Movement

If psychology set off with the twin goals of understanding

EXPERIENCE

and

BEHAVIOUR

and experience is unobservable, one might think that the study of behaviour would be paramount.

What is the relation between

MOVEMENT

and

BEHAVIOUR?

Psychology syllabus from psychology.wikia.com

- Perception
- Categorization
- Memory
- Knowledge Representation
- Numerical Cognition
- Language
- Thinking

No movement at all.

Contents of *Cognitive Psychology: A Student's Handbook*

- Visual Perception: Basic Processes
- Perception, Movement and Action
- Object Recognition
- Attention and Performance Limitations
- Memory: Structure and Processes
- Theories of Long Term Memory
- Everyday Memory
- Knowledge: Propositions and Images
- Objects, Concepts and Categories
- Speech Perception and Reading
- Language Comprehension
- Language Production
- Problem Solving, Puzzles and Expertise
- Creativity and Discovery
- Reasoning and Deduction
- Judgement and Decision Making
- Cognition and Emotion
- Present and Future

No engagement with movement science

The territory is vexed, but here is a suggestion:

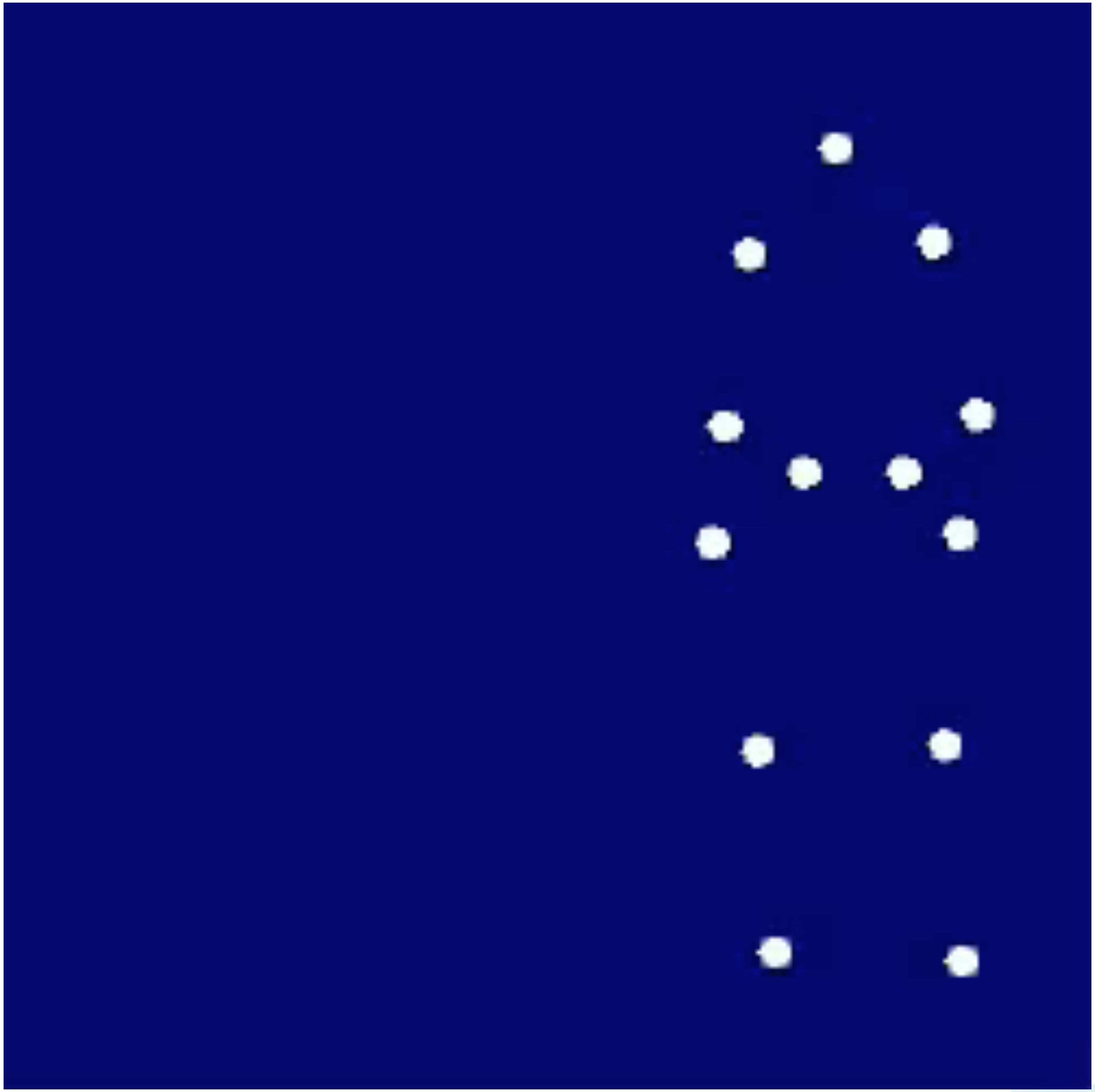
Behaviour as *goal-directed movement.*

Now, goals and purposes have no place in a “simply” objective science.

Can there be an objective science of behaviour?

or is the observer implicated by their framing of the observed activity?

We are clearly exquisitely sensitive to the form of goal-directed movement.



Historically, movement has played second fiddle to
(A) Higher cognitive functions such as reasoning, planning, etc, and
(B) Study of perceptual phenomena

Many fundamental insights from movement studies are still unknown or ignored in most of cognitive science

The inseparability of perception and action is one reason to question the wisdom of this. There are others.

What does the brain/CNS do?

The brain has some role in regulating hormones within the body (including self-regulation).

Other than that, all the brain does that we can see/record/measure, is move muscles.

Even language is only evident through movement (speech, writing, signs...)

Many (all?) of the basic principles of movement are held in common with other species.

Why move?

Food is not evenly distributed in most environments.

Resting may require a different environment to feeding

and, of course, reproduction.....

"The juvenile sea squirt wanders through the sea searching for a suitable rock or hunk of coral to cling to and make its home for life. For this task, it has a rudimentary nervous system. When it finds its spot and takes root, it doesn't need its brain anymore, so it eats it! It's rather like getting tenure." (Daniel Dennett)

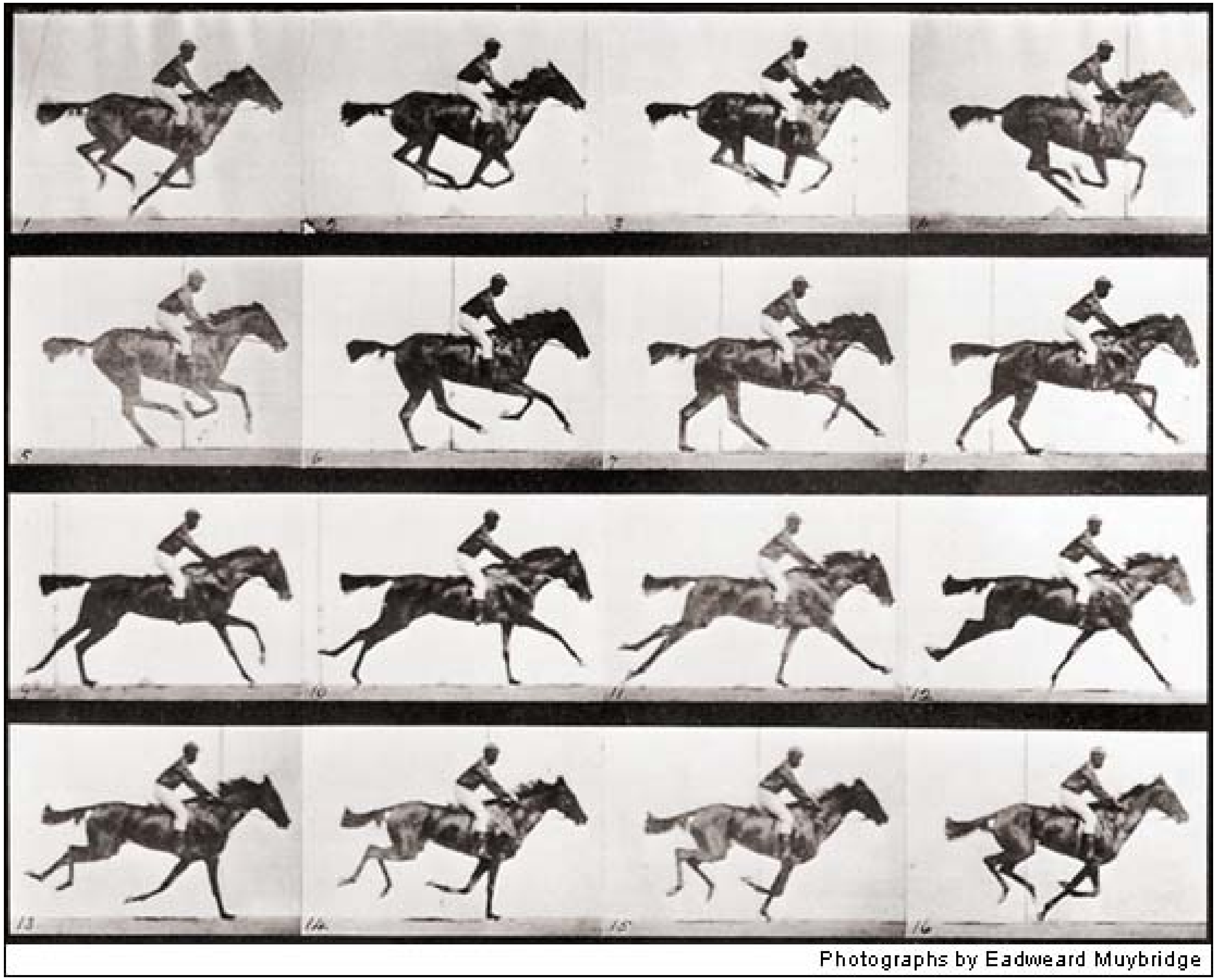
Inaccurate, but close. The sea squirt undergoes a metamorphosis, and digests its ganglion (bunch of nerves, kinda like a brain) in the process.

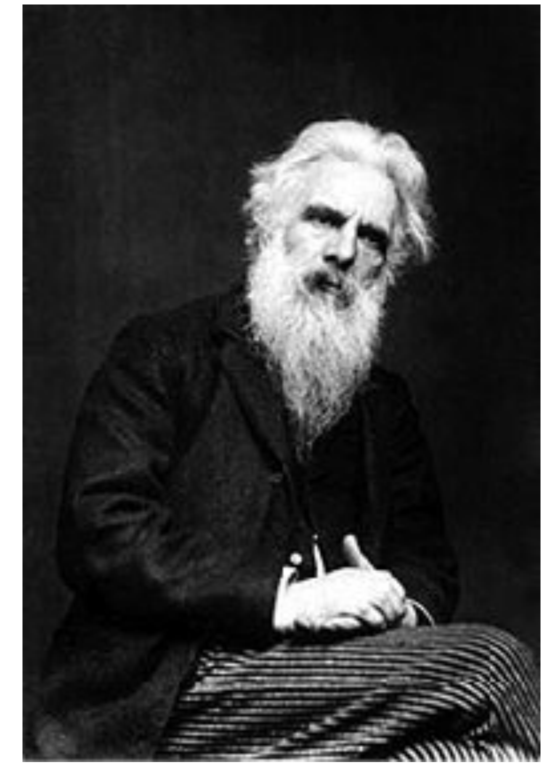
The ganglia are costly to maintain, and needed only for locomotion.

Locomotion

Where is the wheel in nature?

1872..1878: Does a horse have all four feet off the ground when galloping?





Eadweard Muybridge

What is **not** going on in locomotion?

brain decides where foot should go next

brain figures out which muscle combination will get it there

brain commands those muscles to move just enough

Brains do not “decide”

Brains do not “figure stuff out”

Brains do not “see”

Brains do not “feel”

Brains are not people.

How many degrees of freedom does this puppet have?

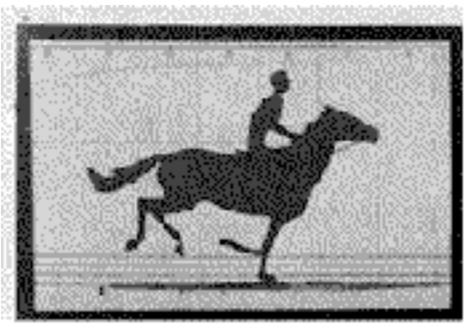
How many things can be separately controlled?

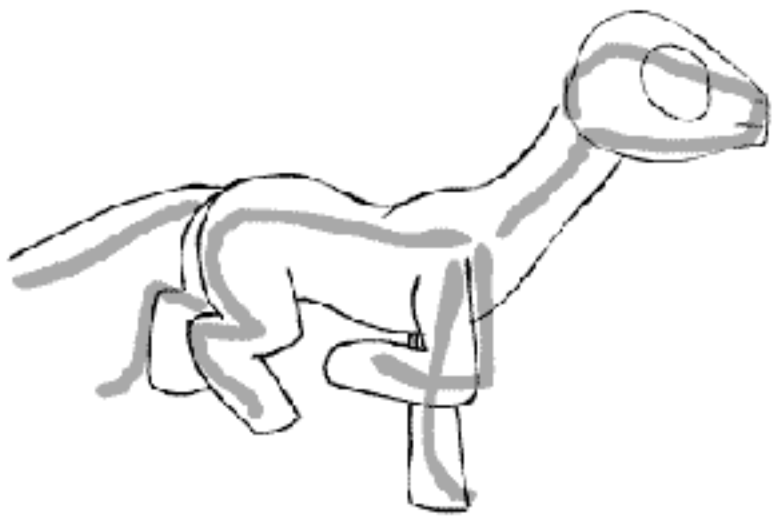
The two legs are not independent

Each repeats a cycle

The two cycles are linked

Lots of repetition. Not much pattern.





. . . or 8

This is true if you have 4 legs too . . .

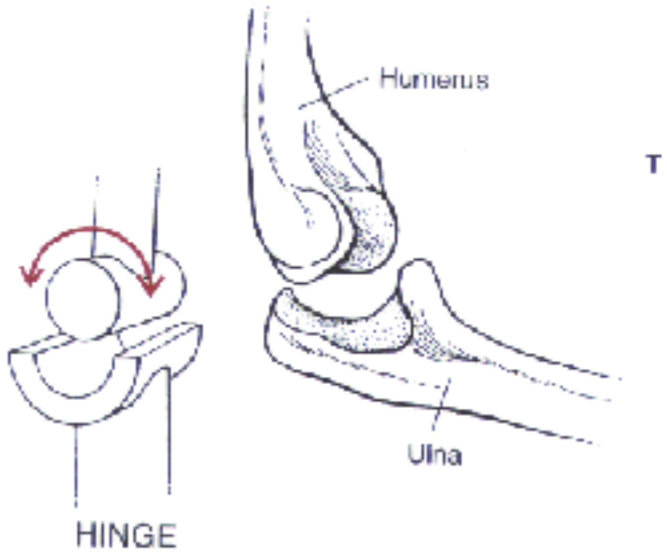
A centipede was happy quite
Until a toad in fun said
"Pray, which leg moves after which?"
This raised her doubts to such a pitch
She fell exhausted in a ditch
Not knowing how to run.

Katherine Craster, *The Centipede's Dilemma*, 1871

Some general principle must be involved here!

If we consider the brain to be controlling everything in movement, how many ‘things’ is it controlling?

7 degrees of freedom in the *joints* of one arm



Elbow: hinge joint (1 degree of freedom)

Shoulder: 3 d.o.f. (latitude, longitude, rotation)

Wrist: 3 d.o.f. (side to side, up down, rotation)

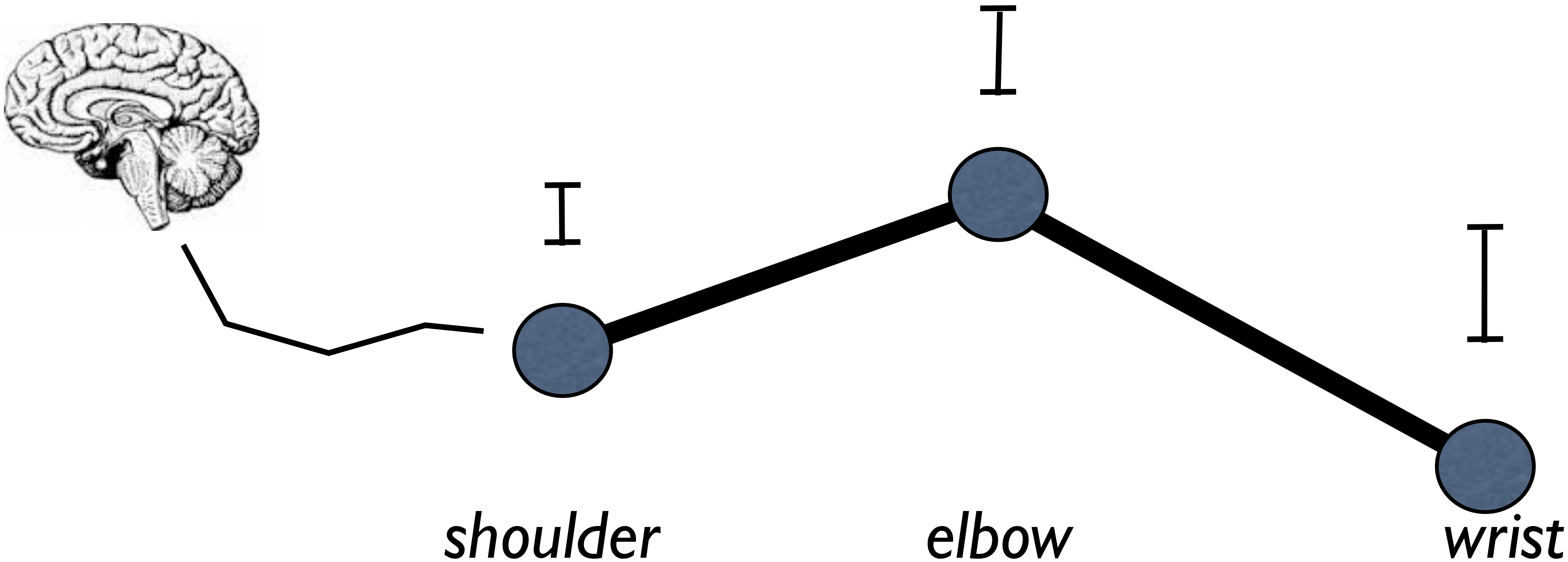
Each joint movement is controlled by multiple muscles (more degrees of freedom)

Each muscle consists of individual packages (yet more…), which break down even further.… (yet more….)

