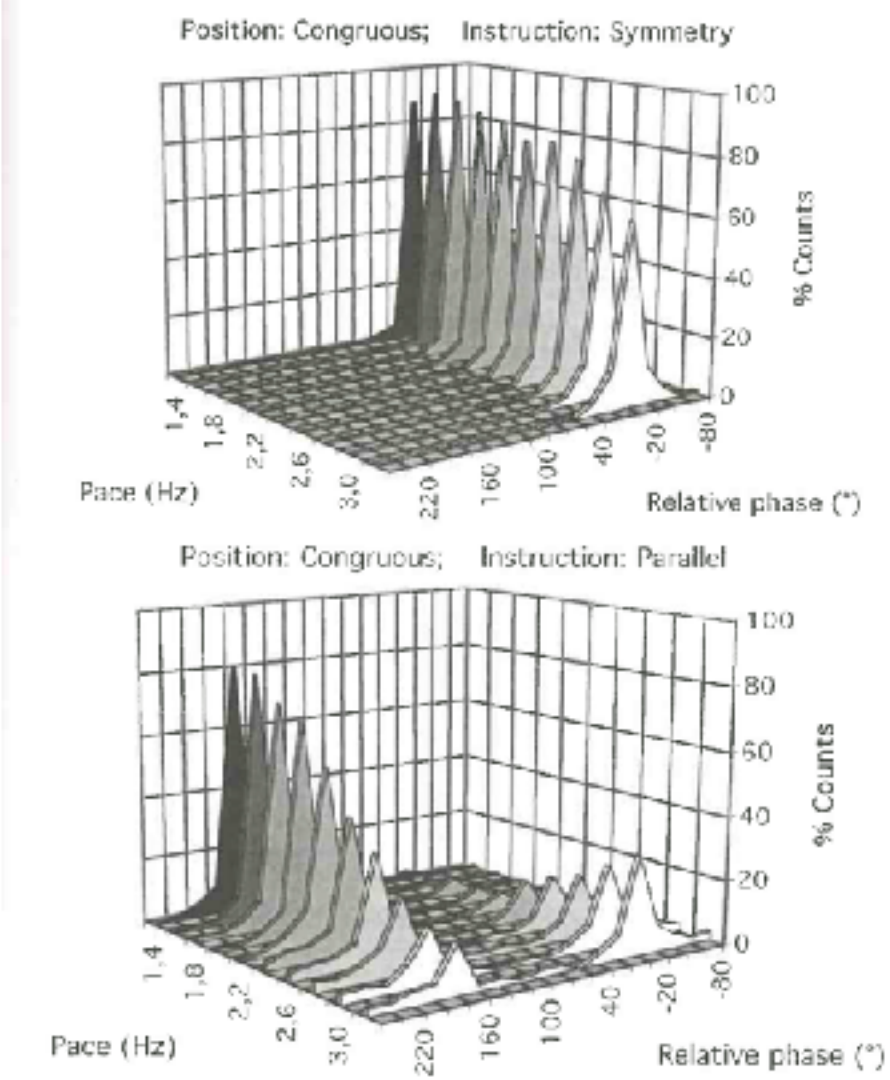
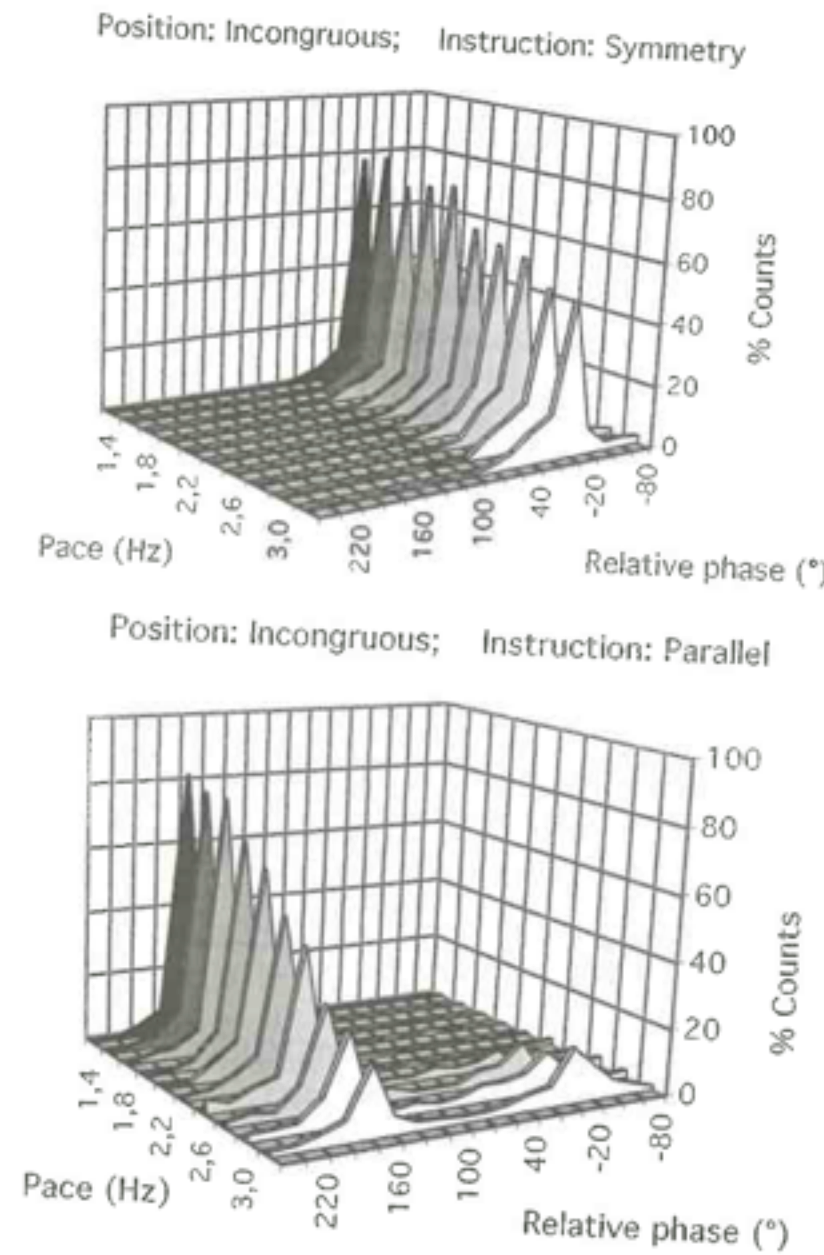
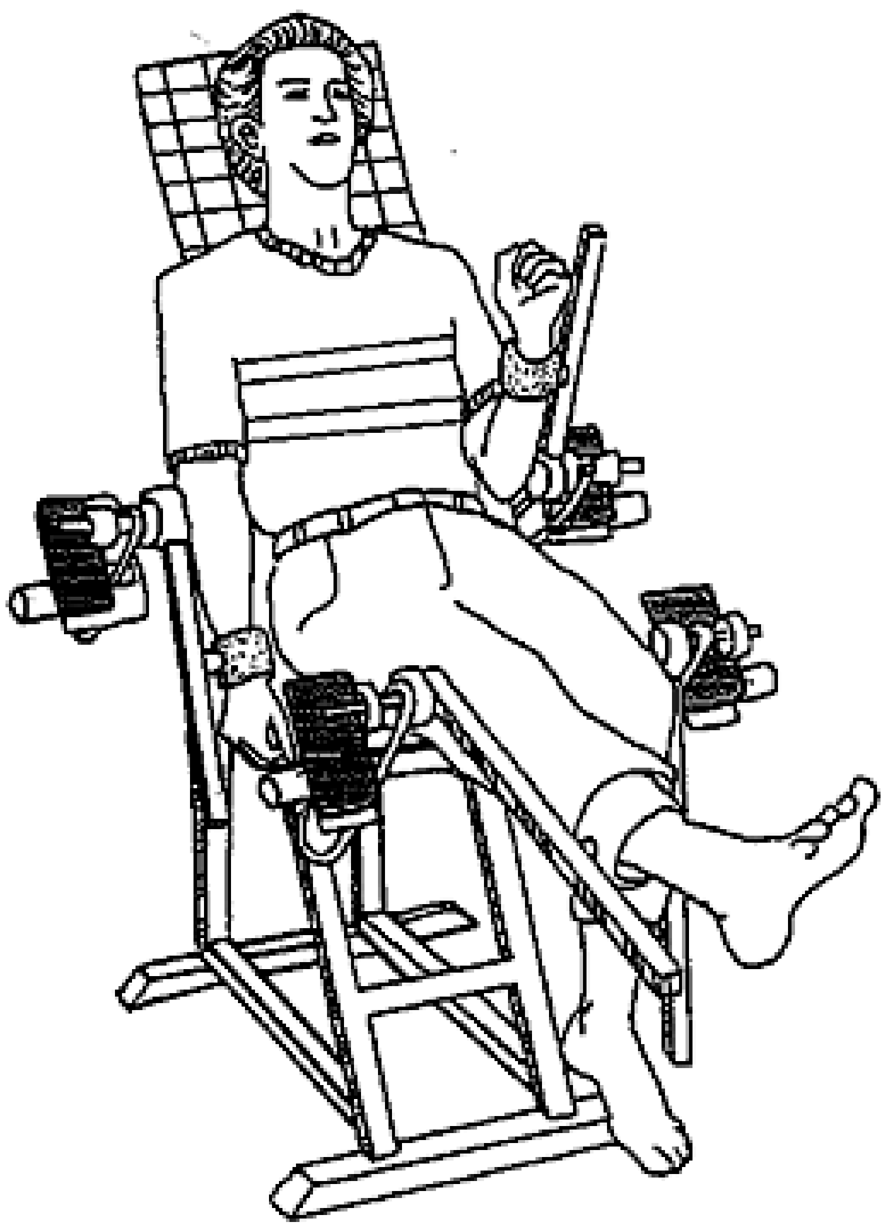
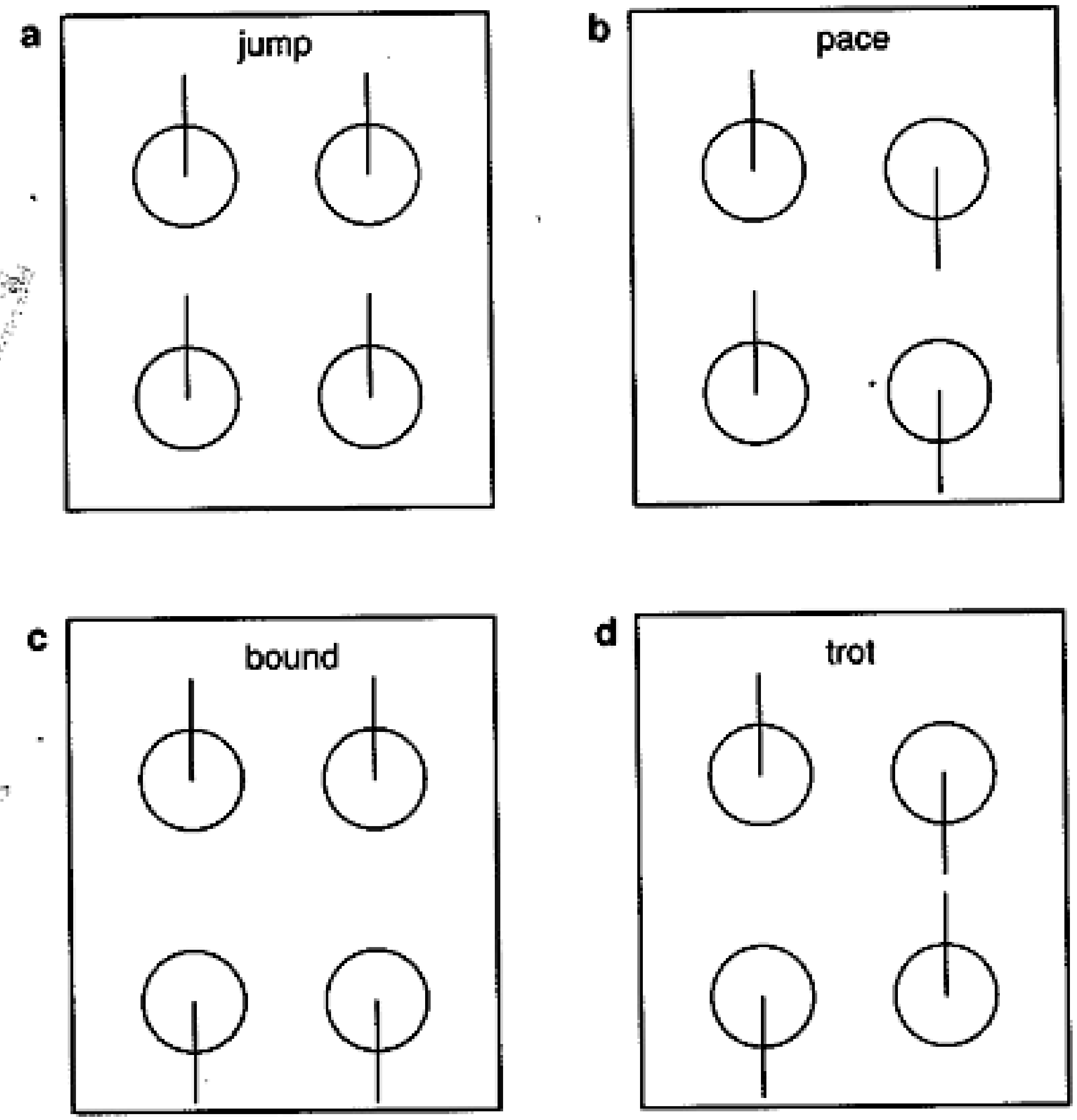
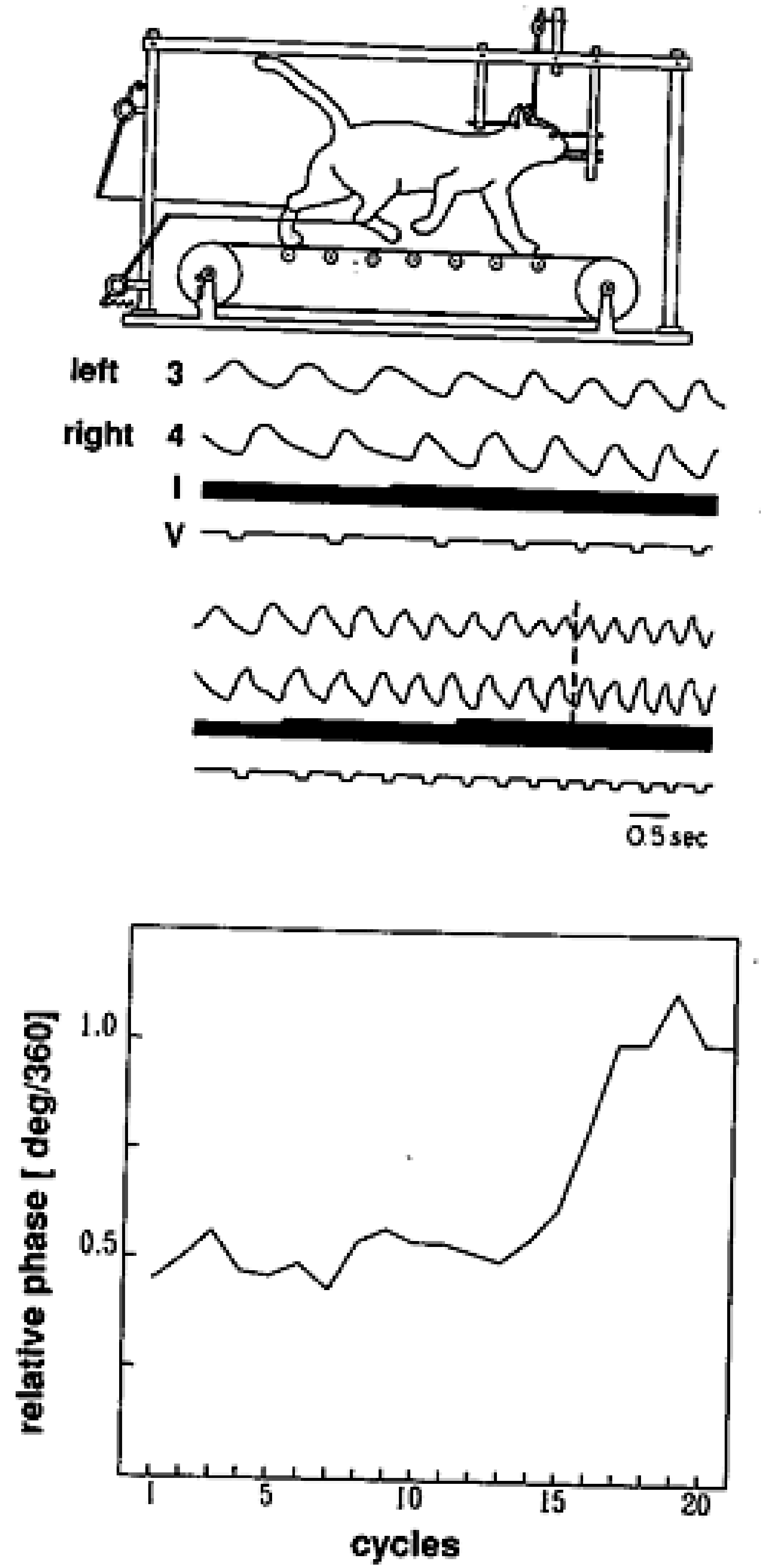