There are too many individual degrees of freedom for each to be separately controlled. (Nikolai Bernstein, Russian physiologist)

Body components move in a coordinated fashion, not as independent units

In the 1920's and 1930's the Russian physiologist Nikolai Bernstein studied the form of skilled action in blacksmiths.



If movement were *controlled* from the brain:
Var(shoulder) < Var(elbow) < Var(wrist)

Variability at the hammer tip is less than variability of individual joints in highly skilled blacksmiths

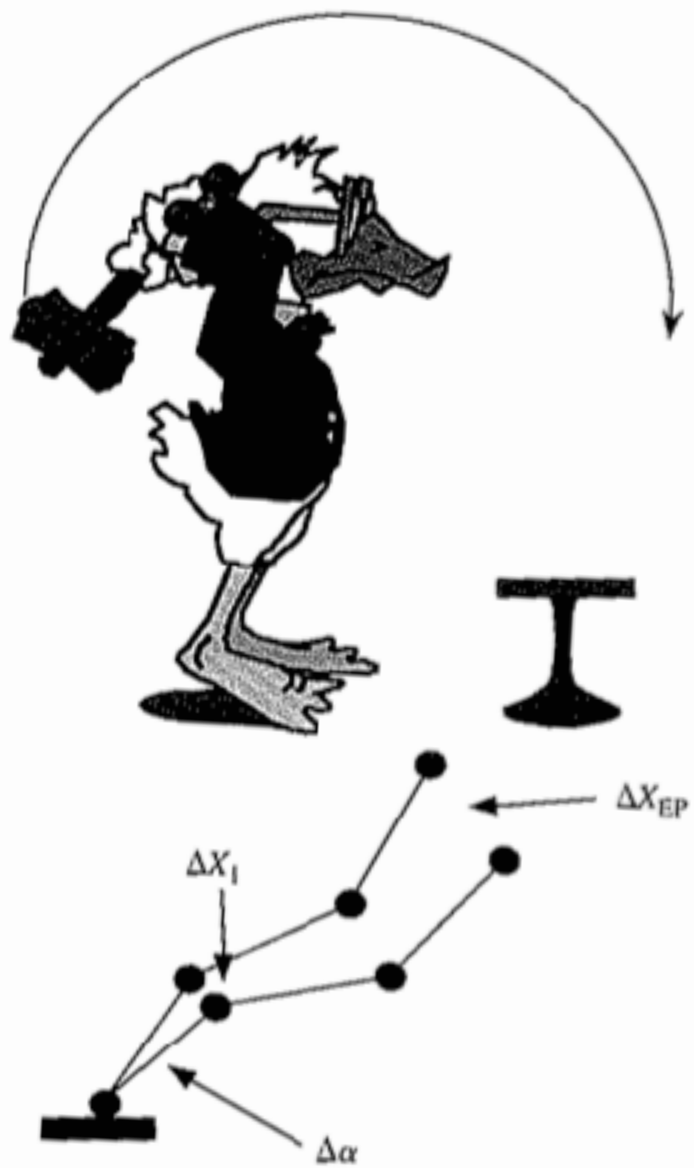


Figure 2.1. When a blacksmith hits an object with the tip of the hammer, small errors in proximal joint angles ($\Delta\alpha$) are expected to lead to larger deviations of the endpoint (ΔX_{EP}, the tip of the hammer) than of more proximal joints (ΔX_1).

Joints do not act independently. They correct each others' movements

The brain is not a puppeteer!

We tend to think intuitively that all behaviors arise from controllers.

The study of coordinated movement suggests otherwise.

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MOVEMENT

and

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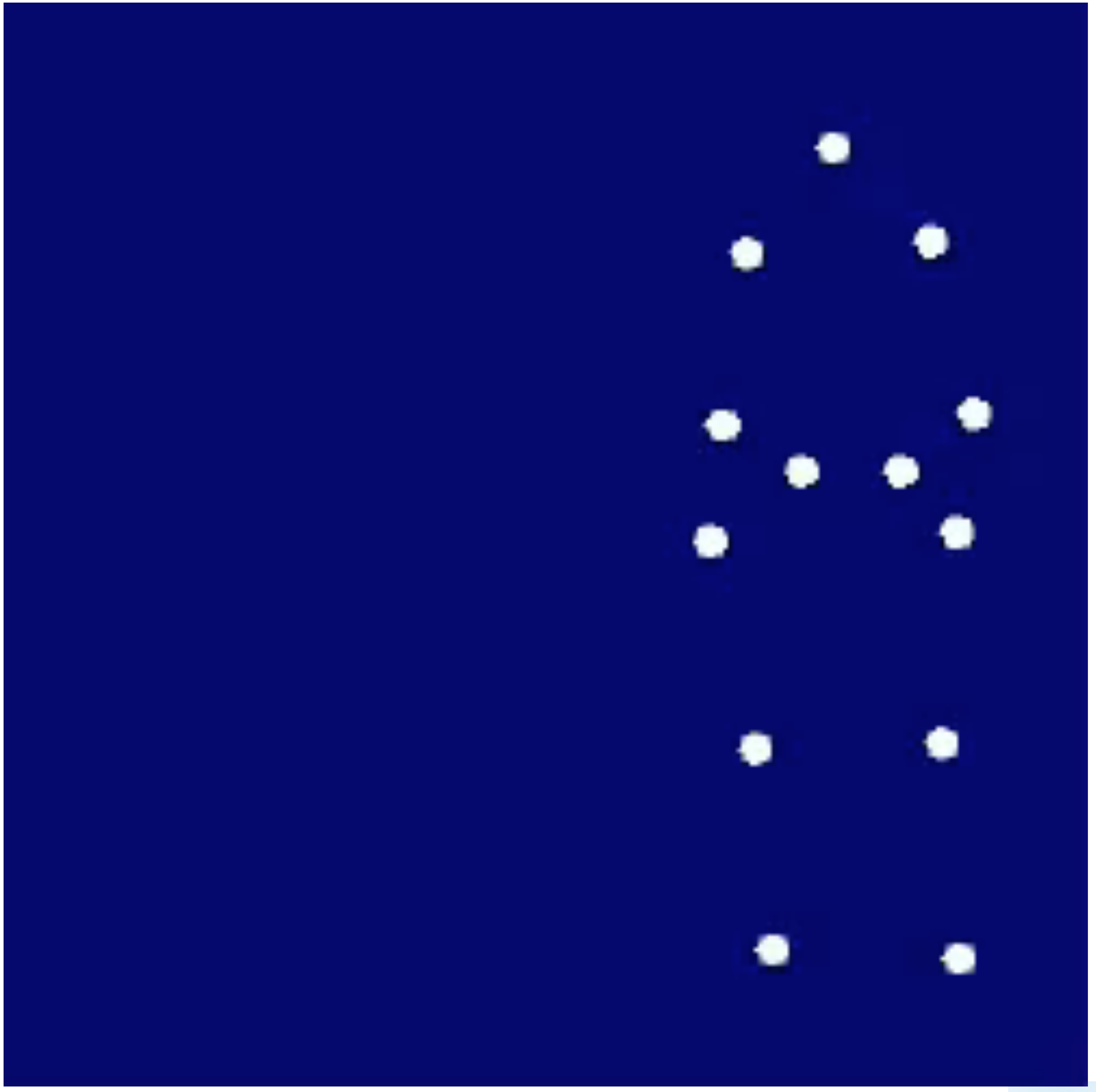

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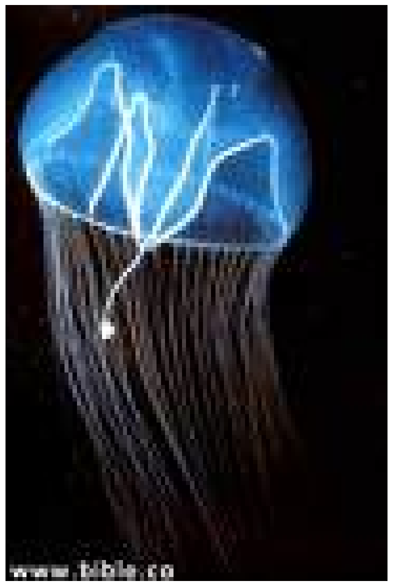
Locomotion



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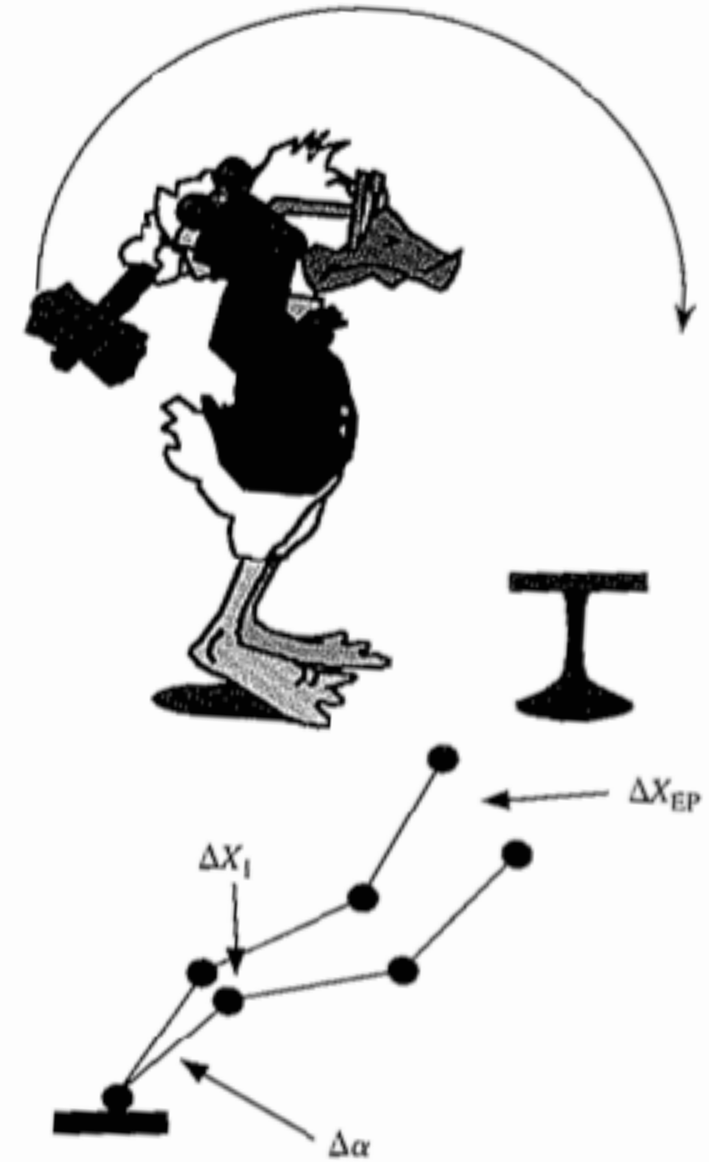

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James Watt’s Centrifugal Governor

A negative feedback control system for regulating steam pressure

Arm angle is proportional to steam pressure, and it also affects steam pressure

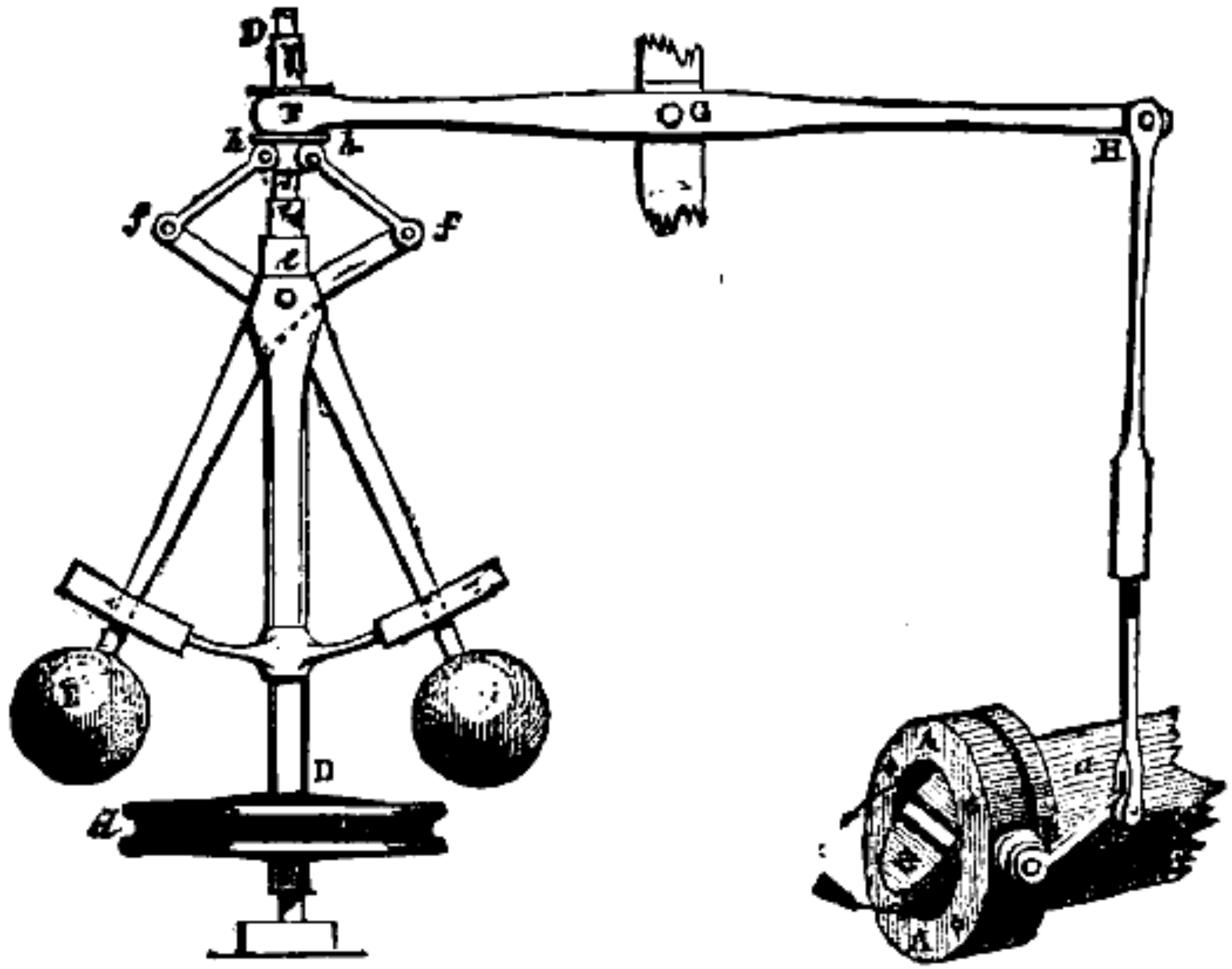
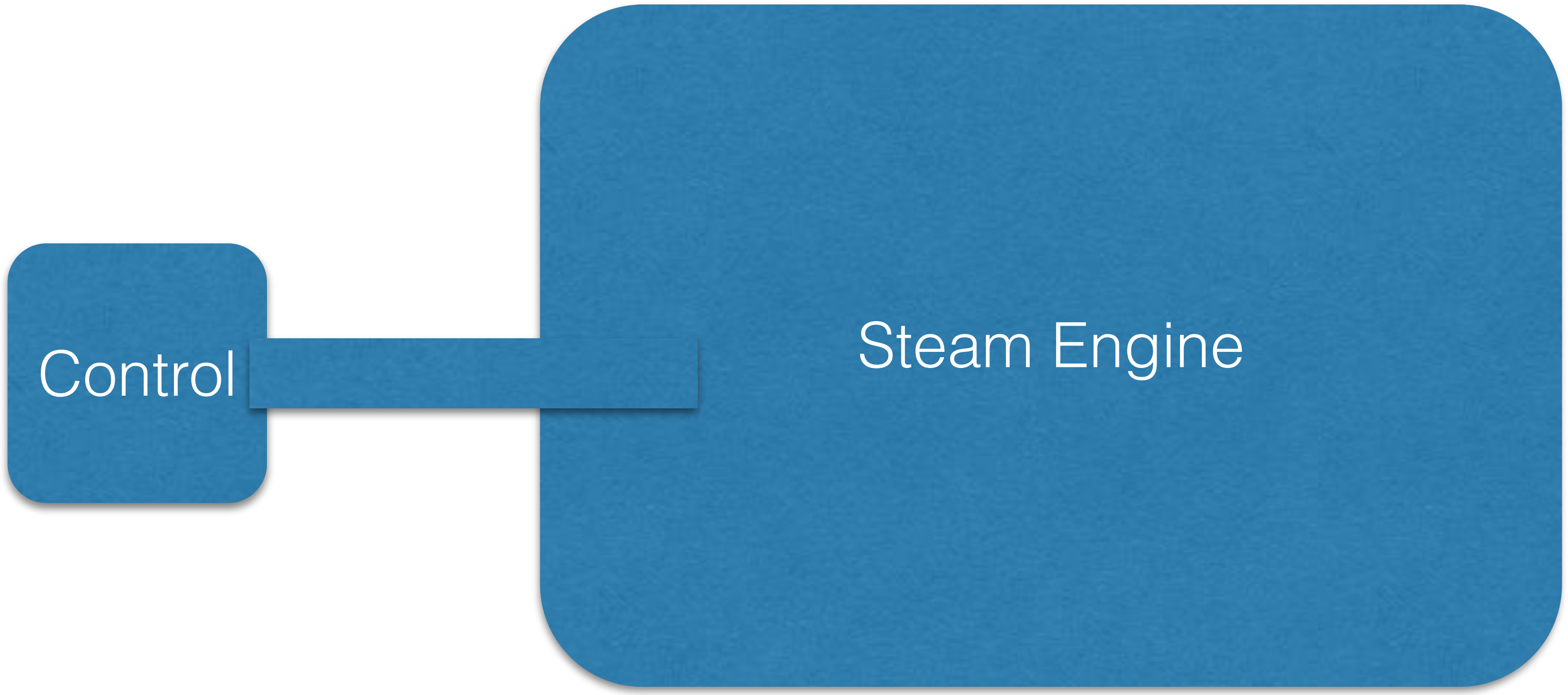


FIG. 4.---*Governor and Throttle-Valve.*

A black-box description



If you did not know how this works, you could arrive at a complex computational account. What would that look like?

1. Measure the speed of the flywheel.
2. Compare the actual speed against the desired speed.
3. If there is no discrepancy, return to step 1. Otherwise,
    a. measure the current steam pressure;
    b. calculate the desired alteration in steam pressure;
    c. calculate the necessary throttle valve adjustment.
4. Make the throttle valve adjustment.

Return to step 1.

A computational account is possible, if ungainly.

An alternative dynamical account is available, and in this case, more insightful.

We recognize the role of the watt governor because we know the design goals of the steam engine.

From the perspective of the composite machine, there is no controller and no controlled system. This is the *domain of the operation of the system*.

Knowing the goals, we can distinguish between the controller and the controlled. This lies in the *domain of our description of the system*.

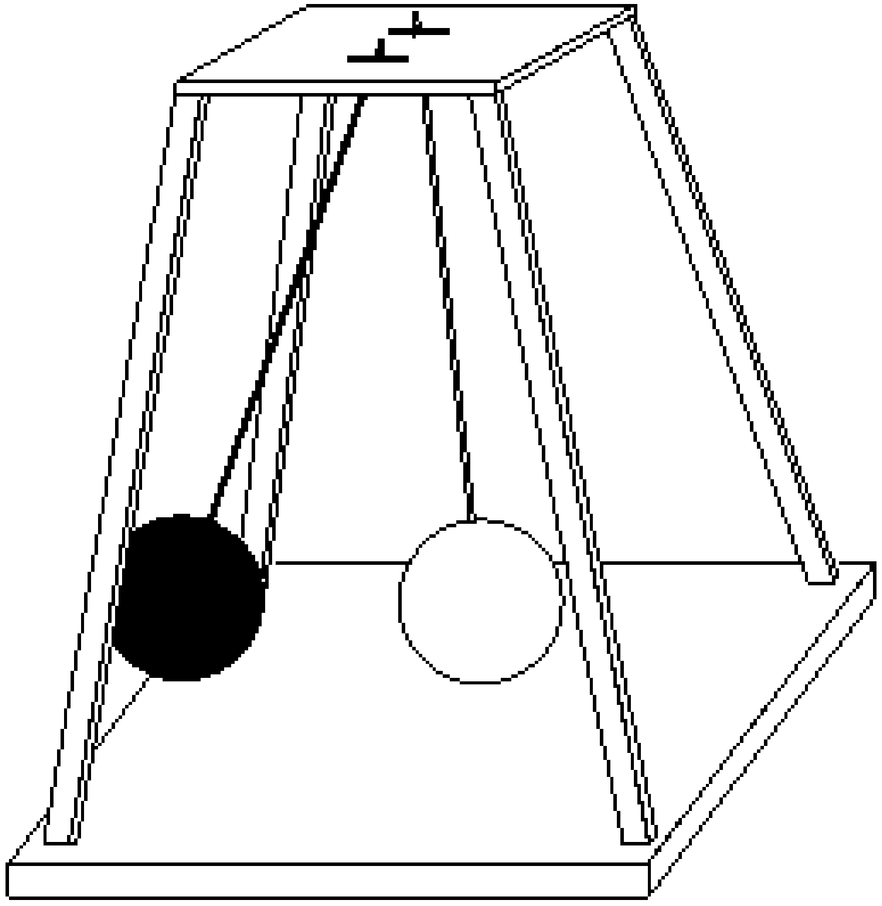
It is very common to confuse these two.

For thought: what are the implications for our view of the function(s) of the brain?

Rolf Pfeifer illustrates 1 controller with 3 behaviors using Lego MindStorms.
Full video here: http://vimeo.com/28811223

Bodies are physical things. They have physical properties (mass, inertia, etc). We need to consider the physics of bodies and the physics of locomotion. These problems are not dis-embodied!

Oscillation



- Oscillations are periodic processes
- Position within one cycle is measure in *phase*
- Phase conventions include [0..1], [-π..π], [0..2π].
- Two periodic processes may become *entrained* or *coupled*, as when 2 pendula swing in synchrony.

Entrainment Demonstrated

The video illustrates the process of *entrainment*, whereby the cycles of individual metronomes become yoked together into a higher-level pattern.

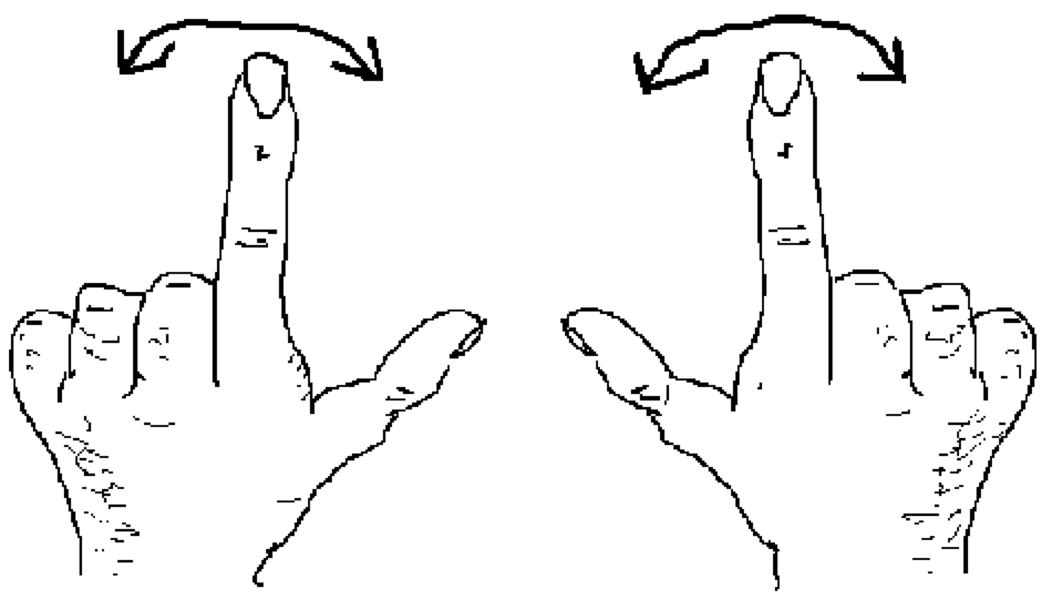
You can also hear how the intrinsic oscillation of the individual metronomes "seeks" to assert itself against the emerging pattern.
Models of entrainment allow us to capture both individual autonomy, and collective patterning

- There are simple regularities underlying the coordination of the limbs in *all* locomoting animals

Sometimes, a simple model system can help to uncover deep regularities.

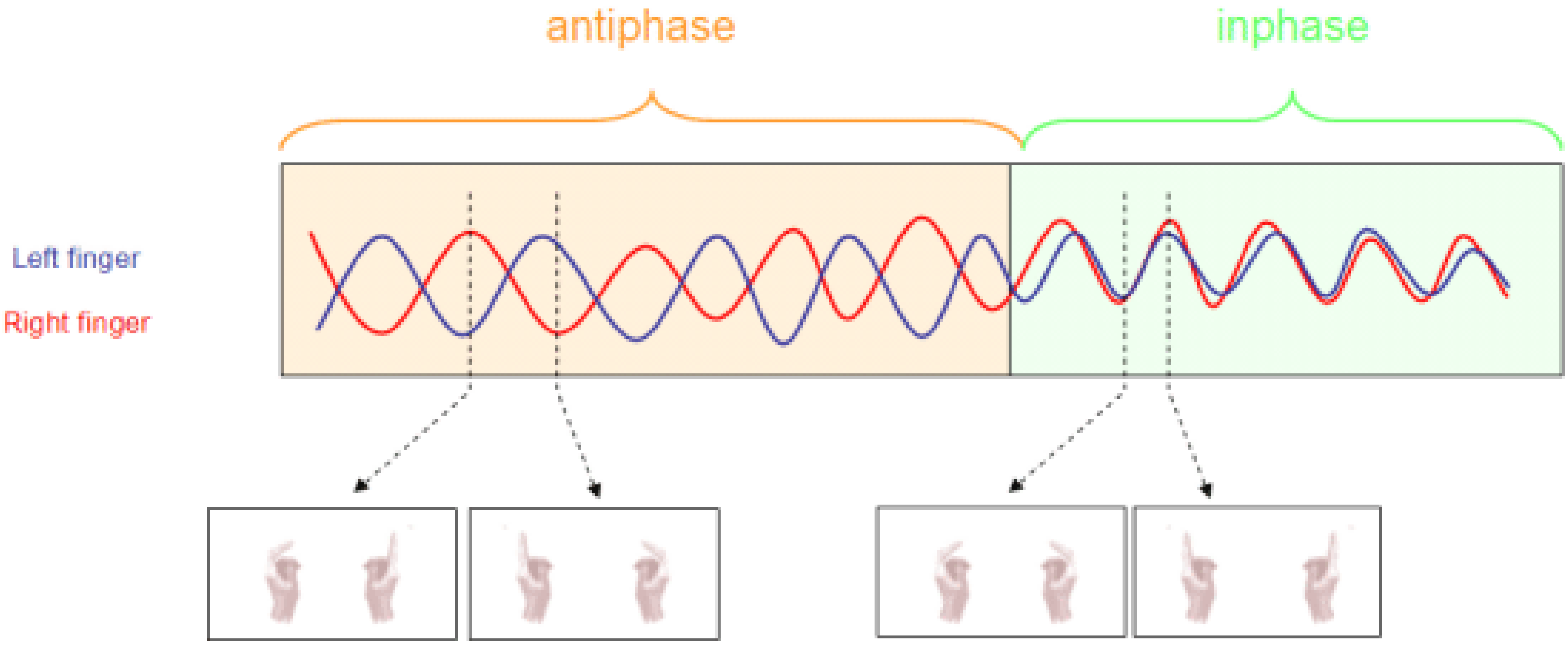
Coordination Dynamics: Scott Kelso and co-workers

A **model system** for studying coordination

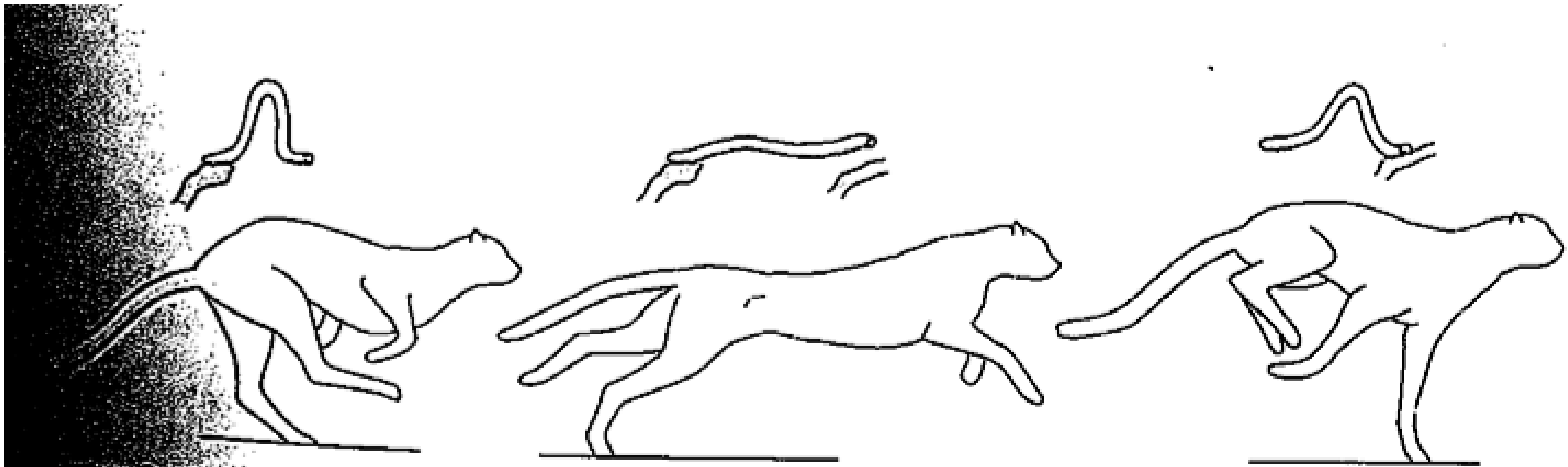


in phase

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



3-13 Measuring worm–like progression of the cheetah resulting from oscillation of the back coupled ppropriate timing of footfalls.

Similar principles govern the form of locomotion in the inchworm and the cheetah.