Fig. 2a,b. Histograms of relative phase of the fingertips, averaged across subjects in Experiment 1. a (top), Congruous hand positions & symmetrical movement instruction. b (bottom), Congruous hand positions & parallel movement instruction






a
jump
b
pace
c
bound
d
trot



By stimulating a single site in the mid-brain (mesencephalon), changes in walking speed were induced, leading to abrupt gait changes at critical velocities.

Haken, H., Kelso, J. S., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological cybernetics*, *51*(5), 347-356.

Modelling strategy:

(1) Model joint behaviour as a single system (1 d.o.f. total)

(2) Model each hand as an oscillator (2 d.o.f. each)

(3) Model coupling between hands to derive 2 from 1

Then consider extensions, refinements, etc.

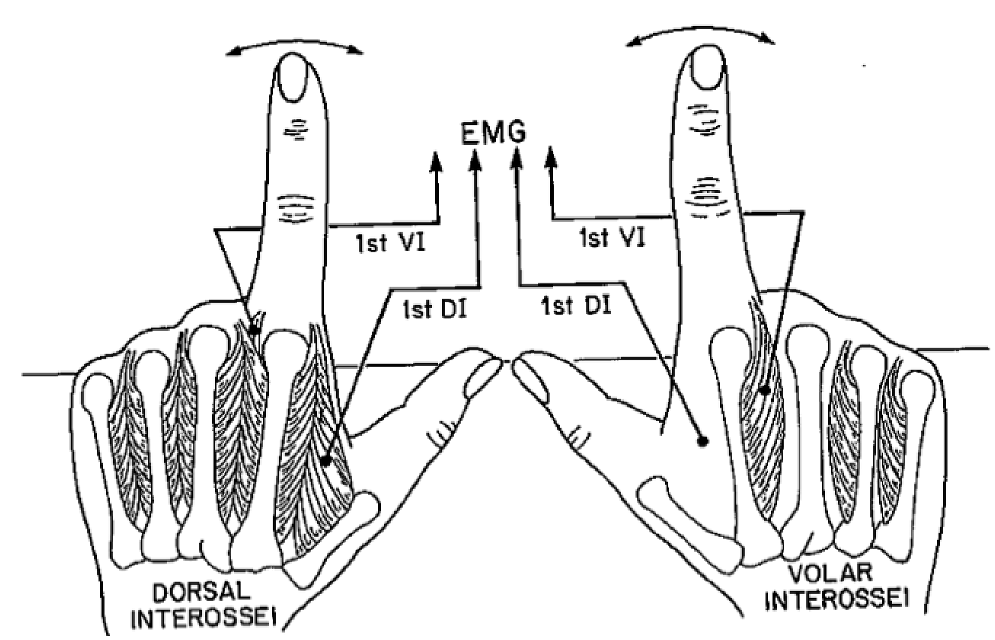
(1) Model joint behaviour as a single system

The state of the system is a single number: the relative phase i.e. phase if hand 1 - phase of hand 2

Kelso describes the state of the system using one number (ϕ), and the dynamic using a single *potential function, V.*

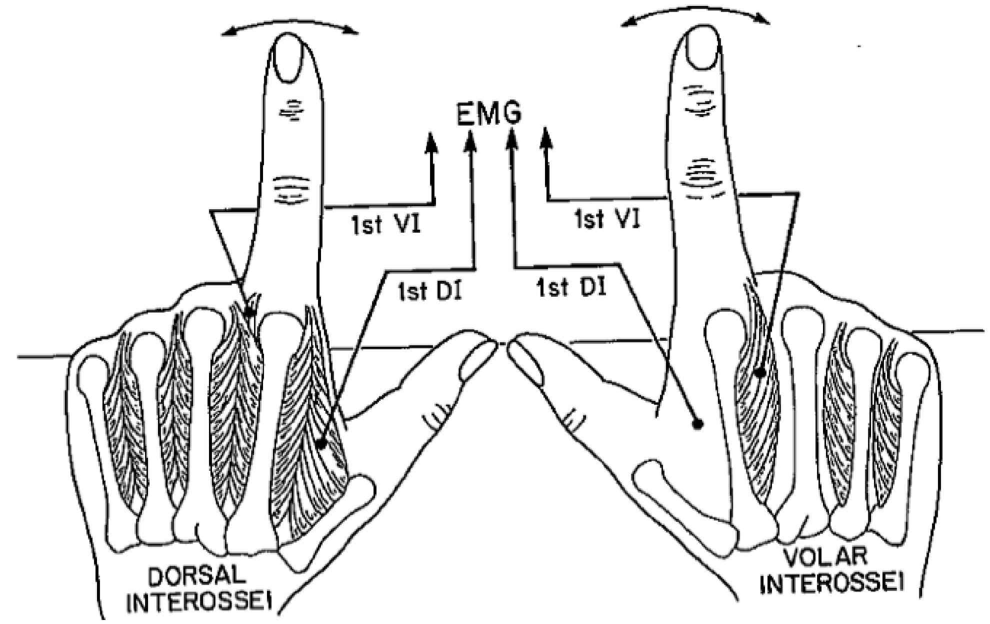
ϕ = *relative phase*

= *difference between 2 phases*



ϕ = relative phase

= difference between 2 phases



Relative phase is an appropriate number for succinctly capturing the overall state of the system. Such a term may be called a *collective variable* or (confusingly) an *order parameter*.

The state space is one dimensional. Over that we define a *potential function*, with minima at the desired places. The dynamic is then the (negative) slope of this potential function.

$$
\begin{aligned}
V(\phi + 2\pi) &= v(\phi) \\
V(\phi) &= V(-\phi)
\end{aligned}
$$

$$
\begin{aligned}
V(\phi) &= -a\cos\phi - b\cos 2\phi \\
\frac{d\phi}{dt} &= -\frac{dV(\phi)}{d\phi} \\
&= -a\sin\phi - 2b\sin 2\phi
\end{aligned}
$$

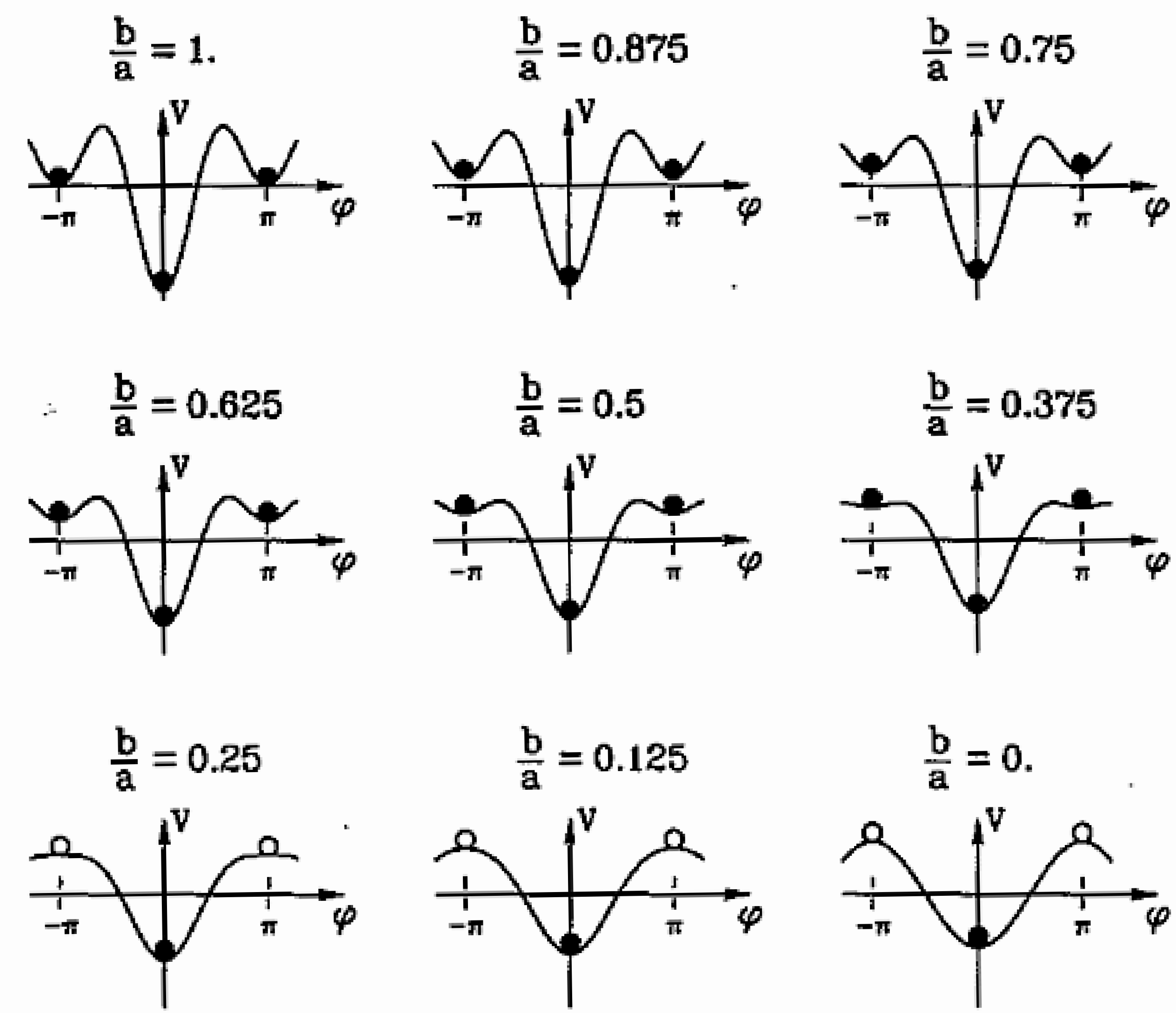


Figure 2.7 The HKB model of coordination. The potential, $V(\phi)$, as the ratio b/a is changed. The little ball illustrates the behavior of the system initially prepared (upper left corner) in the antiphase state. White balls are unstable coordinative states; black balls are stable.

(2) Model each hand as an oscillator (2 d.o.f. each)

Data was obtained looking at how the amplitude of osciallation varies with rate for a real hand.

This required constructing a hybrid form combining two well-known simple oscillators. The hybrid form matched the hand data.

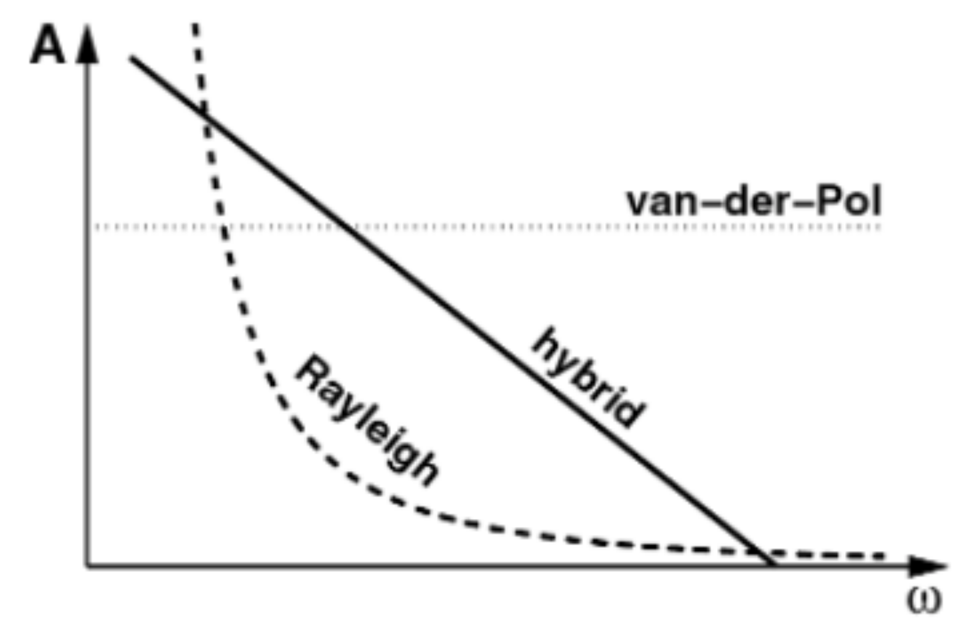
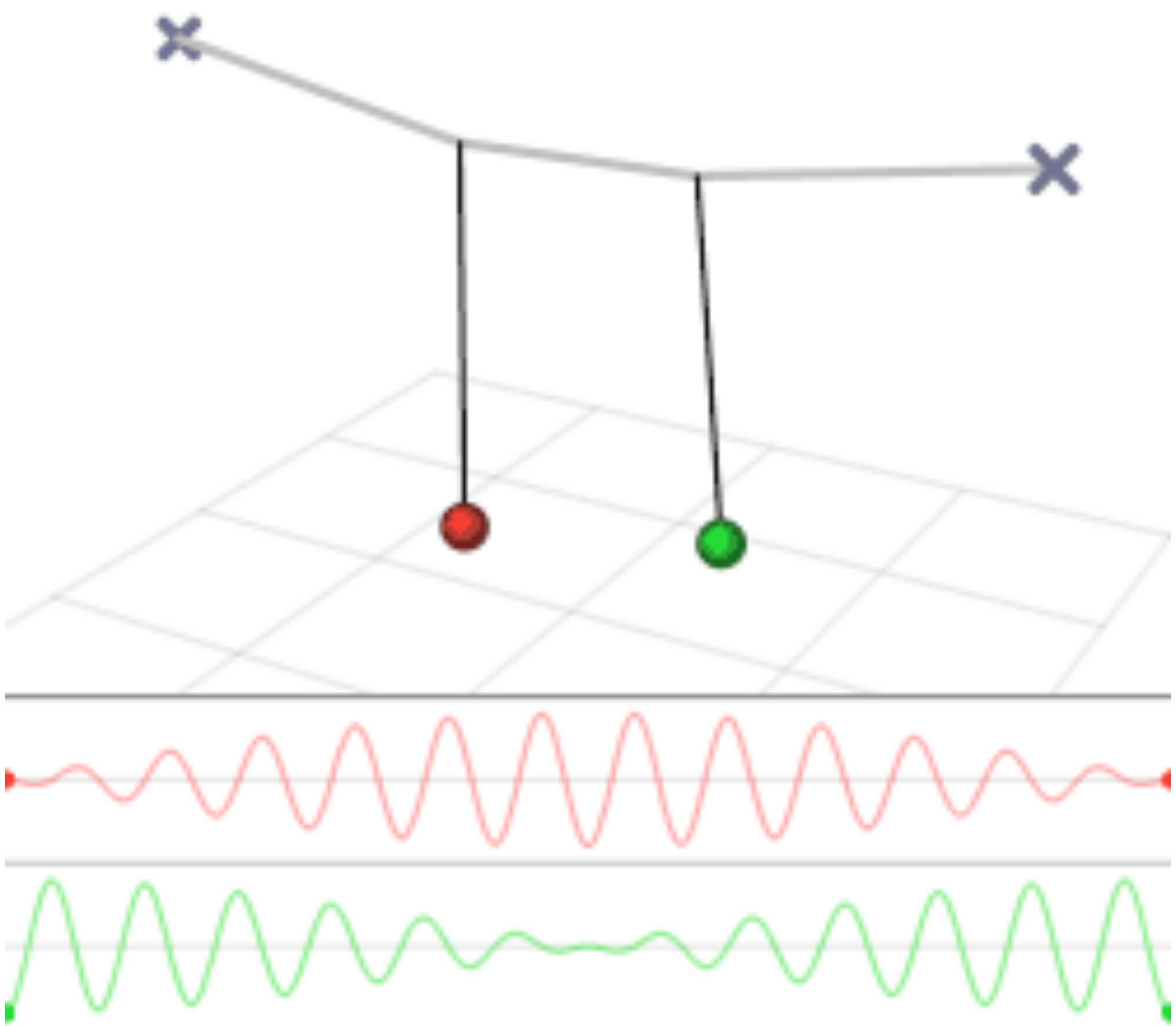


Fig. 28 Amplitude-frequency relation for the van-der-Pol (dotted), Rayleigh ($\sim \omega^{-2}$, dashed) and hybrid ($\sim -\omega$, solid) oscillator.

The details of the coupling matter.

2 coupled oscillators



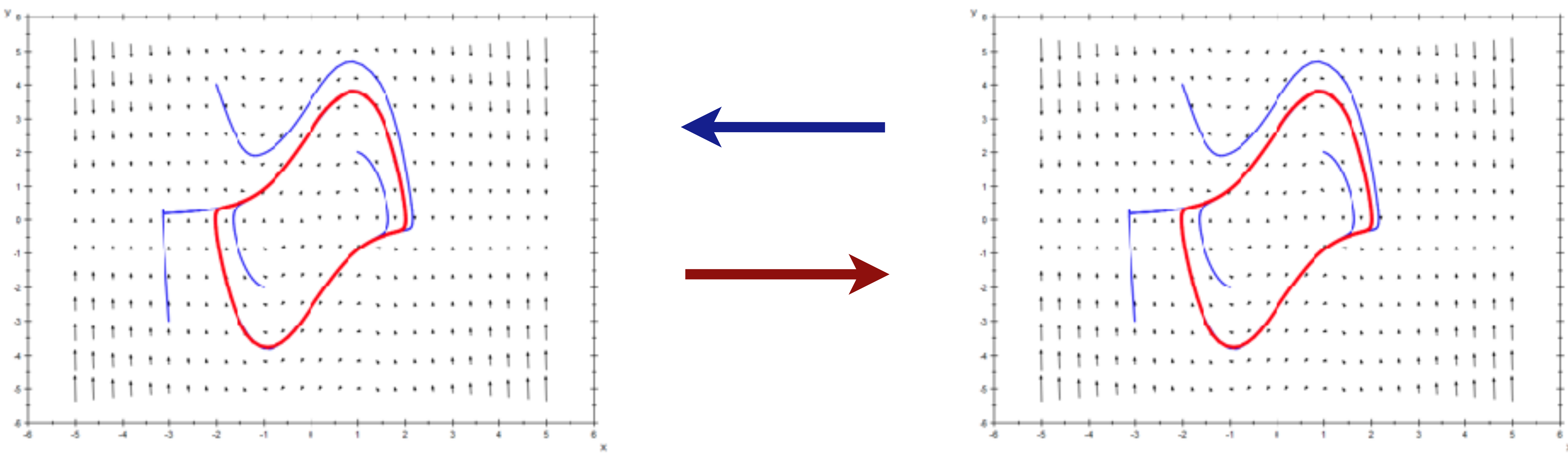
Each oscillator has its own behaviour

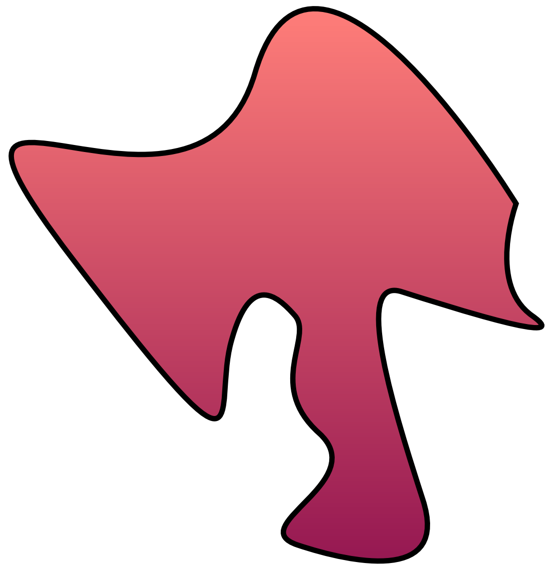
but in their interaction, everything is different!

The 2-hand system is an emergent pattern arising when two hands are coupled.

Each hand is an oscillator in its own right.