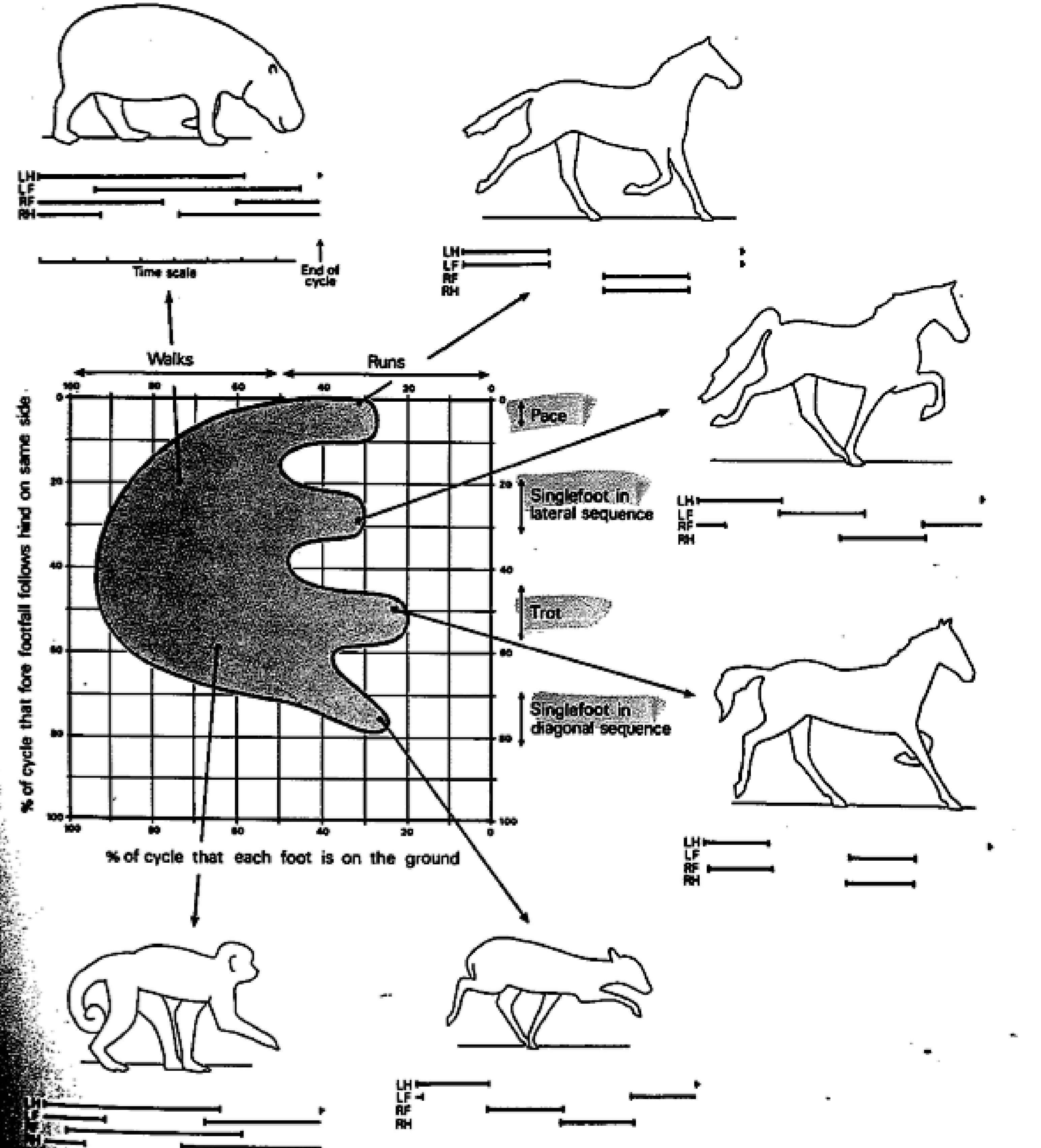
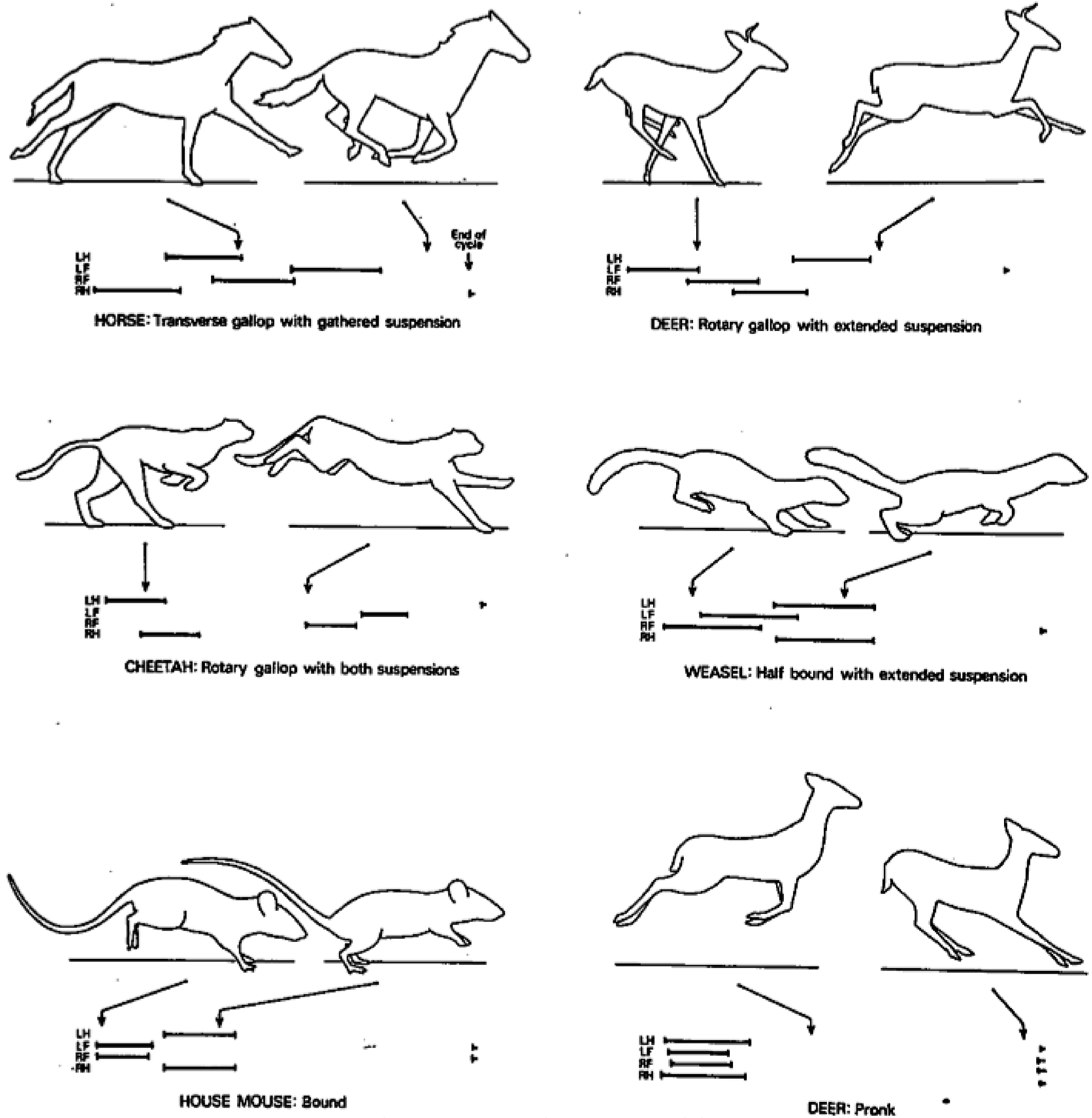


Figure 3-2 Symmetrical gaits as defined by the duration of contacts with the ground and the phase relationship of fore and hind feet. The outlined area encloses nearly 1200 plots for 156 genera, including amphibians, reptiles, and 16 orders of mammals. For the seven gaits recorded, a pigmy hippopotamus, three horses, a duiker, and a monkey are shown at the instant the left hind foot strikes the ground. Gait diagrams indicate the timing and durations of the respective contact intervals. Time scales *(upper left)* for the different animals are independent. H = hind; F = fore; R = right; L = left.


End of cycle
LH
LF
RF
RH
HORSE: Transverse gallop with gathered suspension
DEER: Rotary gallop with extended suspension
CHEETAH: Rotary gallop with both suspensions
WEASEL: Half bound with extended suspension
HOUSE MOUSE: Bound
DEER: Pronk


GOING AFRICA SAFARIS
pronking springboks in Central Kalahari

If an animal has several gaits at its disposal, is it free to choose one over the other at any time?

Or is there lawfulness here too, in the choice of gait?

range of speeds in any given gait. If you

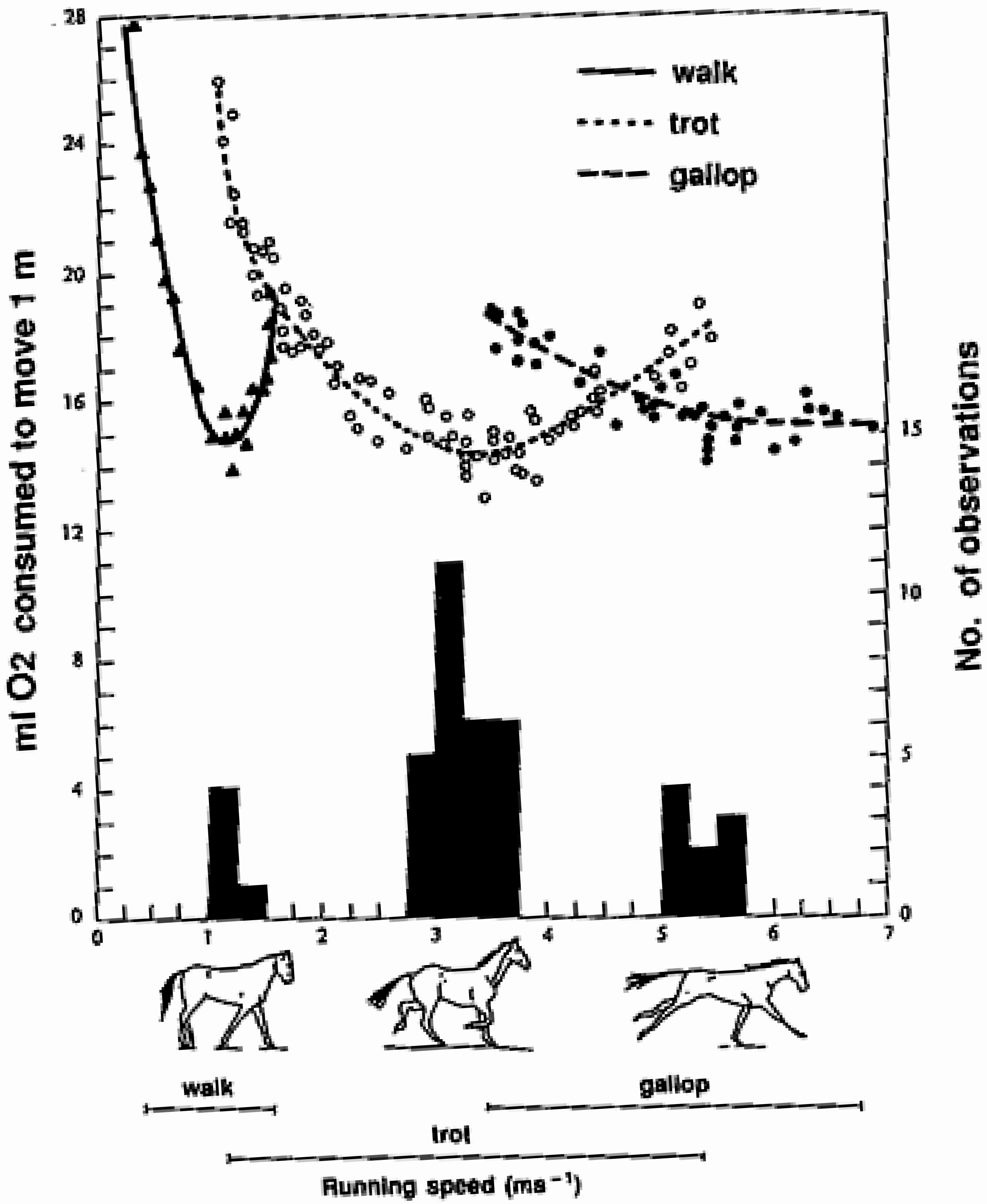


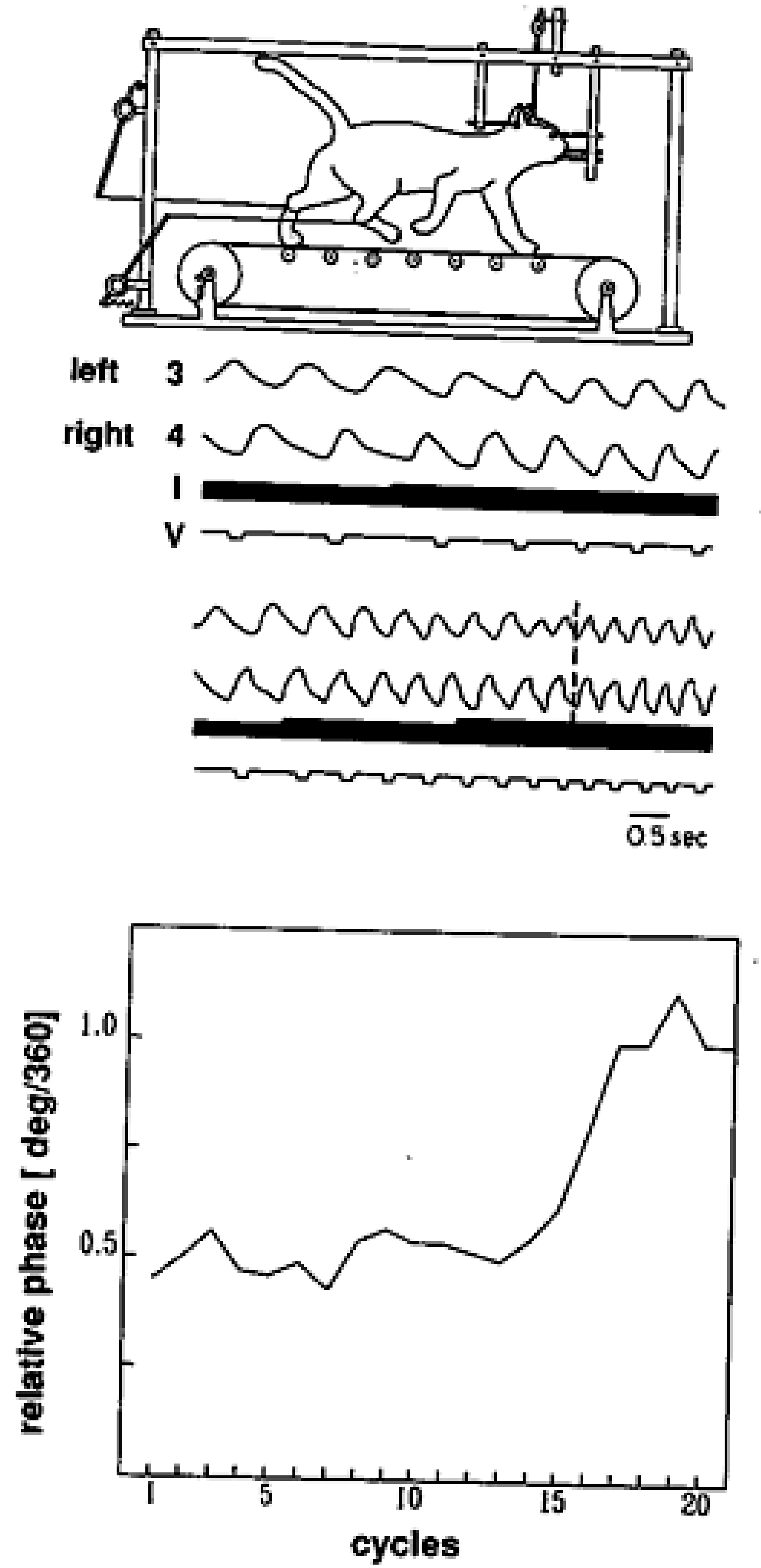
Figure 3.1 Oxygen consumption per meter moved and preferred speed (histograms) of walk, trot, and gallop of ponies. (Adapted from reference 4. Reprinted with permission)

Minimization of metabolic cost, indexed by oxygen consumption

Hoyt and Taylor, Nature, 1981

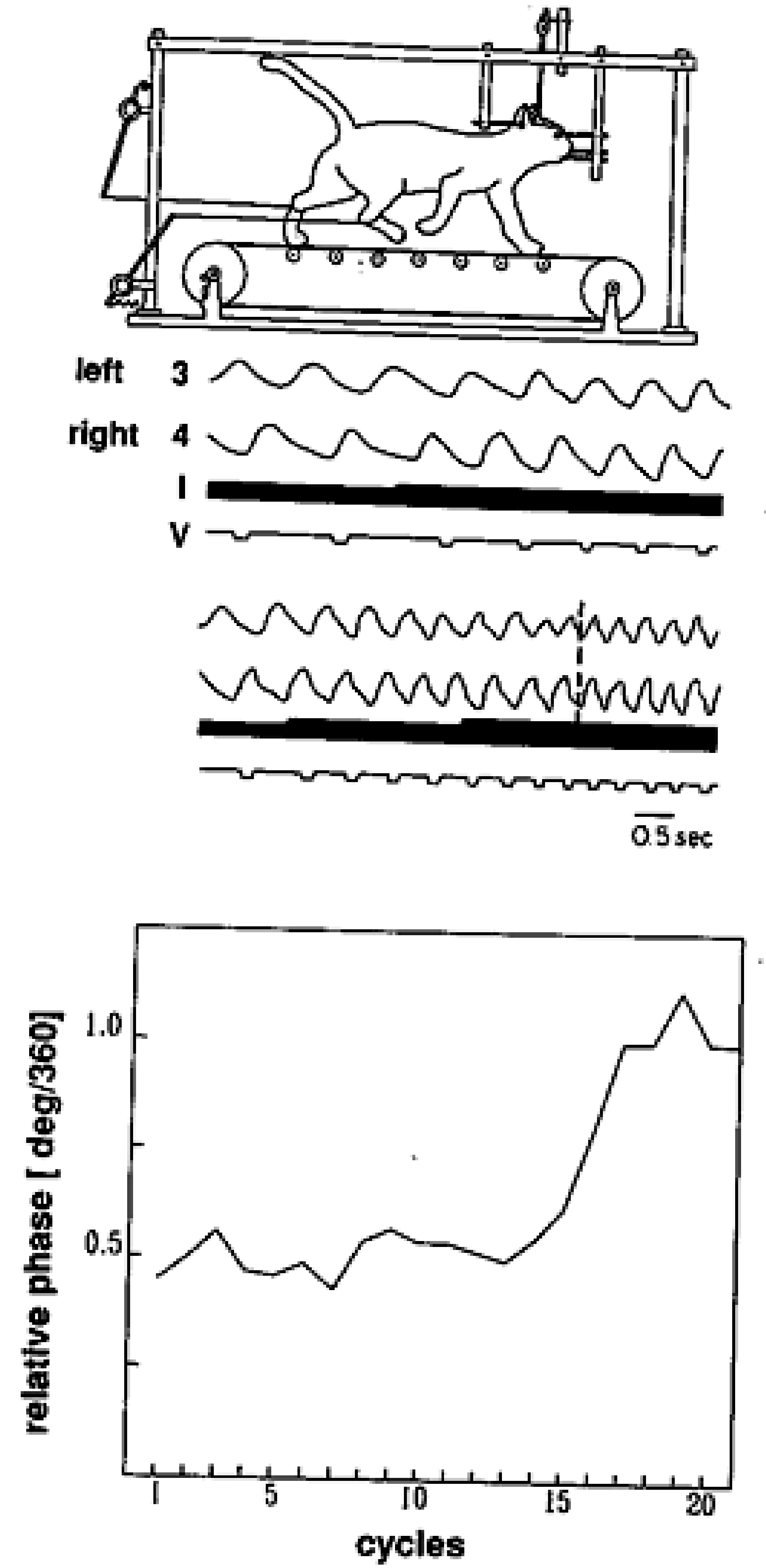
Does the brain do everything in getting an animal to walk, or is it brain + body + simple physical constraints?