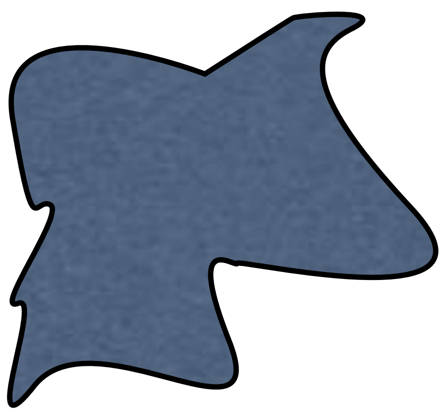
. . . and they are coupled.





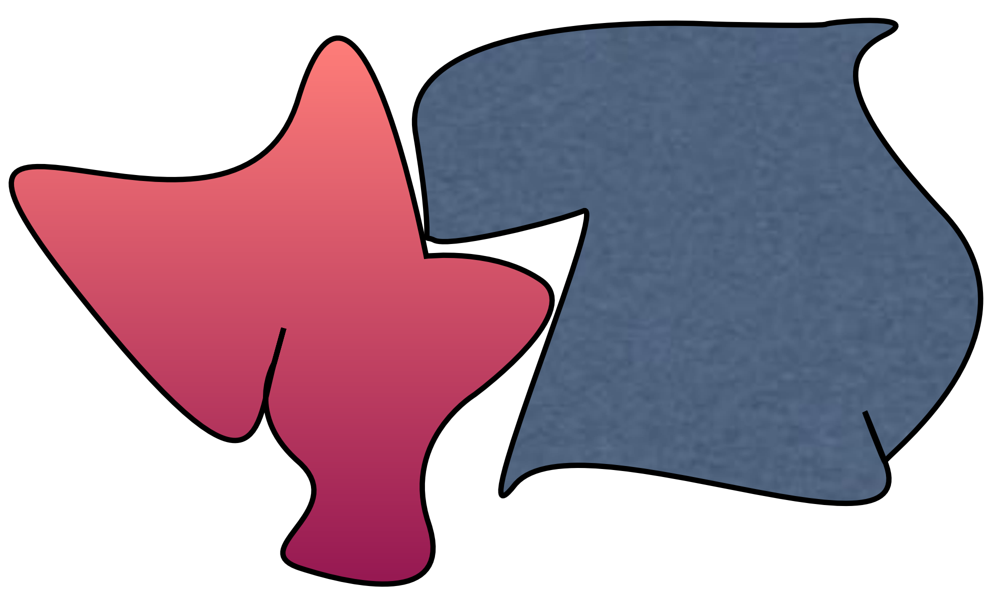
System 1

$$\ddot{x}_1 - f(x_1, \dot{x}_1) = 0$$



System 2

$$\ddot{x}_2 - f(x_2, \dot{x}_2) = 0$$



System 1 * System 2

$$\ddot{x}_1 - f(x_1, \dot{x}_1) = g(x_1, \dot{x}_1, x_2, \dot{x}_2)$$
$$\ddot{x}_2 - f(x_2, \dot{x}_2) = g(x_2, \dot{x}_2, x_1, \dot{x}_1)$$

(3) Model coupling between hands to derive 2 from 1

This is the mathematical work of the Haken-Kelso-Bunz paper from 1985. The maths is non-trivial.😮

$$\ddot{x}_1 - f(x_1, \dot{x}_1) = g(x_1, \dot{x}_1, x_2, \dot{x}_2)$$
$$\ddot{x}_2 - f(x_2, \dot{x}_2) = g(x_2, \dot{x}_2, x_1, \dot{x}_1)$$

$$V(\phi) = -a\cos(\phi) - b\cos(2\phi)$$

This can only work if we have captured the basic characteristics of the oscillators and their coupling

Extensions

Journal of Experimental Psychology:
Human Perception and Performance
1990, Vol. 16, No. 2, 227–247

0096-1523/90/$00.75

Phase Transitions and Critical Fluctuations in the Visual Coordination of Rhythmic Movements Between People

R. C. Schmidt, Claudia Carello, and M. T. Turvey
Center for the Ecological Study of Perception and Action, University of Connecticut, Storrs,
and Haskins Laboratories, New Haven, Connecticut

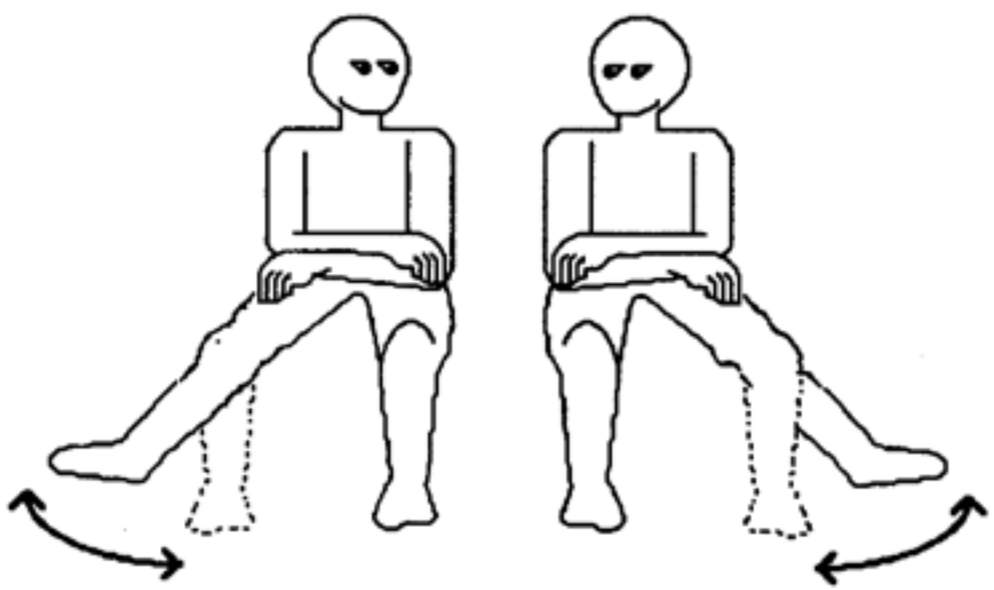


Figure 1. Seating arrangement of the subjects for the experiments.

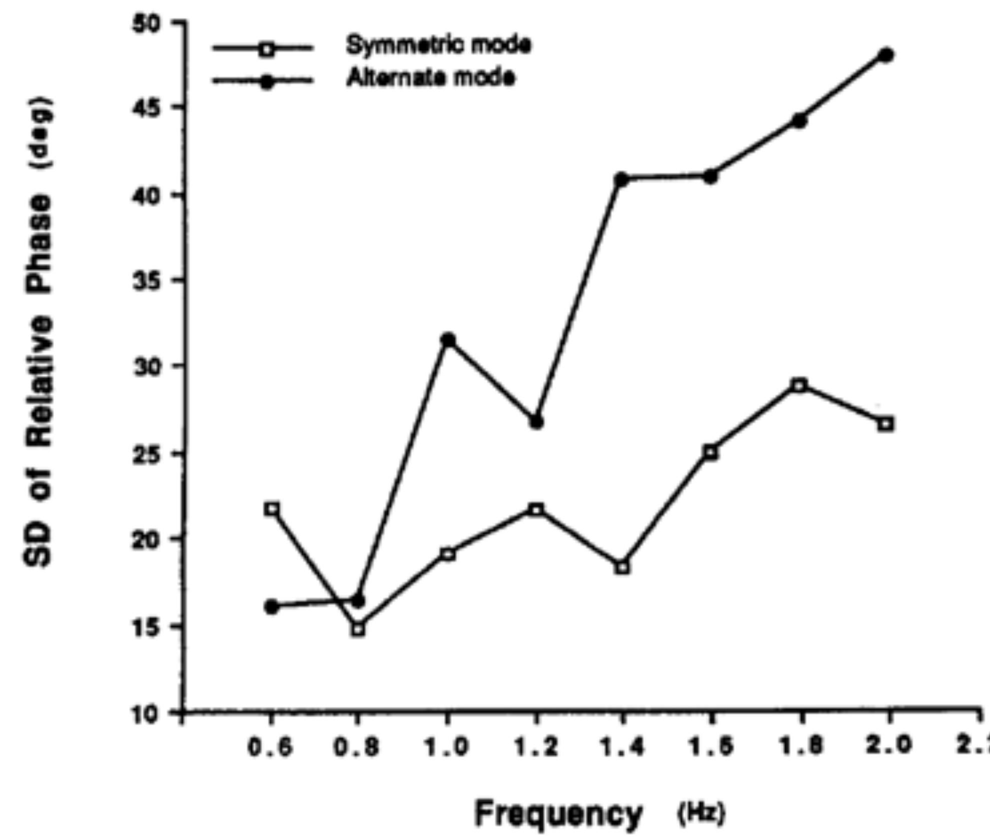


Figure 2. Standard deviation of relative phase at each frequency of the pacing metronome for the two phase modes, symmetric and alternate, in Experiment 1. (Open squares are symmetric mode; closed circles are alternate mode.)