You could not make convincing walking movements without a firm ground support (e.g. when treading water in a pool)

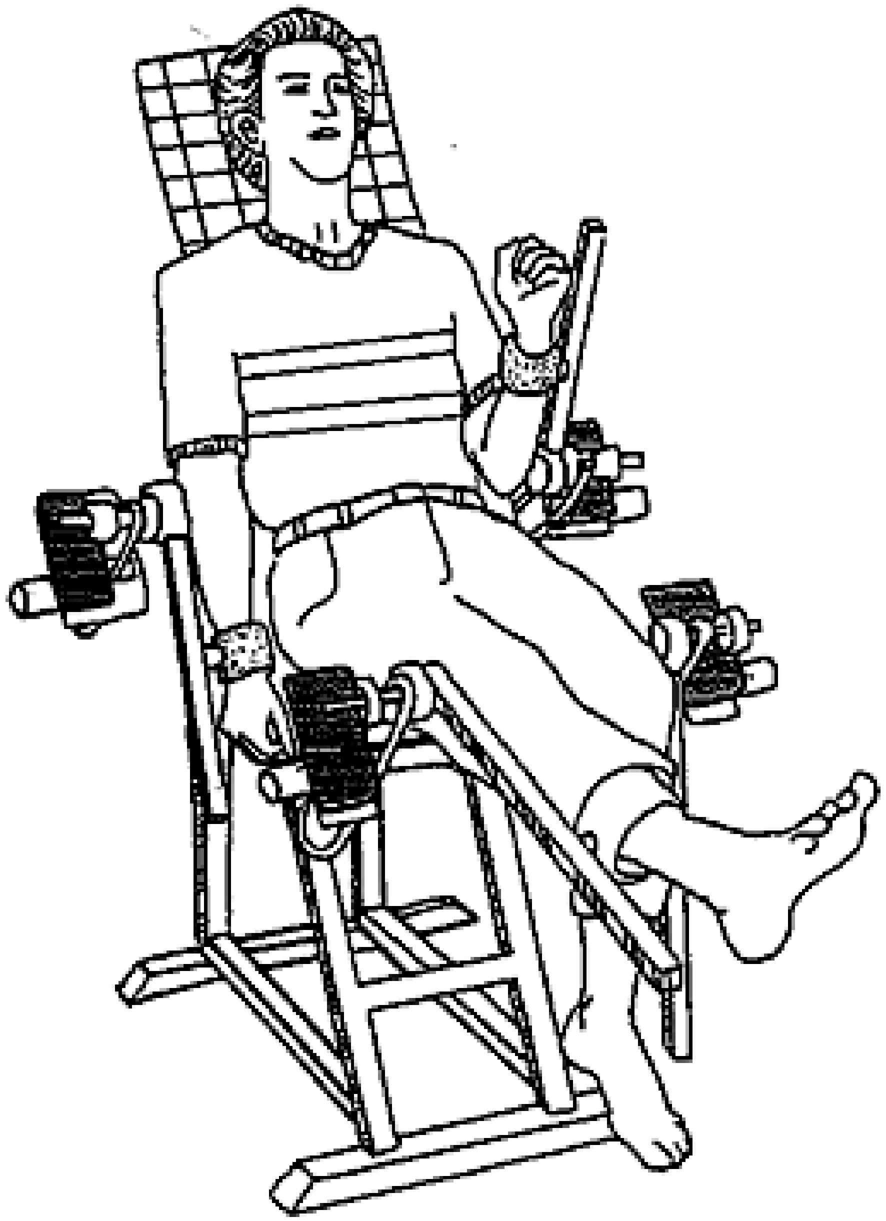


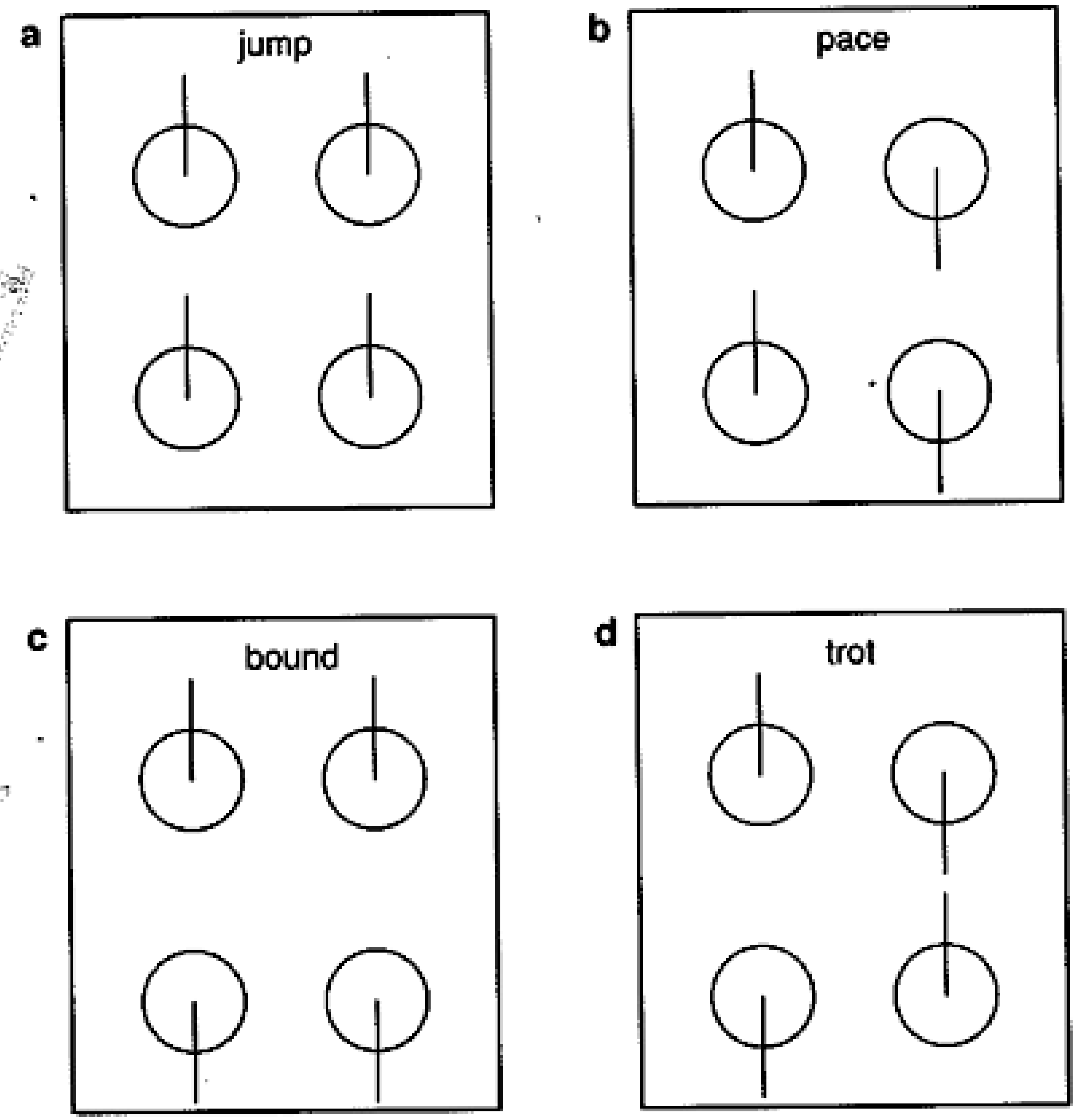
Shik, Orlovskii and Severin, Biophysics, 1966

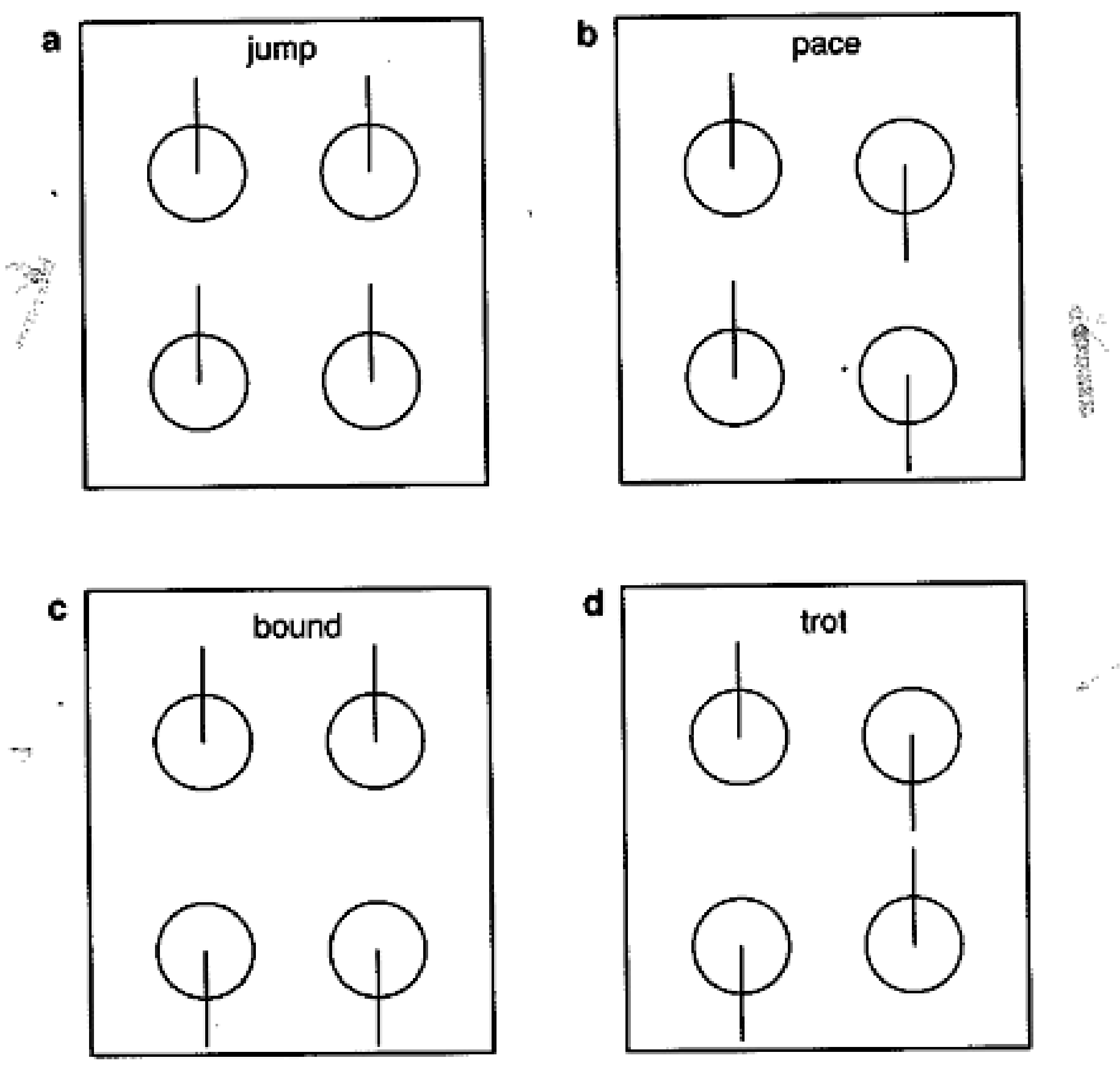
Mesencephalic cat: **self-organization**
(= emergence)
under the control of a single, nonspecific parameter (degree of stimulation, or treadmill speed..)



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




a
jump
b
pace
c
bound
d
trot



When constrained to act as quadrupeds, humans display coordinative modes of the same kind as every other quadruped.

If pairs of legs are removed from a caterpillar, the resulting gait is immediately smooth, fluent, coordinated, and appropriate for the new number of legs.

What is the brain doing here?

Coordination　　　　Constraint

Constraining the many degrees of freedom of the body so that, in interaction with the environment, coordinated movement *emerges*.

In walking, it helps to temporarily construct a ‘locomotion machine’ in which the parts work together to bring about th goal of locomotion

NOT control!!!!

This 'locomotion machine' is:

* Task-specific
* Flexibly assembled
* More than the brain or brain + muscles
* Has less degrees of freedom than the sum of its parts

Within Action Theory/Coordination Dynamics, we call this a ***Coordinative Structure***. or ***Synergy***.

You create *plucking* machines, *picking* machines, *scratching* machines, *catching/throwing* machines, *scrubbing* machines, and so on.....

Time to consider:

What is a machine?

What role do goals play in identifying assemblies that are machines?

Are goals something that can be observed?

Does the observer need to be included in the description of a machine?

A key concept here is the notion of "Emergence".

When multiple components are subject to particular constraints, a pattern may emerge at the level above the components. This is emergence.

A tornado is an emergent pattern. Nobody designs or controls it.

The pinwheel is an emergent pattern. The puppies are the components.

(If you are only looking at the notes, you are missing the fun of lectures, including this fine puppy video.)

Puppy = component

Pinwheel = emergent pattern

Feeding dish = constraint

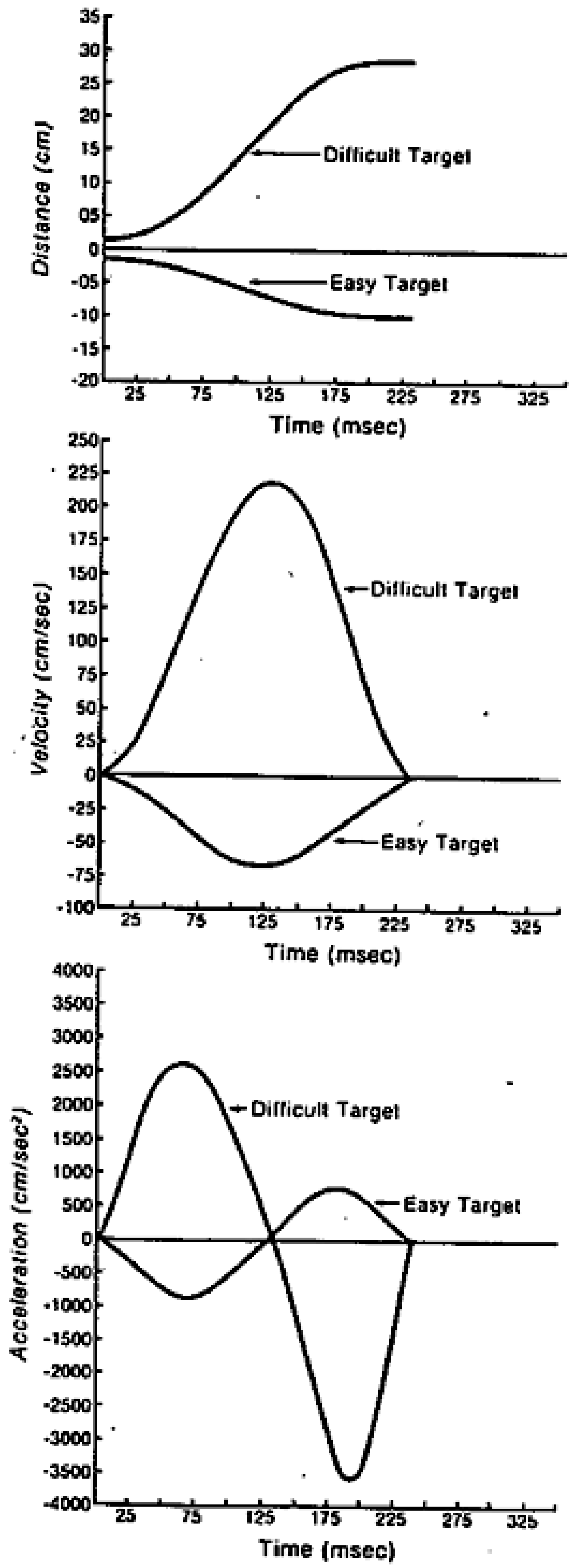
Excited feeding behavior = autonomous dynamical behavior

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.

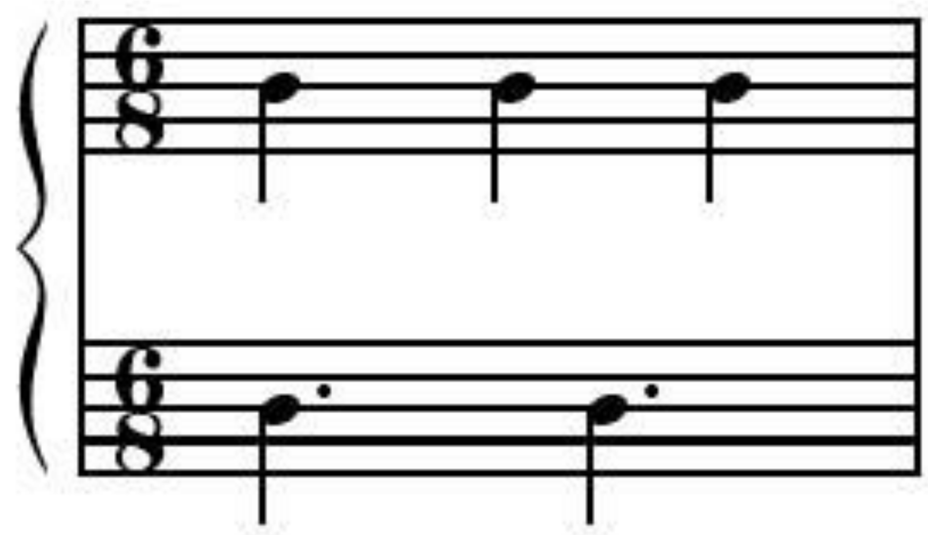
Each row corresponds to one experimental task. Subjects are asked to move, after a signal, from the midline to one or two targets.



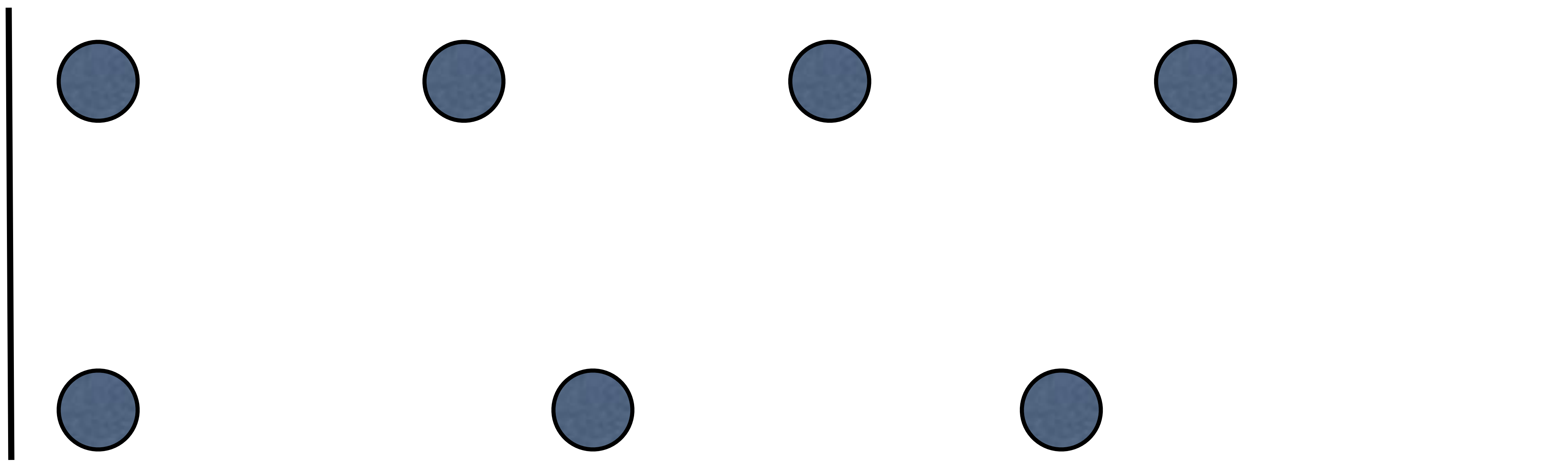
..the brain produces simultaneity of action not by controlling each limb independently, but by **organizing** functional groupings of muscles that are **constrained** to act as a single unit

Why is it hard to pat your tummy and rub your head at the same time? Why is it much harder to do so with each hand moving at a different rate?

1	2	3	4	5	6
X		X		X	
X			X		



"Nice cup of tea"



“Eat your goddamn spinach”

Time to Think!!

A *motor program* is (was?) a concept frequently used in explaining action.

In what ways might this metaphor (computer program -- motor program) be misleading?

Program:

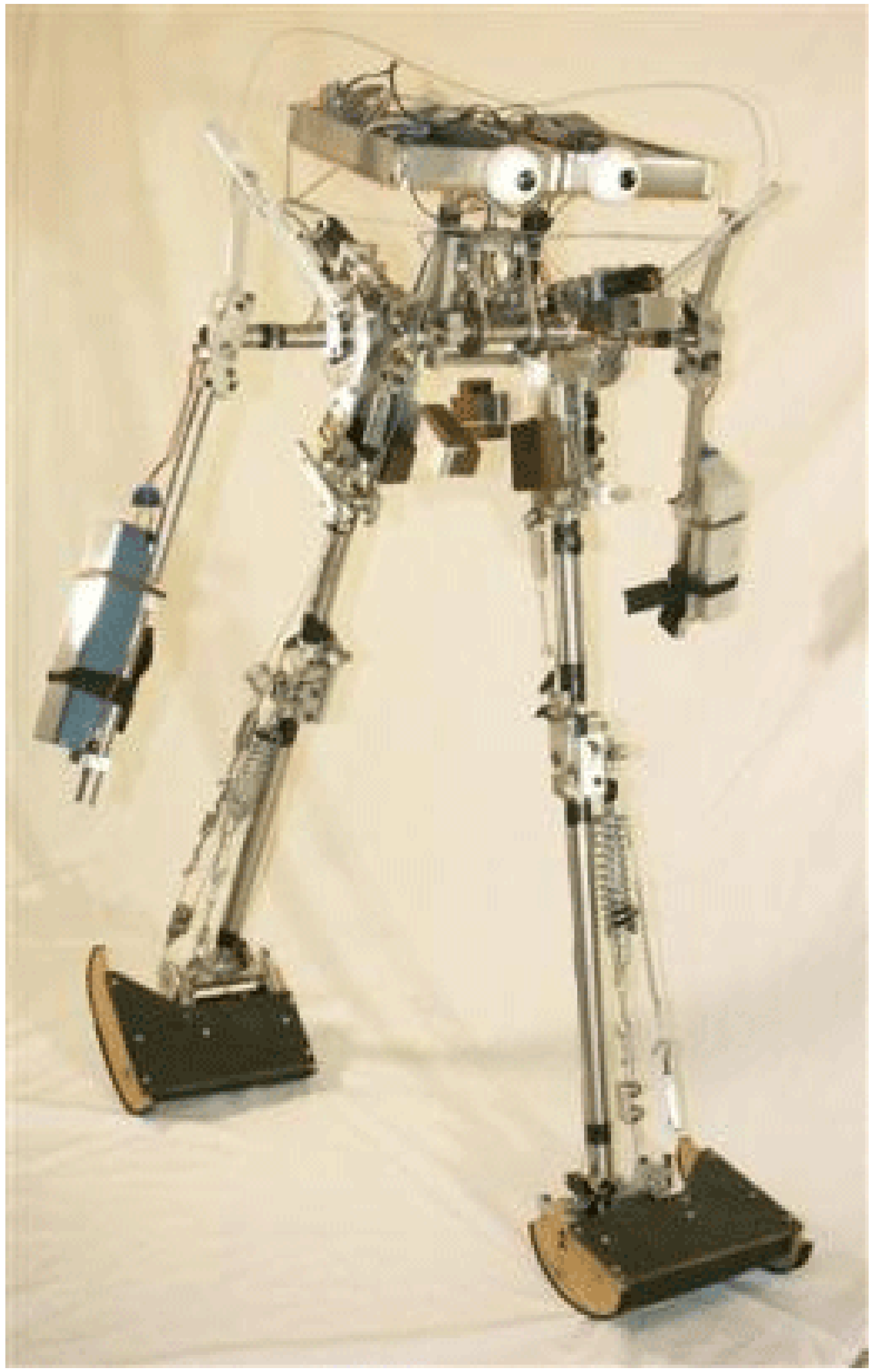
A central executive *instructs* subservient parts as to what they are to do and when.

The chain of *command* is from the centre to the periphery, although some role for feedback might be included.

Using the 'program' metaphor, there appears to be a fundamental divide between the different parts of the system, and between the system and the environment.

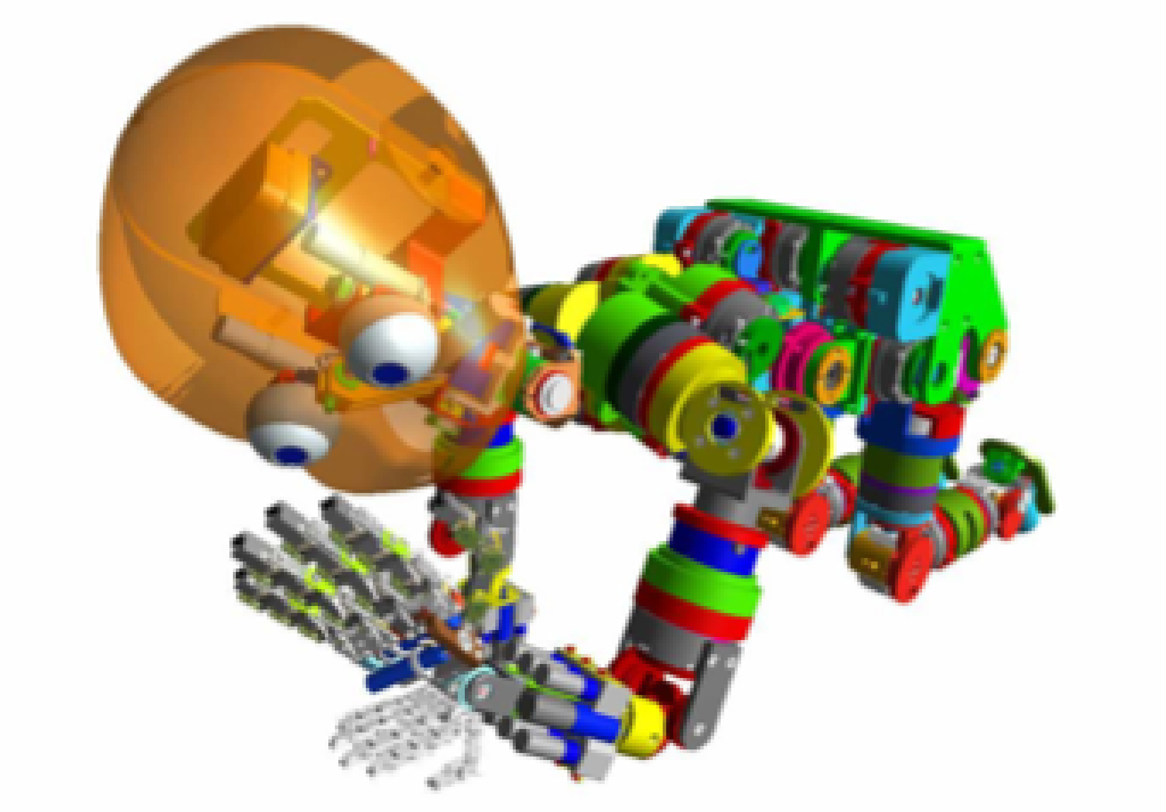
There is no simple chain of command
Brains are massively recurrently connected, with feedback loops everywhere

Testing Theories: Building Robots



Cornell

Rodney Brooks: Ghengis



iCub: www.robotcub.org

Asimo

Big Dog, Boston Dynamics, 2010

Atlas, 2016

Handle, February 2017. Note endpoint control.

https://www.youtube.com/watch?v=-7xvqQeoA8c

Founded in 1992, Boston Dynamic's research was almost all classified, as it was developed exclusively for the military

In 2013, Google bought Boston Dynamics.

Mission: To search . . . and destroy?

In 2013, it was sold on to a Japanese Bank.

Serial Order

Locomotion is roughly periodic.

Coordination is largely a matter of aligning the relative phase of several oscillators.

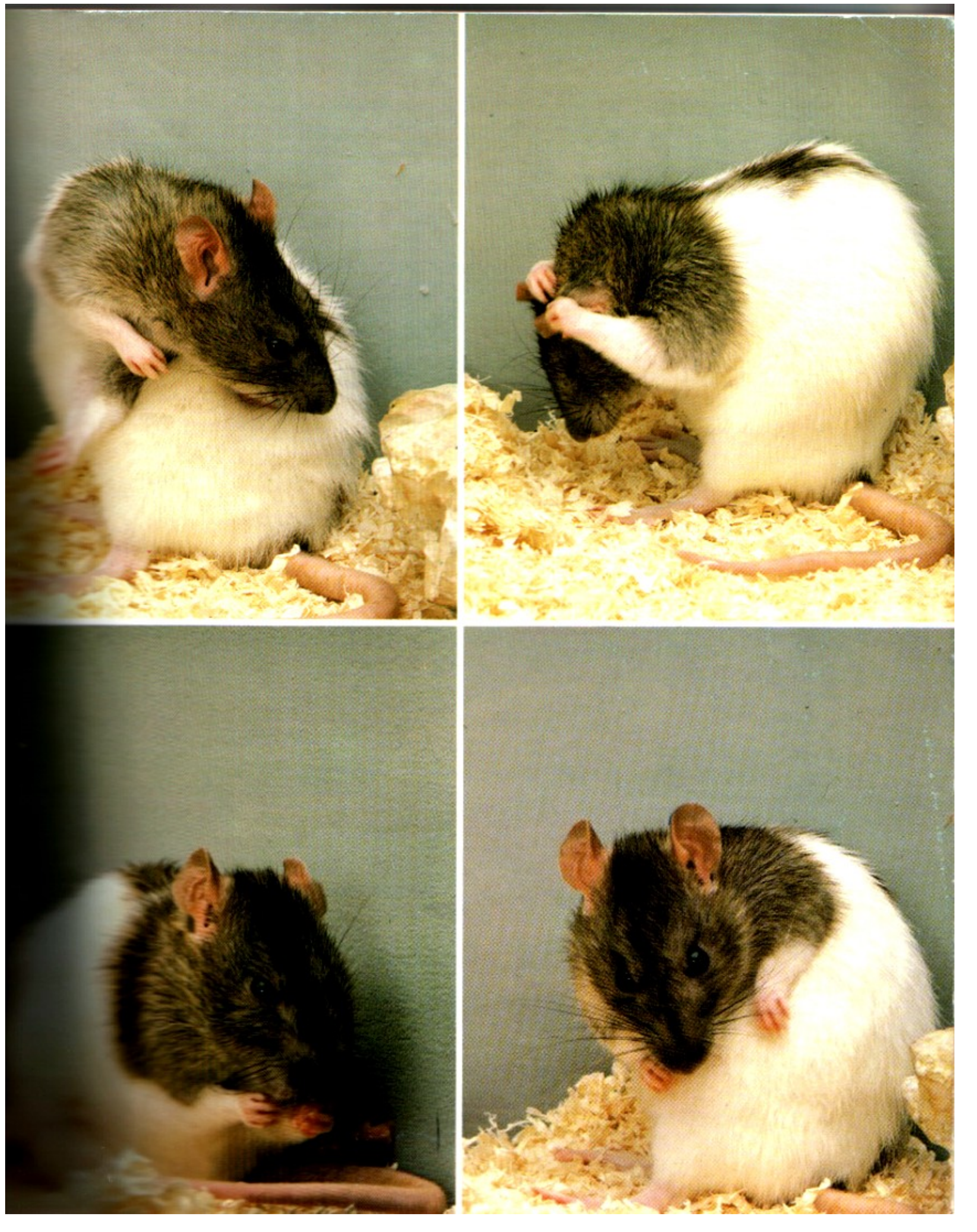
More complex actions are not simply periodic.

For example, speech is not simply repetitive, but requires complex sequences of movements in accordance with the regularities of a language

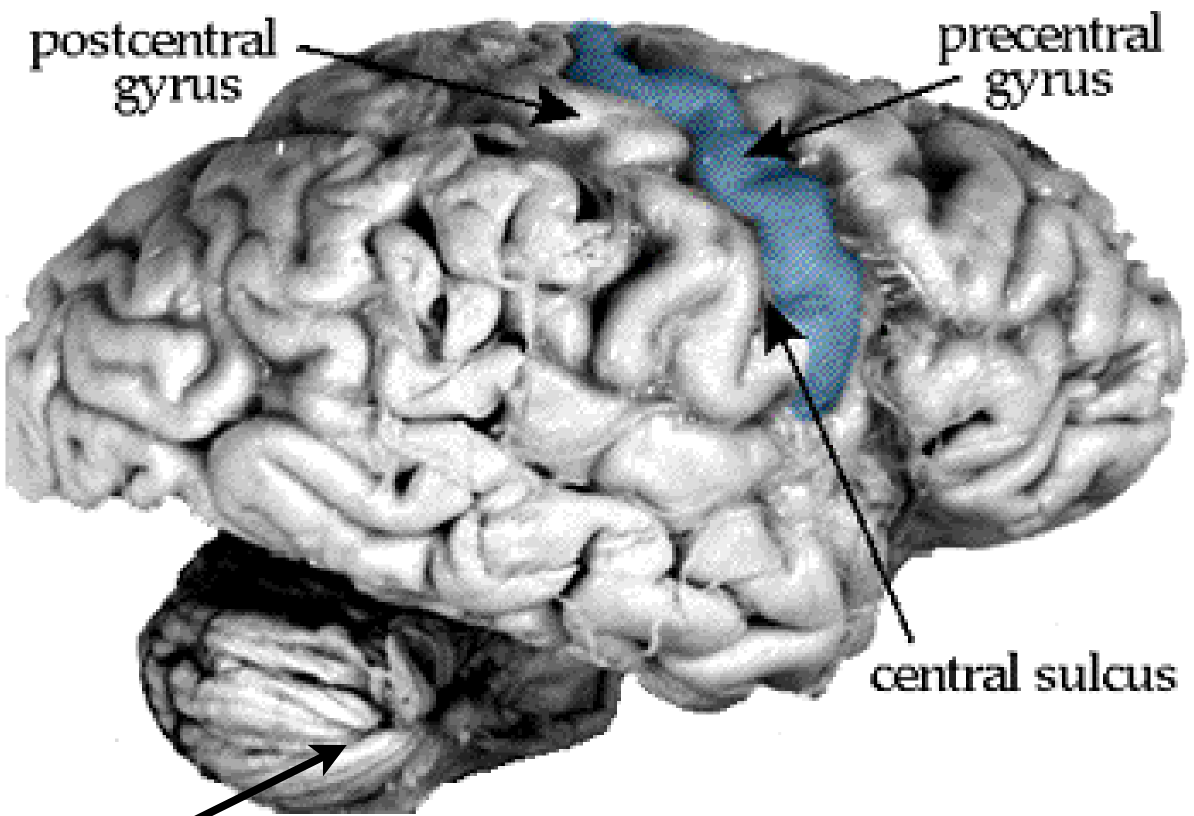
Rodent Grooming has its own Syntax

Specific nerve bundles have been identified that code the sequence (rather than its parts)