Connectionism/Dynamics 2017

Schmidt, Carello, Turvey: Social coordination

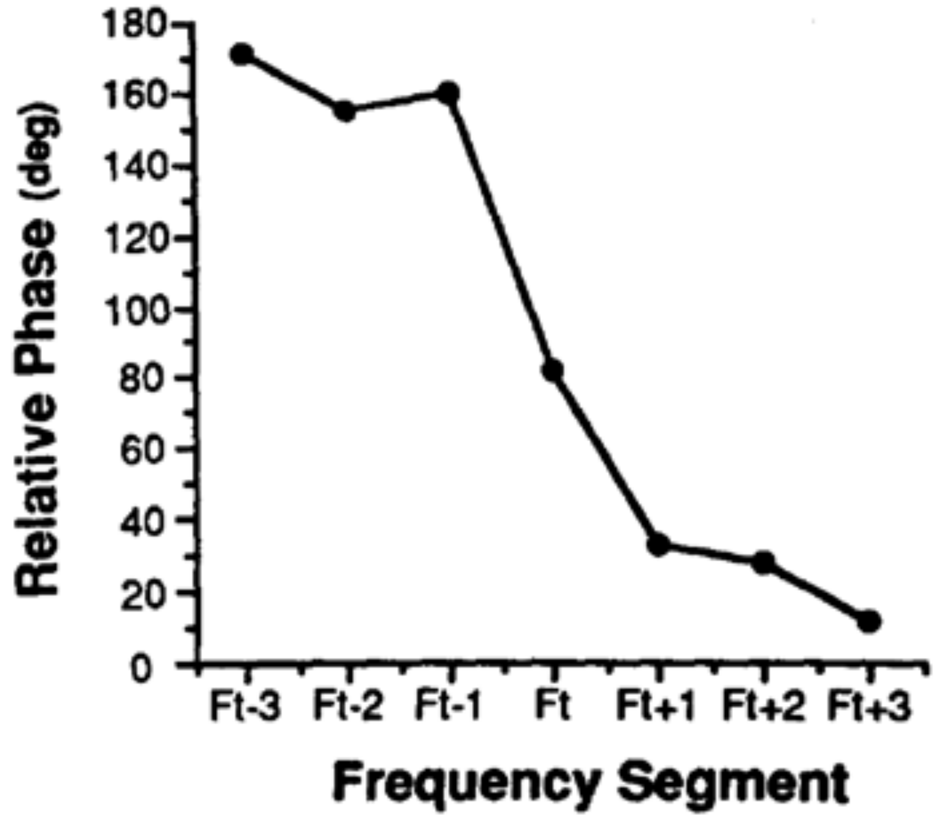
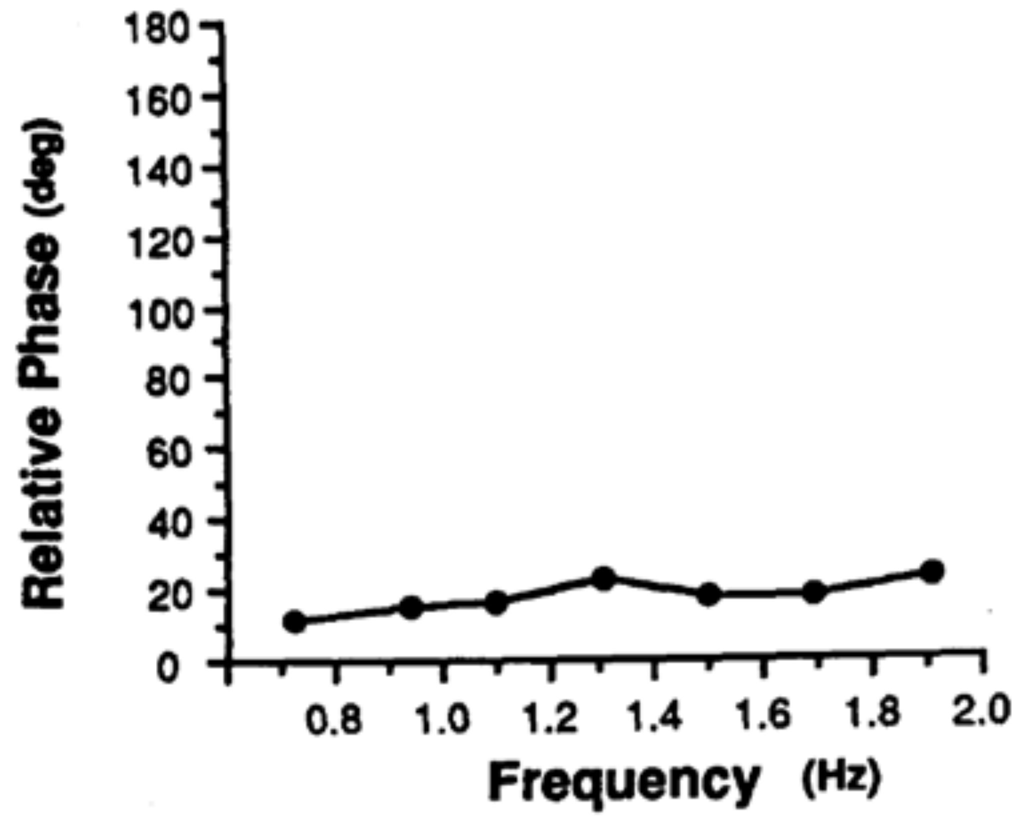
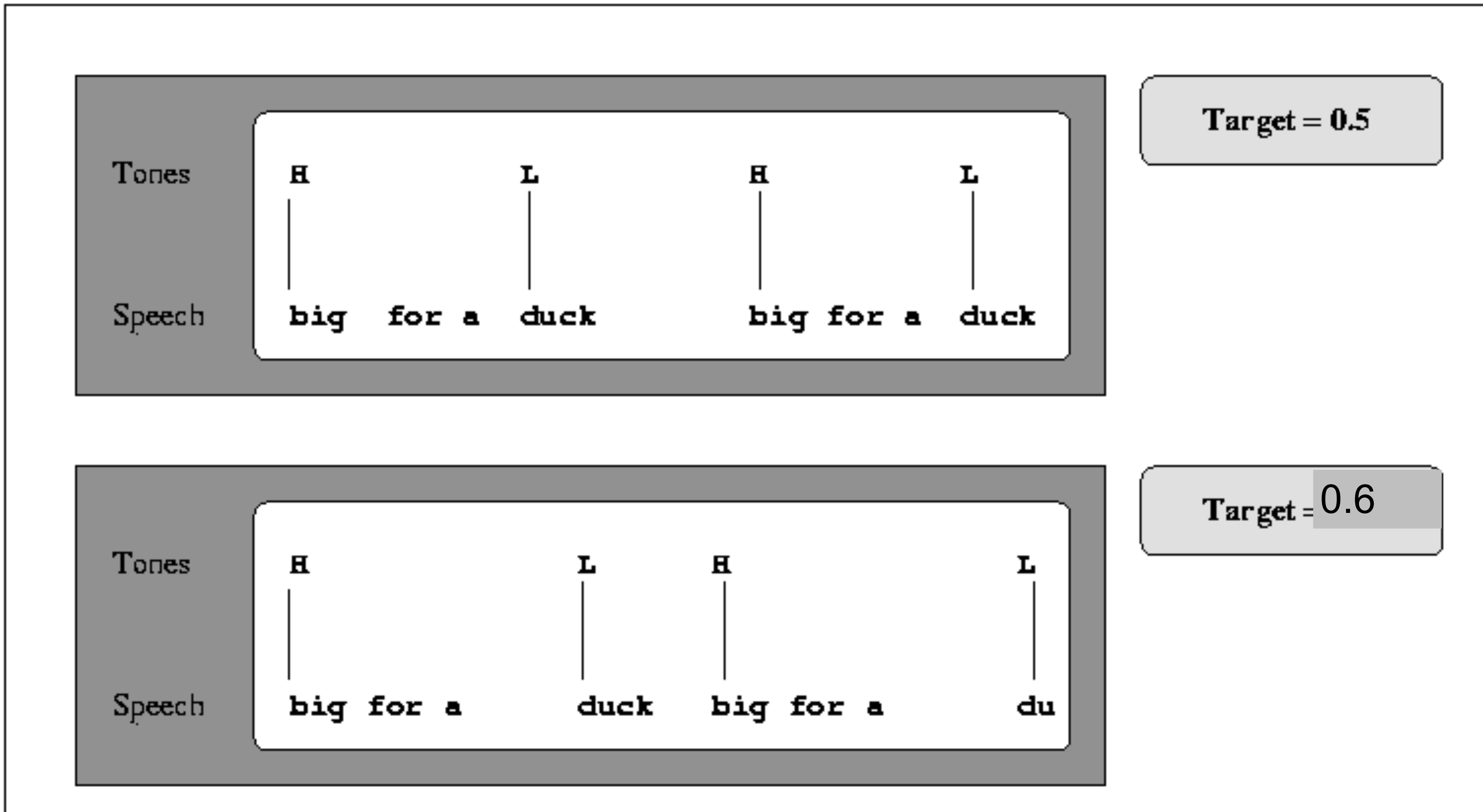


Figure 8. Relative phase as a function of mean frequency for each frequency segment in the symmetric mode (upper panel); relative phase as a function of frequency scaled relative to the transition frequency for the alternate mode (lower panel).

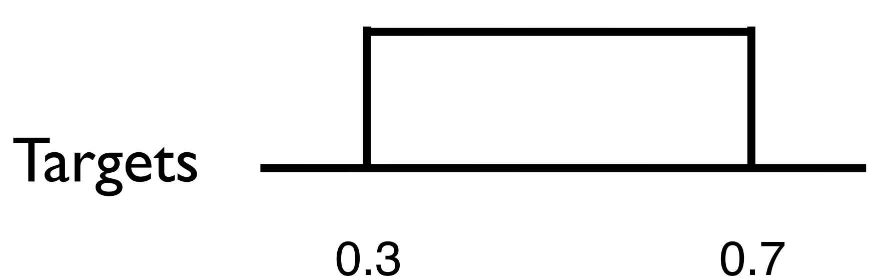


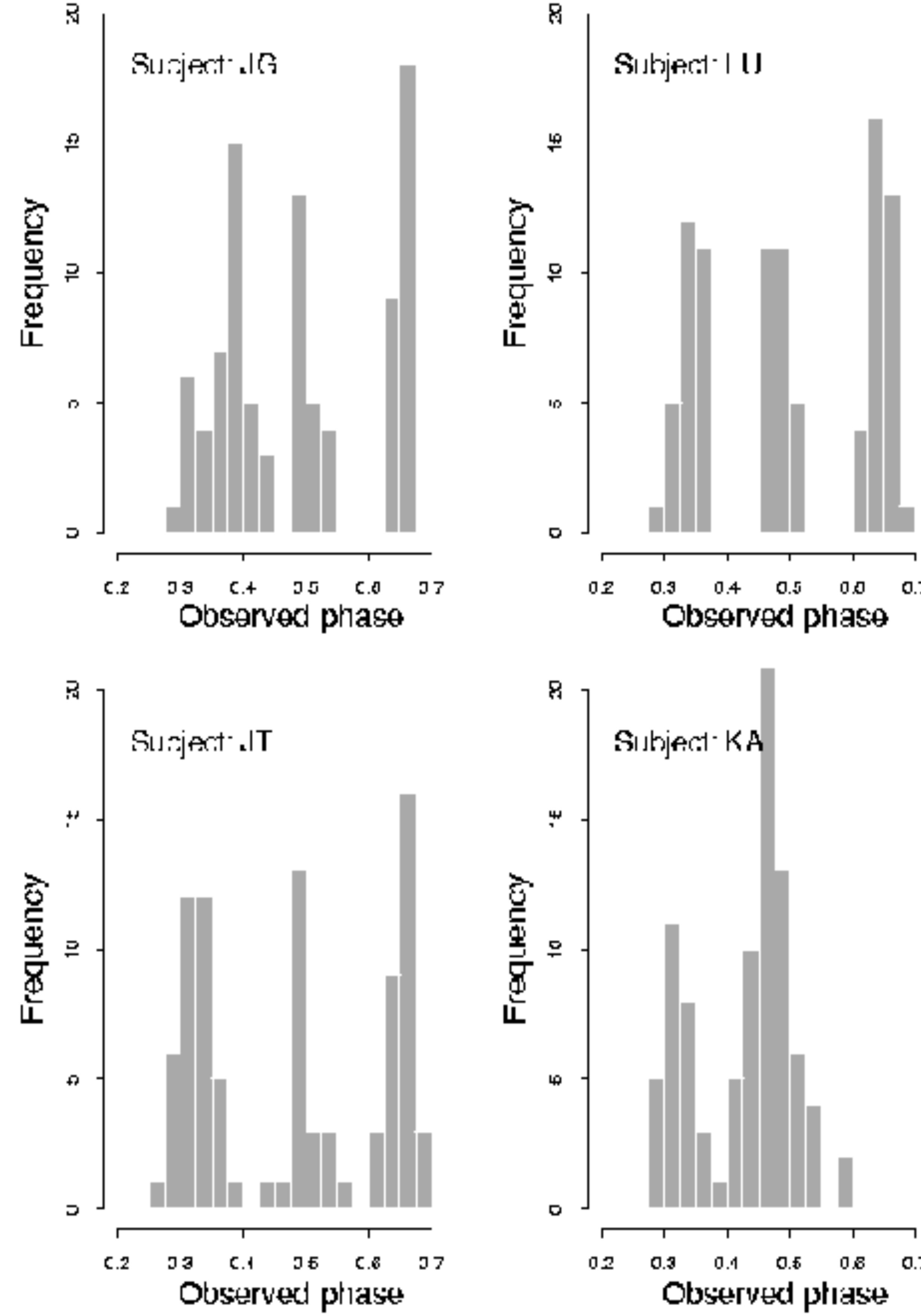
Speech Cycling

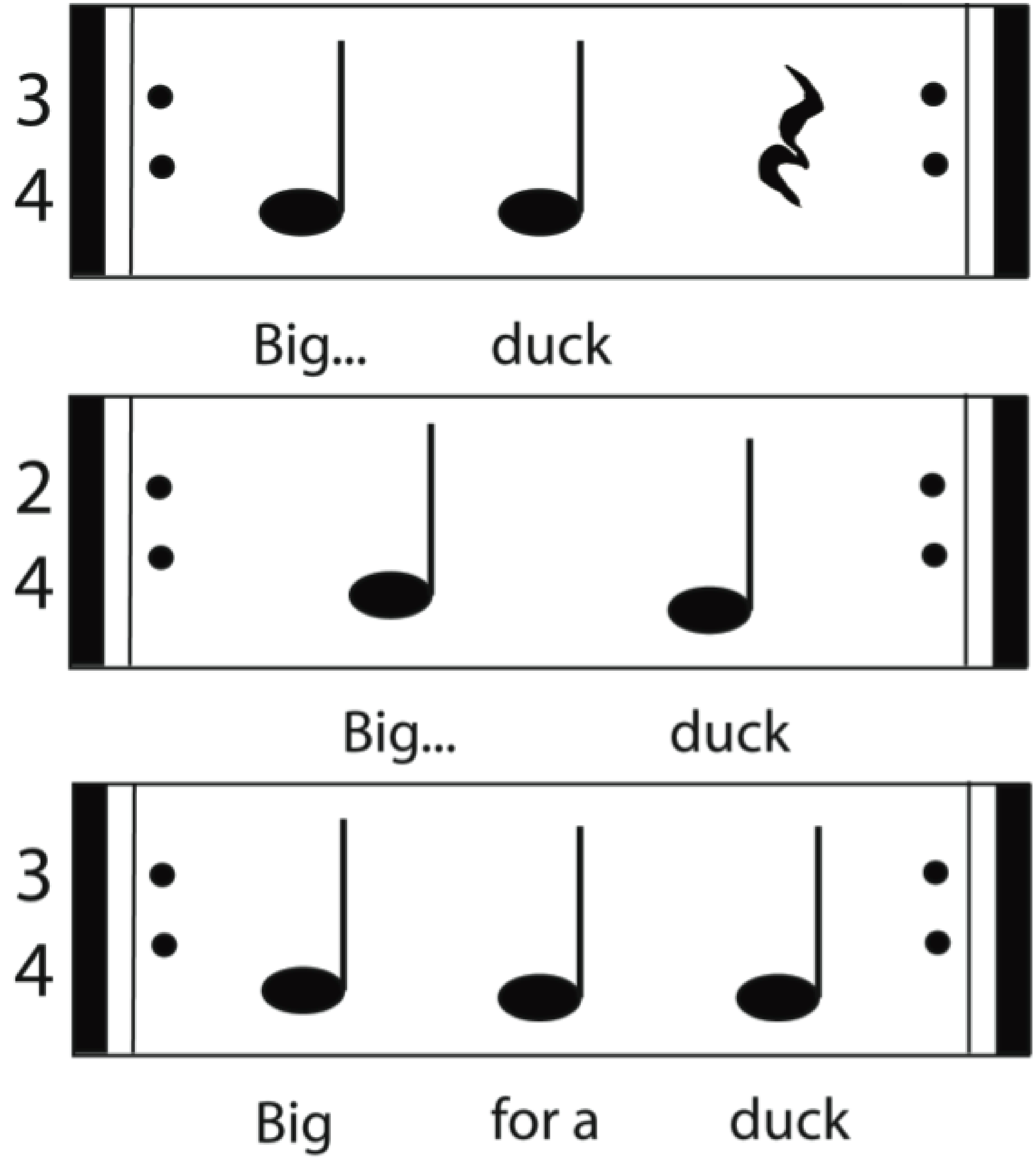
Work done with Robert Port and Keiichi Tajima (Indiana University)


Tones
H
L
H
L
Speech
big for a duck big for a duck
Target = 0.5
Tones
H
L
H
L
Speech
big for a duck big for a du
Target = 0.6

- There are 3 and only 3 stable production forms
- Phases are 1/3, 1/2 and 2/3
- Not all subjects discover the 2/3 pattern (nonce stress)
- Results implicate hierarchically organized, low-dimensional dynamical systems in production
- Consistent in kind with limb results



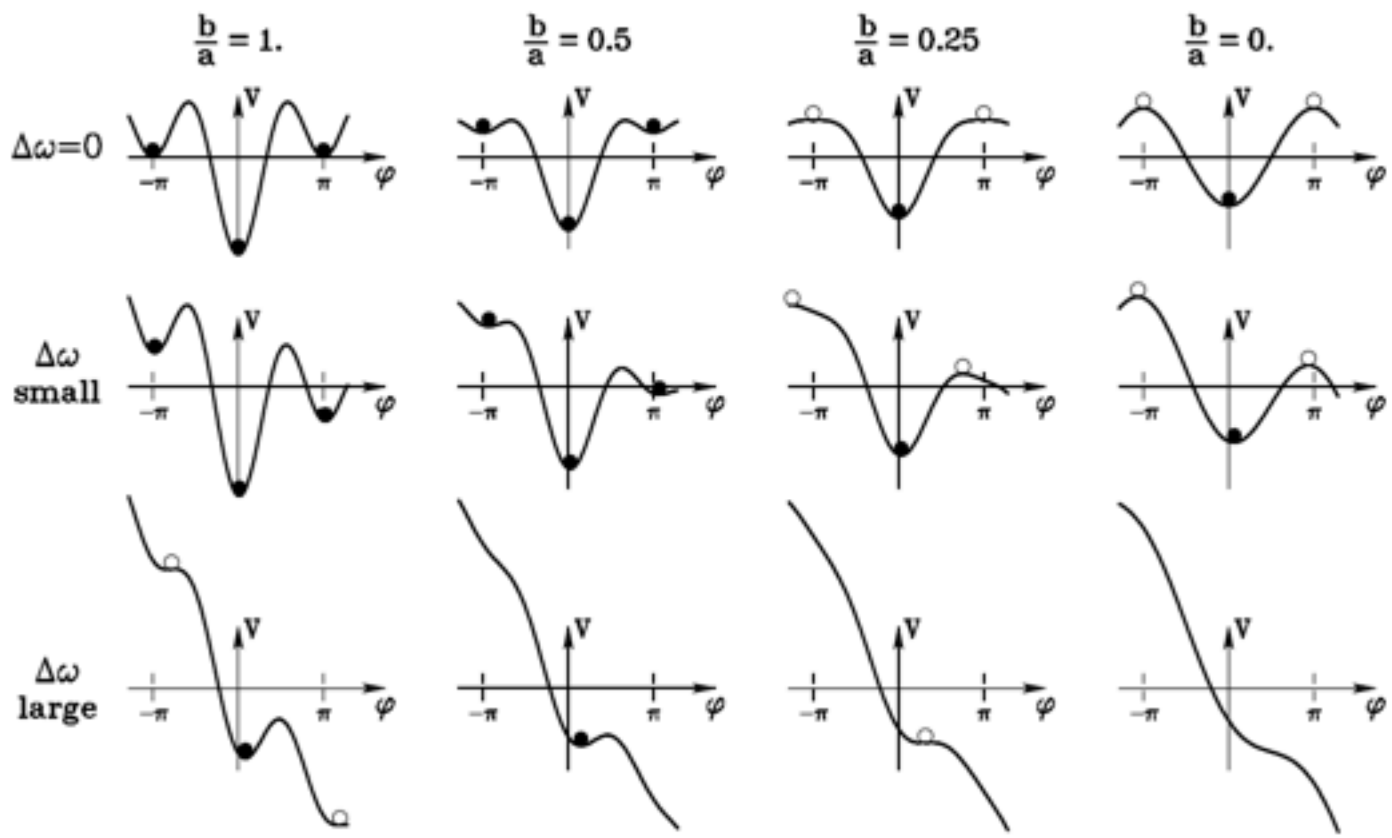



3
4
Big...
duck
2
4
Big...
duck
3
4
Big
for a
duck

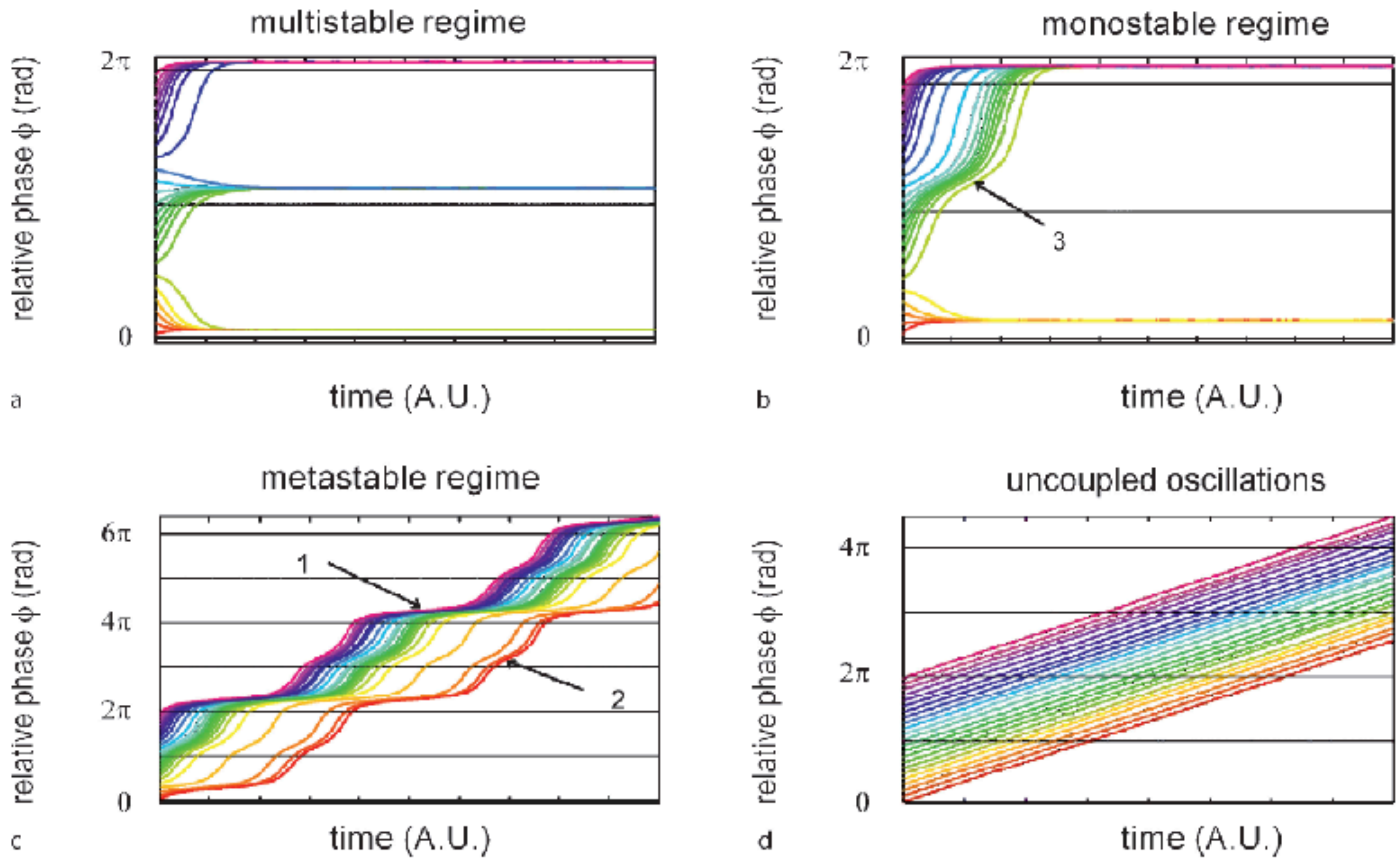
Kelso: mismatched oscillators

What if the two effectors are mismatched, with different eigenfrequencies?

$$\dot{\phi} = \Delta\omega - a \sin\phi - 2b \sin 2\phi \qquad \text{with} \qquad \Delta\omega = \frac{\omega_1^2 - \omega_2^2}{\Omega} \approx \omega_1 - \omega_2$$



$$V(\varphi) = -\Delta\omega\, \varphi - a \cos\varphi - b \cos 2\varphi$$



Coordination Dynamics, Figure 5

How the key coordination variable or order parameter of the elementary coordination law (Eq. (5)) behaves over time. Shown is a family of trajectories of the relative phase ϕ over time (in Arbitrary Units) arising from a range of initial conditions sampled between 0 and 2π radians, in the multistable (a), monostable (b) and metastable régimes (c) of Eq. (5). For the uncoupled case (d) the trajectories never converge indicating that the oscillations are completely independent of each other. Trajectories in the multistable régime (a) converge either to an attractor located slightly above $\phi = 0$ rad modulo 2π or to another attractor located slightly above $\phi = \pi$ rad modulo 2π. In the monostable régime (b), trajectories converge to an attractor located slightly above $\phi = 0$ rad modulo 2π. In the trajectories of relative phase for the metastable régime (c unwrapped to convey continuity), there is no longer any persisting convergence to the attractors, but rather a succession of periods of rapid drift (*escapes*) interspersed with periods inflecting toward, but not remaining on the horizontal (*dwells*). Note dwells near $\phi = 0$ rad modulo 2π in the metastable régime (e.g. dwell at about 4π rad annotated 1 in c) and nearby $\phi = \pi$ rad modulo 2π (dwell at about 3π rad annotated 2 in c) are reminiscent of the transient obtained for certain initial conditions in the monostable régime (Fig. 5b, annotation 3). The key point is that in the metastable régime the system's behavior is a blend of coupled and independent behavior