There may be common abstract principles underlying even such complex behavior as speaking, if we view syntax as a matter of sequencing and coordination

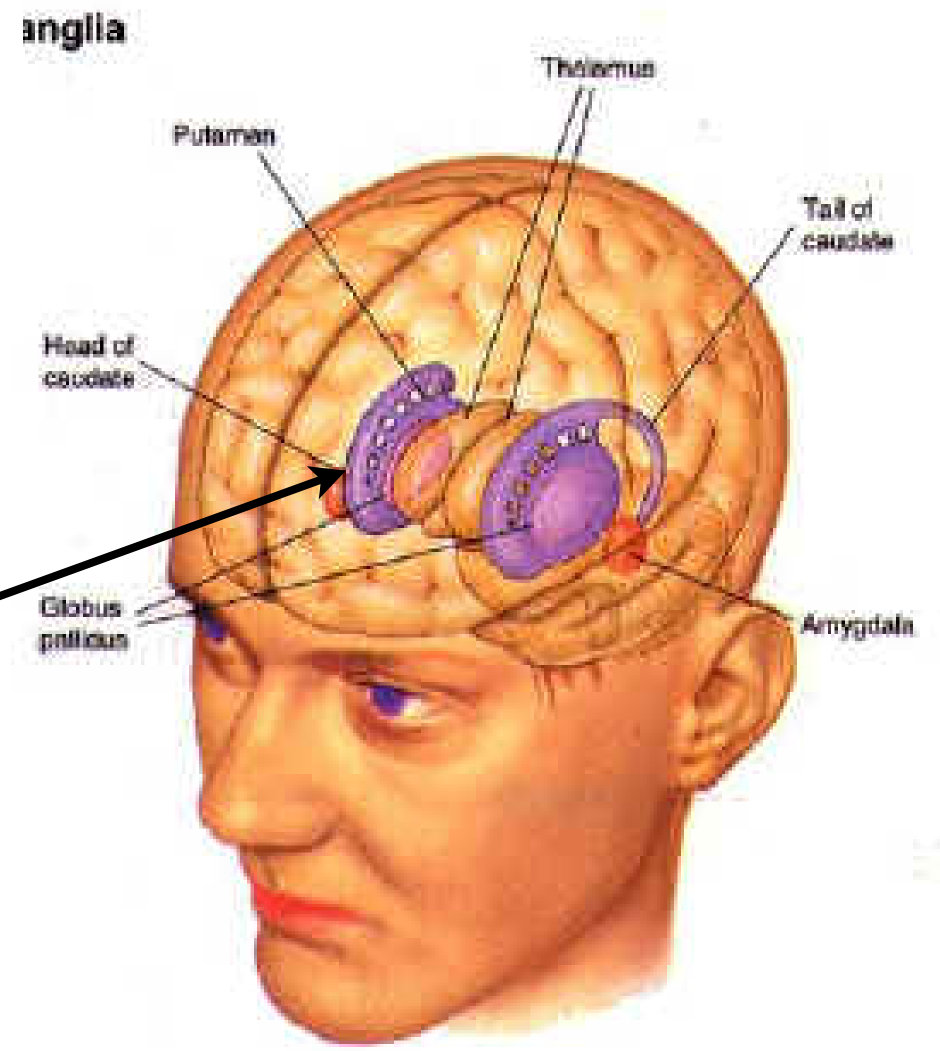


Principal parts of the nervous system involved in movement...

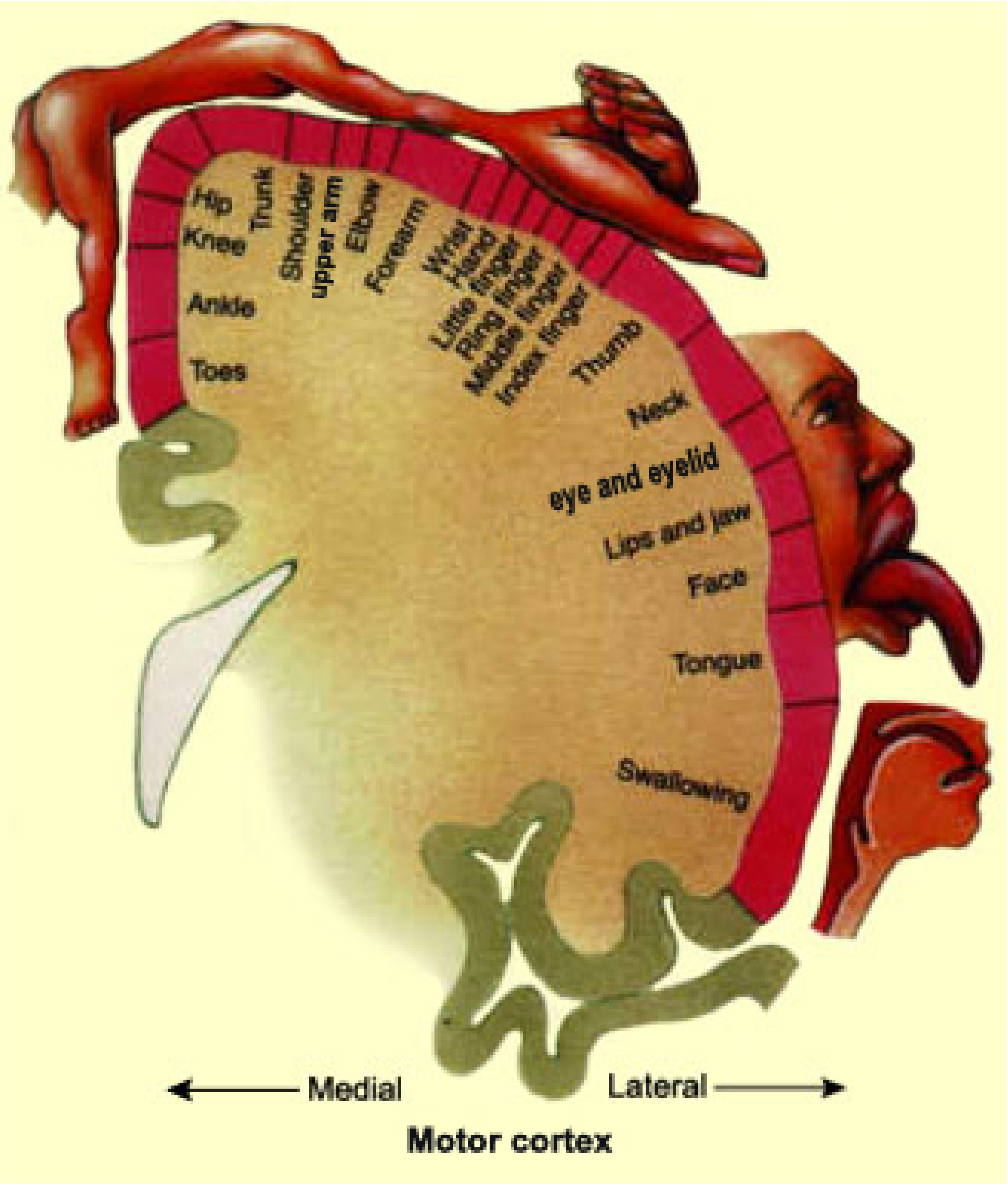


(primary motor cortex)

cerebellum



basal ganglia

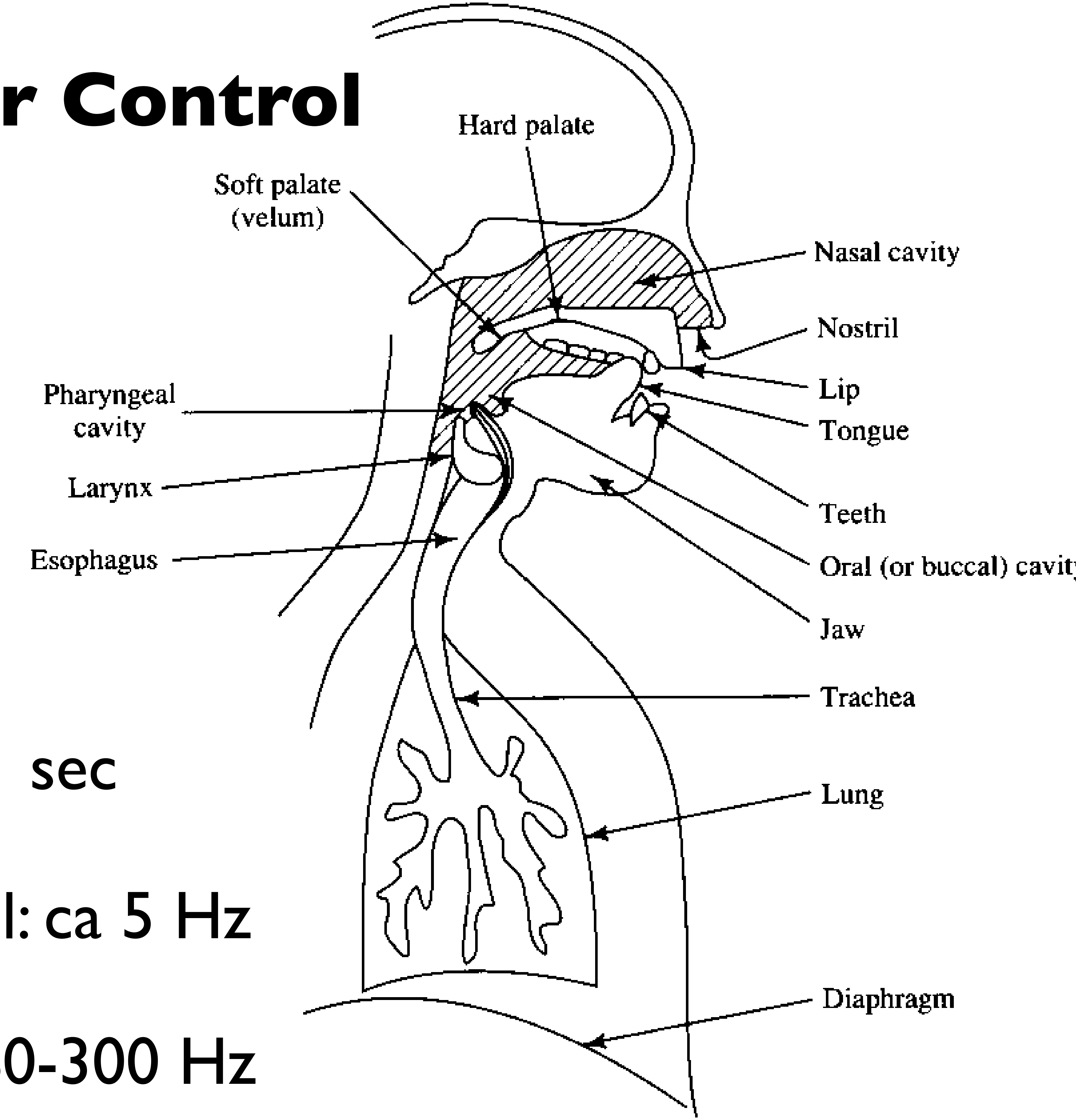

Hip
Trunk
Shoulder
upper arm
Elbow
Forearm
Wrist
Hand
Knee
Ankle
Toes
Little finger
Ring finger
Middle finger
Index finger
Thumb
Neck
eye and eyelid
Lips and jaw
Face
Tongue
Swallowing
Medial
Lateral
Motor cortex

Unilateral cerebellar ataxia: Dyssynergia

Hypokinetic Gait (Parkinsons, basal ganglia underfunction)

Motor cortex	Principal source of nerve impulses to muscles
Cerebellum	Stability, posture, control of well learned coordinations
Basal ganglia	Sequencing and fine tuning of sequences of skilled actions

Speech Motor Control



Breath control: > 1 sec

Articulator control: ca 5 Hz

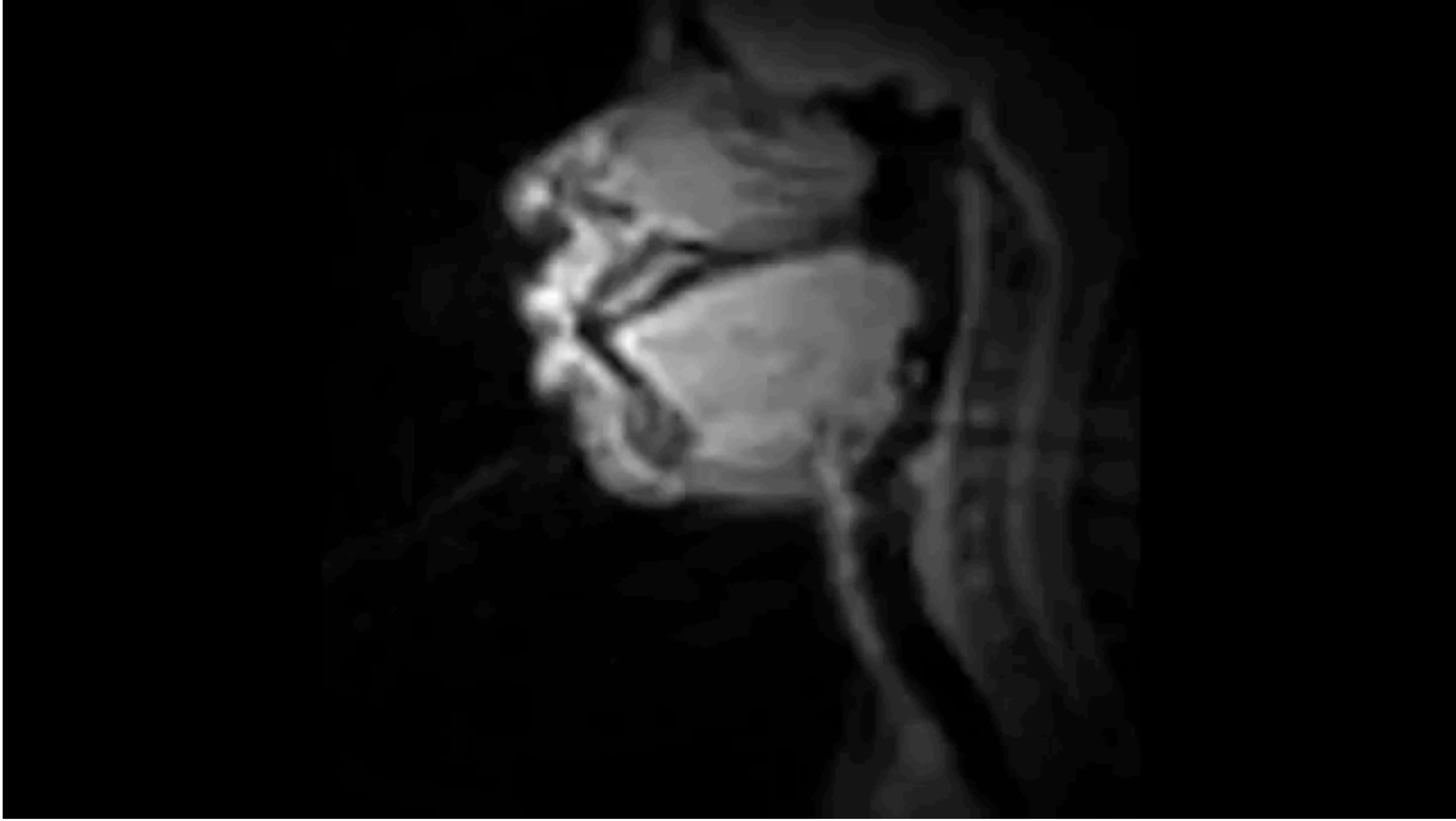
Glottal vibration: 80-300 Hz

Is speech movement special?