Investigating the displacement of the stable equilibria with weighted pendula

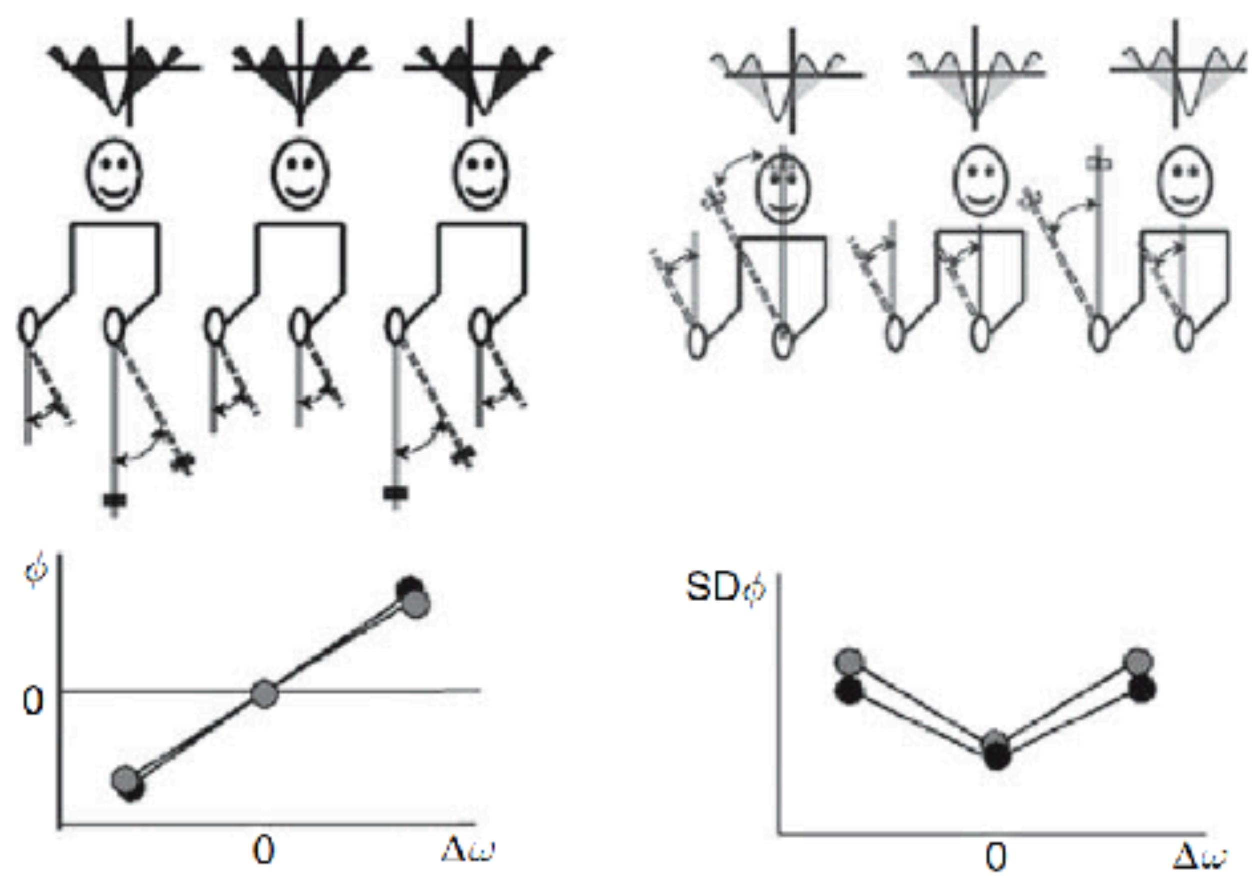


Fig. 3. Effect of $\delta = \Delta\omega$ on the coordination equilibria for coupled ordinary (*black*) and vertical (*gray*) handheld pendulums (see text for details)

Thelen & Smith: generic patterns of development

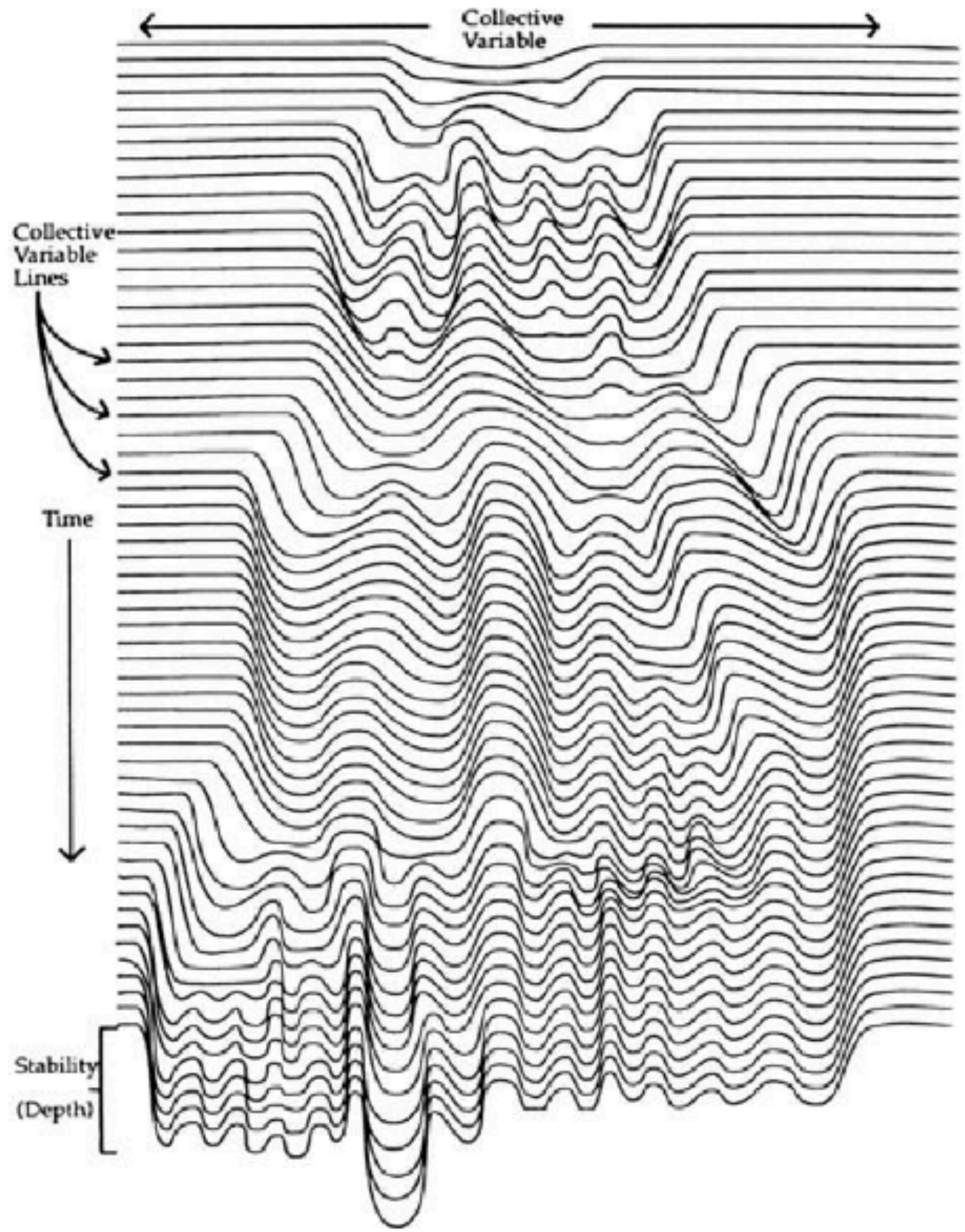


Fig. 3. The multiple time scales of motor development (from [23])

Kelso, Dumas, Tognoli: Coordination at different scales within the CNS

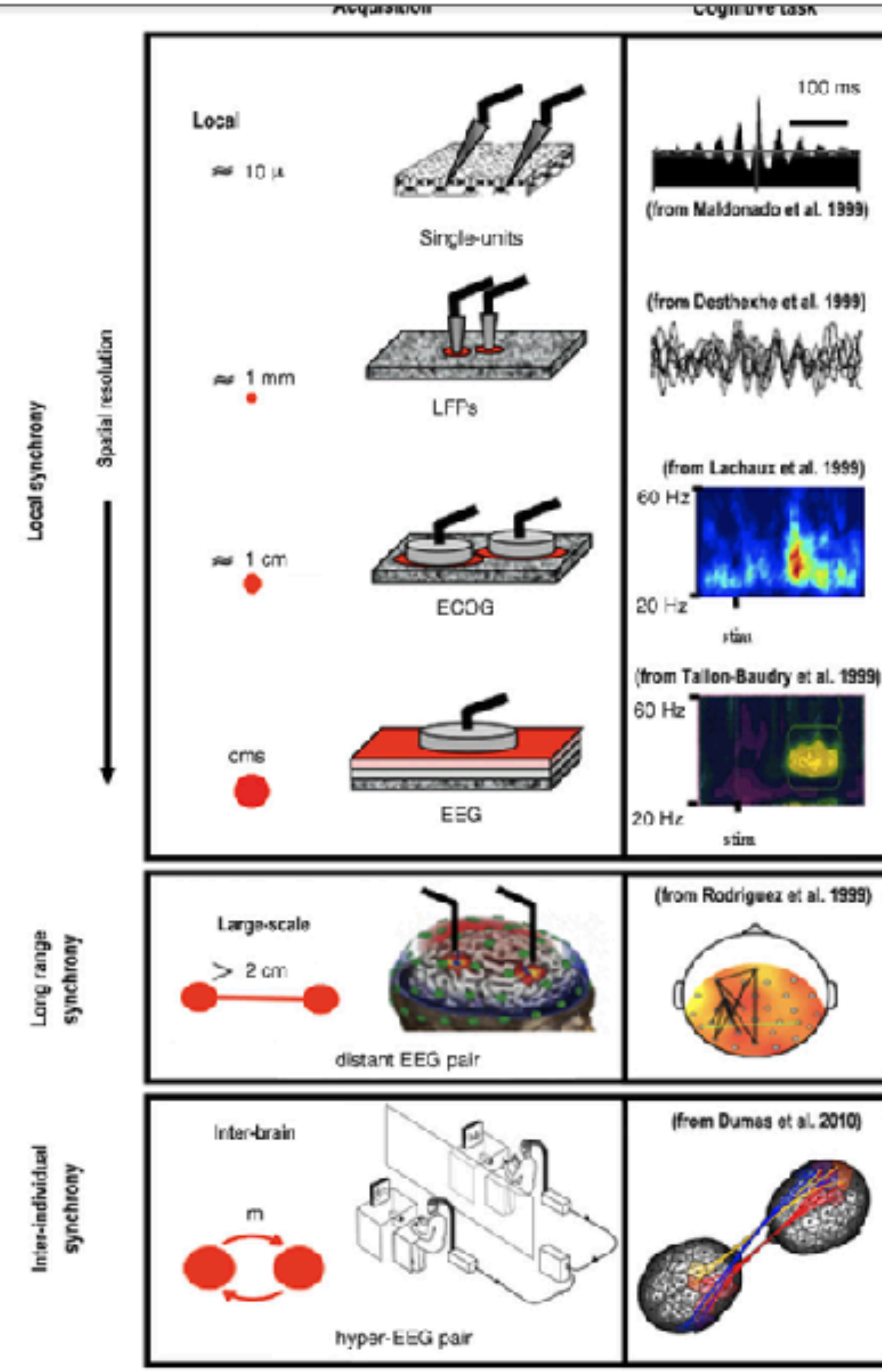
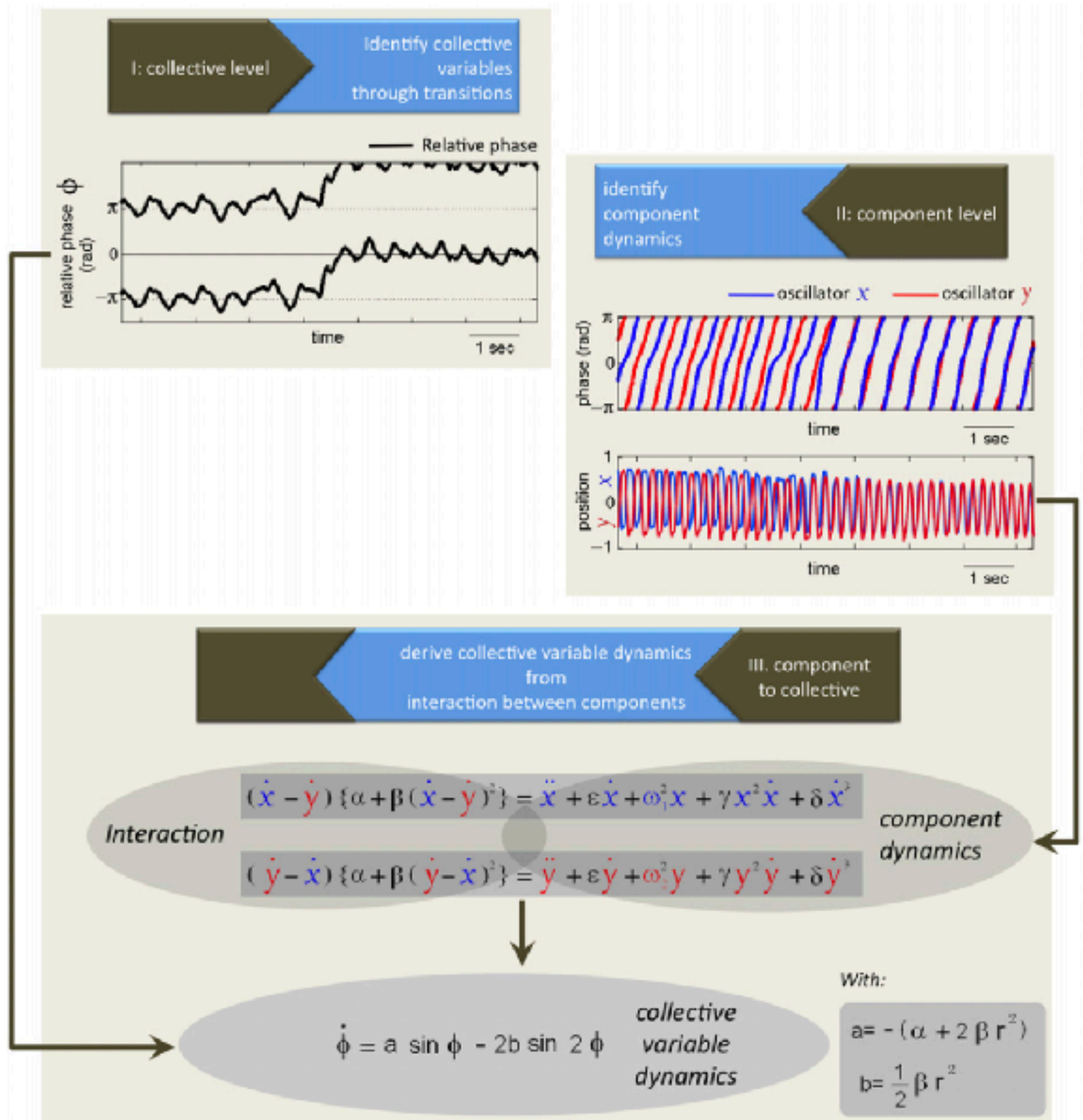