Moving parts (articulators) are in relative isolation from the outside environment

Coordination of movement at a vast range of timescales, from very fast to quite slow (breathing)

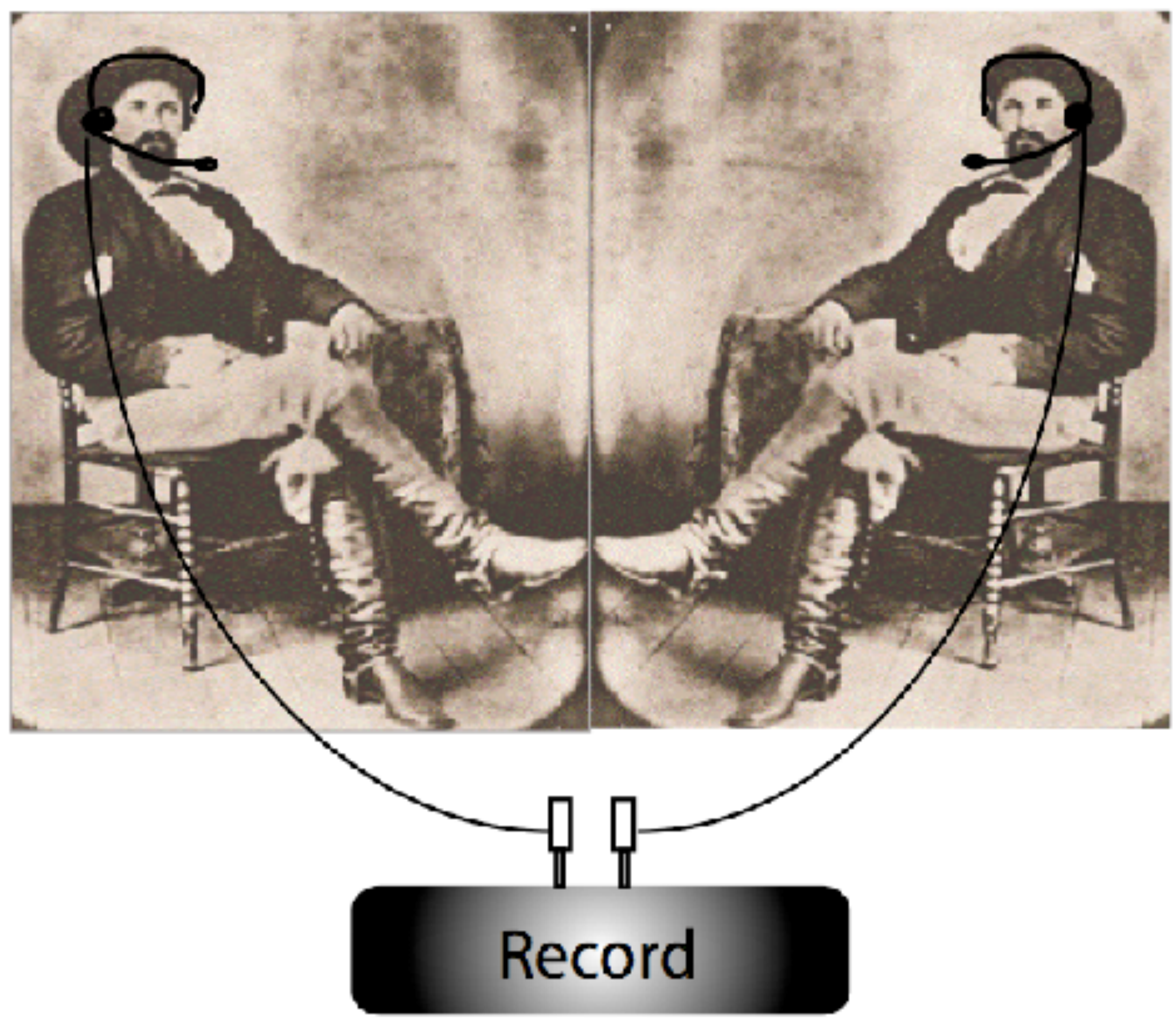
Must manage to convey symbolic, discrete information at a high transmission rate

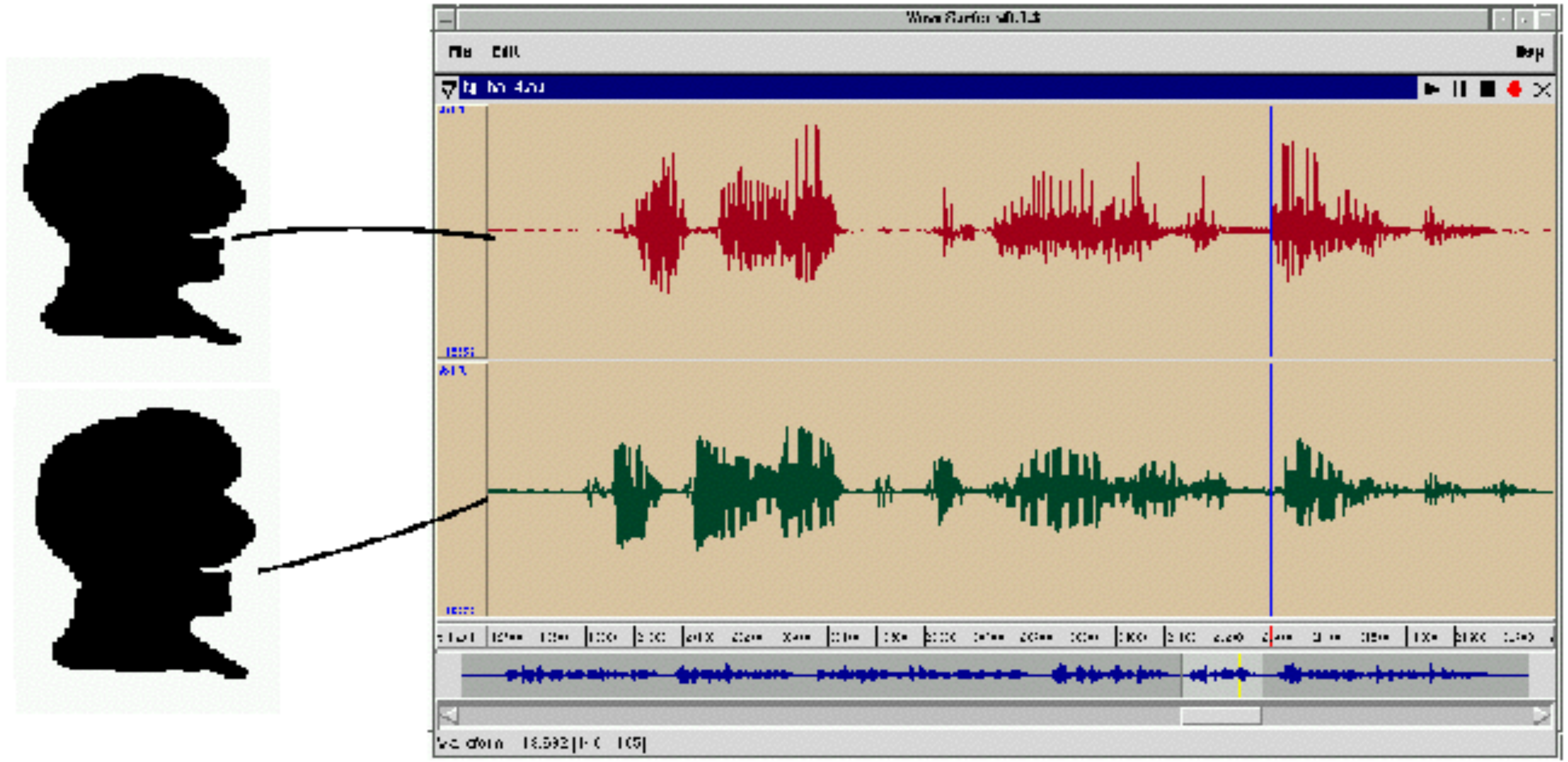


Real time MRI of speech production
USC-EMO-MOR corpus for emotional speech

https://www.youtube.com/watch?v=T4KRbENmFDk

An Interesting Puzzle: Synchronous Speech

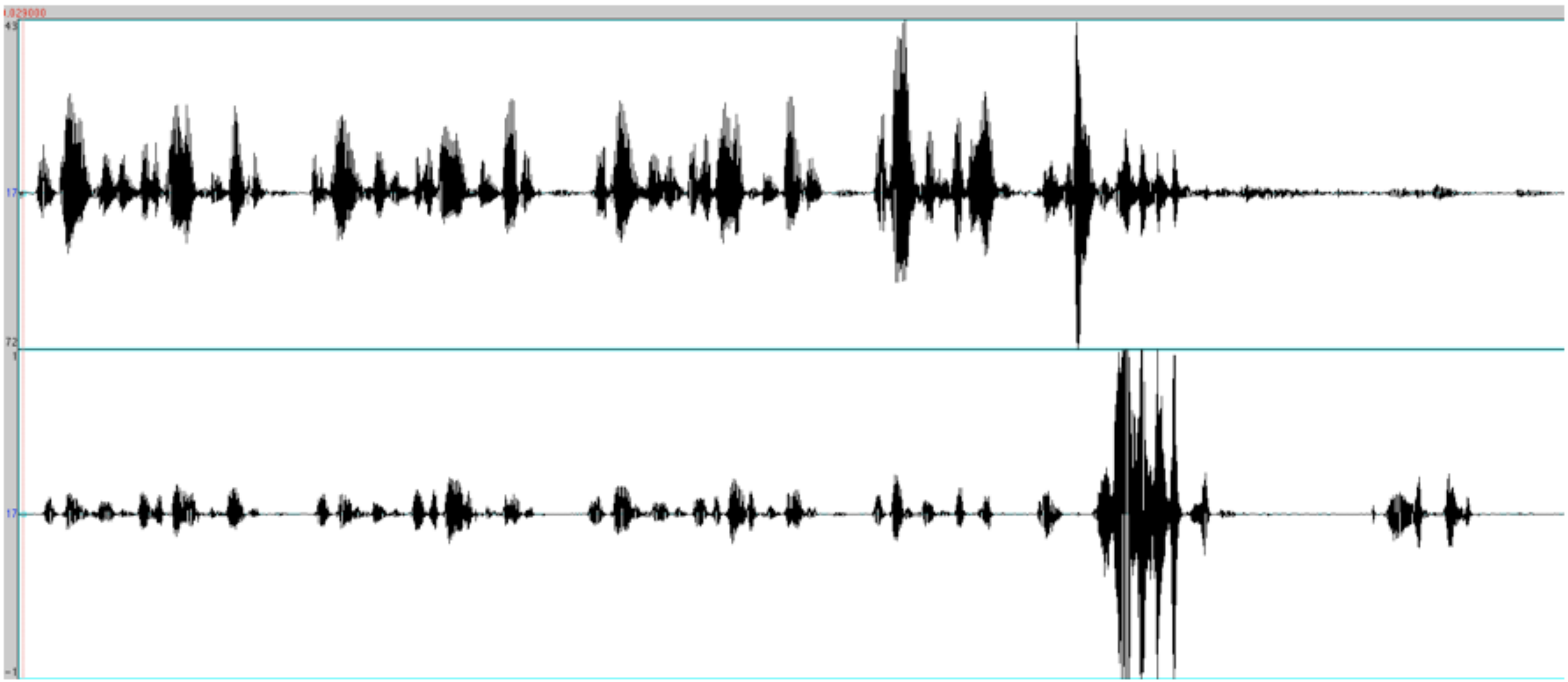




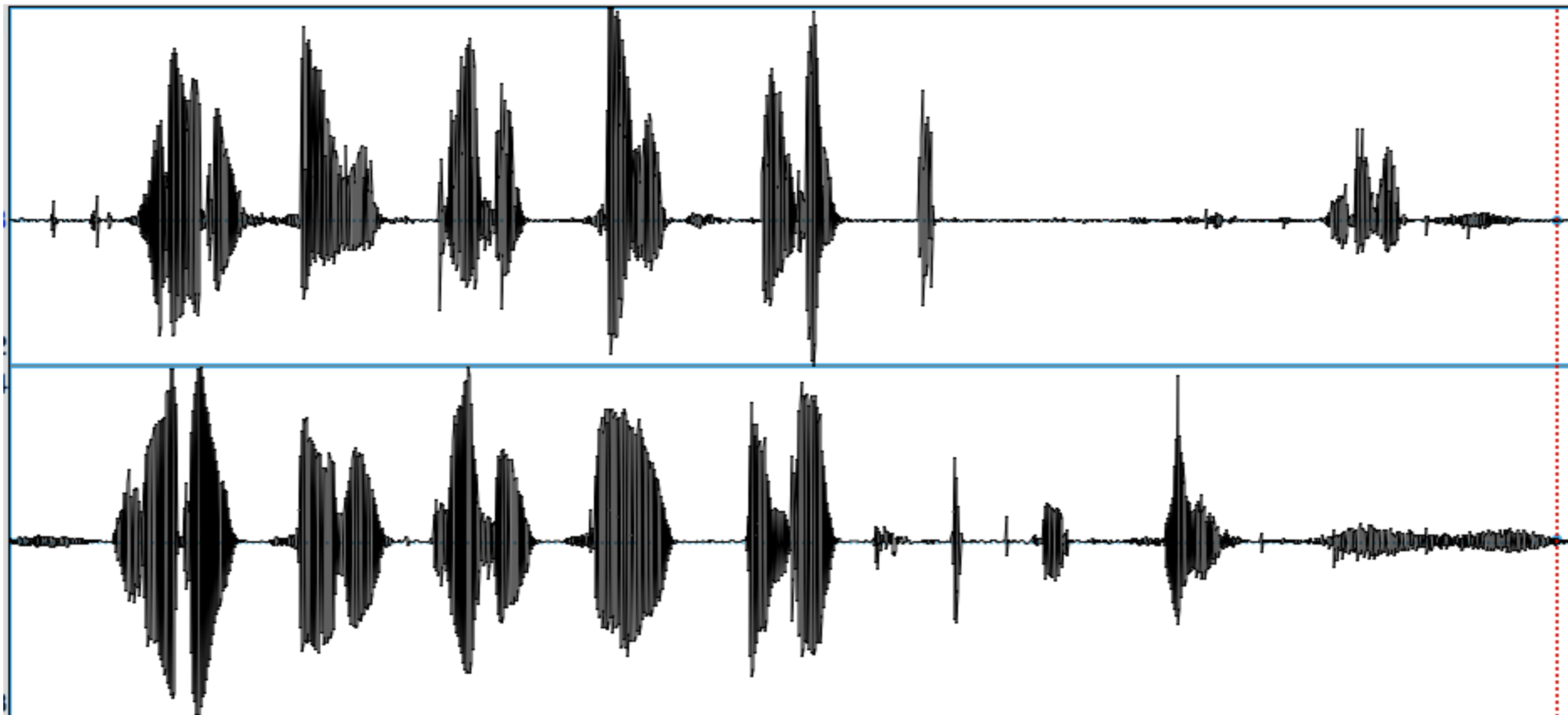
Synchrony is very tight: typical asynchrony ~ 40 ms.

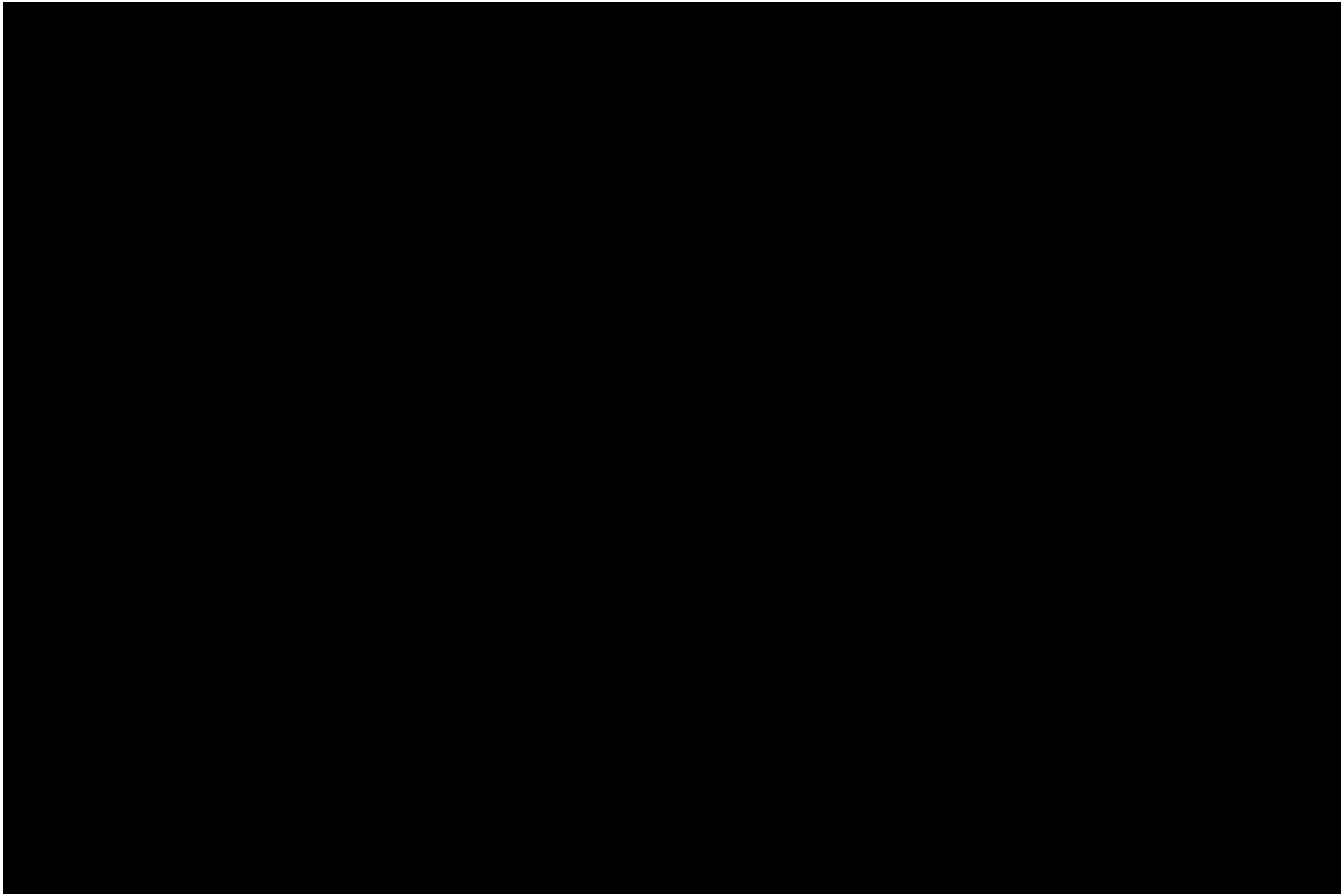
No periodic basis!

Disintegration of a 2-person coordinative domain



Example 2





Coda: Synchronization and Creativity

(If you are viewing the slides, there was a dolphin video here in the lecture)