Fig. 1. Multiple scales of the nervous system using synchrony as an example of neural coordination. Notice the right column corresponds to effects that are observed in various task settings. The 'local scale' has three levels of analysis: single units, local field potentials (LFP) and ECOG/EEG. At larger scales, long range synchrony may be observed between distant brain regions. At the inter-individual scale, neural synchronization emerges between different brains through reciprocal social interaction.
Source: Adapted from Varela et al. (2001).

Coordiantion dynamics is a very general approach built around a consistent strategy

J.A.S. Kelso et al. / Neural Networks 37 (2013) 120–131



$$(\dot{x}-\dot{y})\{\alpha+\beta(\dot{x}-\dot{y})^2\} = \ddot{x}+\varepsilon\dot{x}+\omega_1^2 x+\gamma x^2\dot{x}+\delta\dot{x}^3$$

$$(\dot{y}-\dot{x})\{\alpha+\beta(\dot{y}-\dot{x})^2\} = \ddot{y}+\varepsilon\dot{y}+\omega_2^2 y+\gamma y^2\dot{y}+\delta\dot{y}^3$$

$$\dot{\phi} = a\sin\phi - 2b\sin 2\phi$$

$$a = -(\alpha+2\beta r^2)$$

$$b = \frac{1}{2}\beta r^2$$

Fig. 3. A specific example of deriving the collective variable, relative phase dynamics from the (nonlinear) components and their (nonlinear) interaction.

Coordination Dynamics of the Horse~Rider System

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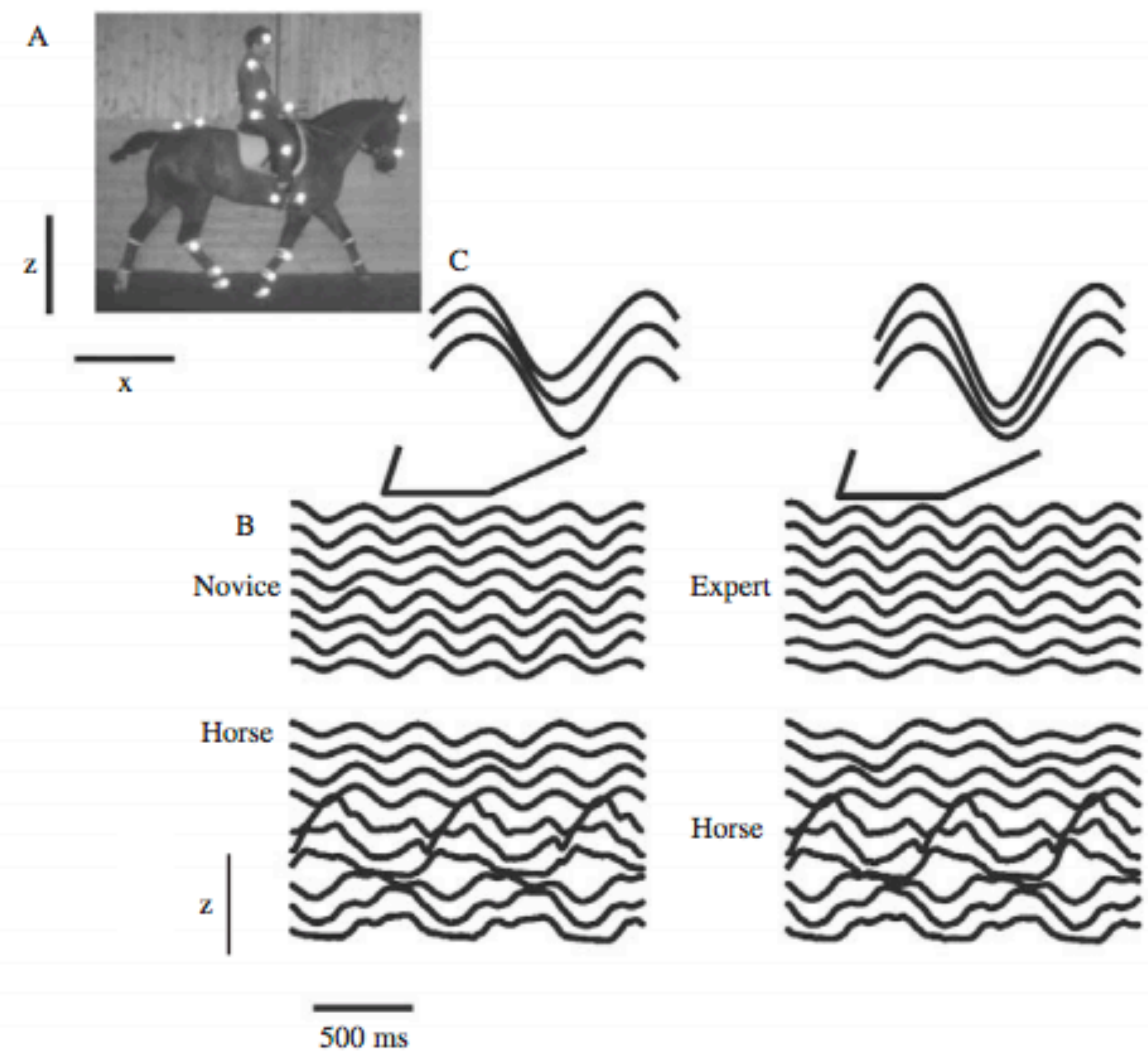

FIGURE 1. Time series of vertical displacement. **A.** Locations of the 18 markers on the bodies of the rider and the horse, recorded on the *x*–*z* plane (axes shown). **B.** Representative time series of the oscillations along the *z* coordinate. **Top.** Riders. **Bottom.** Horse. **Left.** Novice rider. **Right.** Expert rider. The displacements are shown with an offset for clarity. From bottom to top, each trajectory represents, for the riders, motion of the toe, heel, knee, hip, wrist, elbow, shoulder, and head; and for the horse, motion of the right hind hoof, right hind fetlock, right hock, right fore hoof, right fore fetlock, right carpal joint, sacral bone back, sacral bone front, nasal bone, and frontal bone. **C.** One cycle of vertical oscillation of the shoulder, elbow, and wrist for the two riders, isolated from the data shown in **B**. For the novice rider, the oscillations were synchronized together at the maxima of vertical displacement, whereas at the minima, corresponding to the extension of the horse, an increasing phase shift evolved from the shoulder to the wrist. For the expert, the synchronization was maintained during the entire cycle.

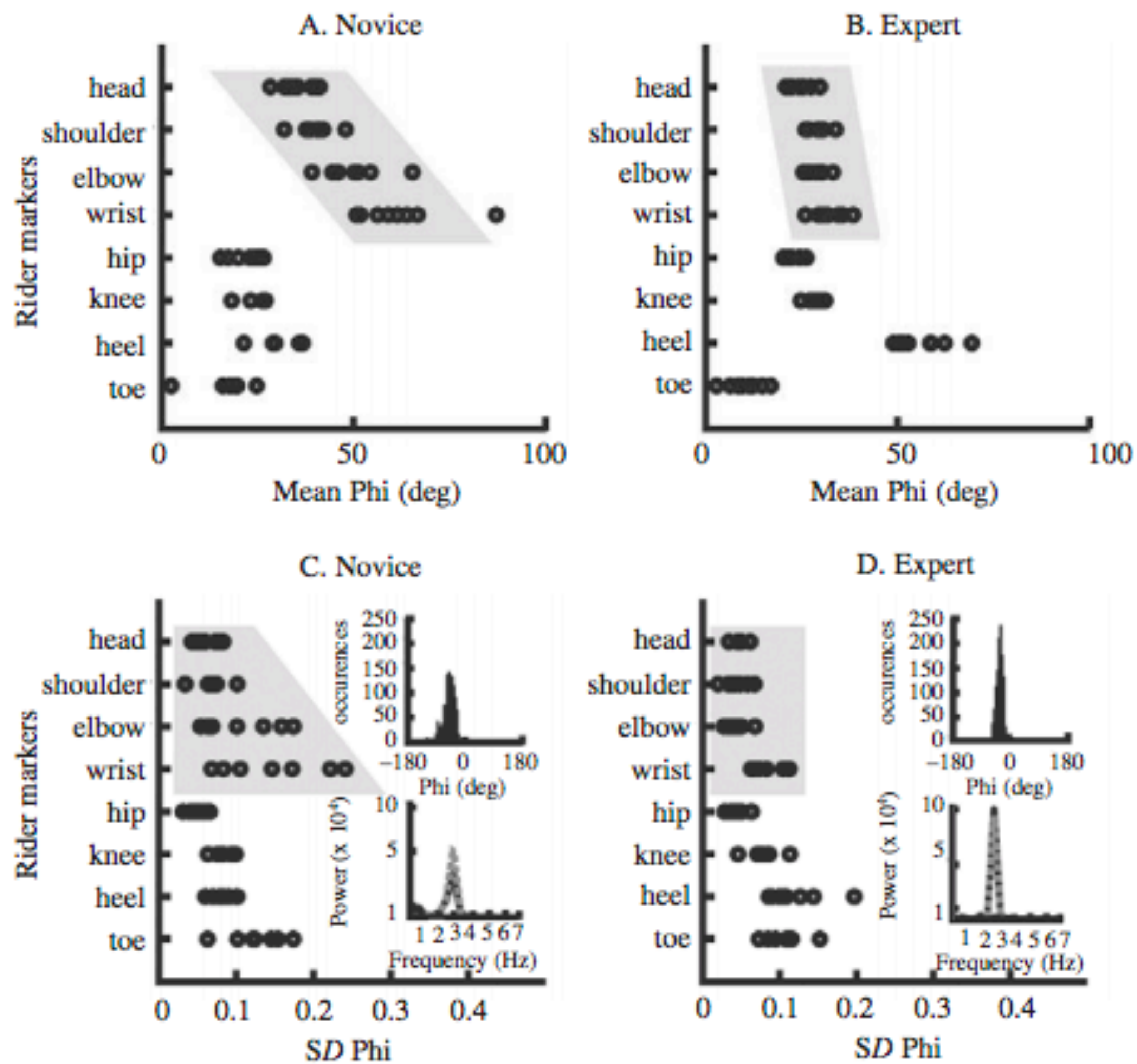

FIGURE 2. Mean and standard deviation of relative phase of the vertical oscillations of the rider with respect to the sacrum of the horse. **A.** Mean relative phase in degrees for the novice for all the markers and all the trials ($n = 8$). **B.** Mean relative phase for the expert ($n = 8$). **C.** Standard deviation of the relative phase for the novice. **D**. Standard deviation of the relative phase for the expert. The insets in **C** and **D** show (top) the distribution of the relative phases between wrist and sacrum, including all the trials; and (bottom) for a representative trial, the power spectra of the oscillation of the sacrum of the horse (dotted line) and the wrist of the rider (solid line).