A theory unifying movement, music and speech

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Essence of life

- All organisms, from cells to giant sequoias, comprise a set of moveable parts which they have to coordinate to couple with other organisms and with the inanimate environment.

Biological Information

- In order to coordinate movements, organisms must include an organized system of flow of biological information.
- Biological information is a temporal pattern of physical power, mainly electro-chemical power flowing in the nervous system, or equivalent system in cells.
- Biological information is a physical analogue quantity that does something directly, not via an arbitrary digital code.

Use of biological information

To control purposeful actions, by

- Prescribing actions
- Perceptually monitoring actions
- Performing actions

Nature of biological information

- Must be prospective
- Must be independent of the level of physical power
- Must be specific to its source
- Must fit with physical laws -
  notably the Inverse Square Law

Rho/Tau
Body-environment perceptual information

- Intensity of stimulation at a receptor is proportional to (intensity of source)/(square of distance away).
- Means that distance away is not specified.
- Thus, there is no direct information about distance, velocity, acceleration, or jerk of the gap between source and receptor.
- The only information that is directly available is Rho,

the relative-rate-of-change $(dX/dt)/X$ of the gap, *X*, to the receptor

(or Tau, the inverse of Rho).

- Rho of intensity at receptor = -2 x rho of distance away (from the Inverse Square Law).

Stimulus Rho => Perceptual Neural Rho

- Rho (optical power) => Rho (neural power)
- Rho (acoustic power) => Rho (neural power)
- Rho (chemical power) => Rho (neural power)
- Rho (mech. power) => Rho (neural power)
- Rho (thermal power) => Rho (neural power)
- Rho (electric power) => Rho (neural power)

Rho/Tau
The currency of biological information

Biological information must be in the same currency, of the same form, both within and across organisms, to make coupling of movements efficient. Since, as shown, rho/tau is the perceptual information currency, this must be the general biological information currency.

Controlling movement requires three functional Rhos

- Prescriptive
- Perceptual
- Performatory

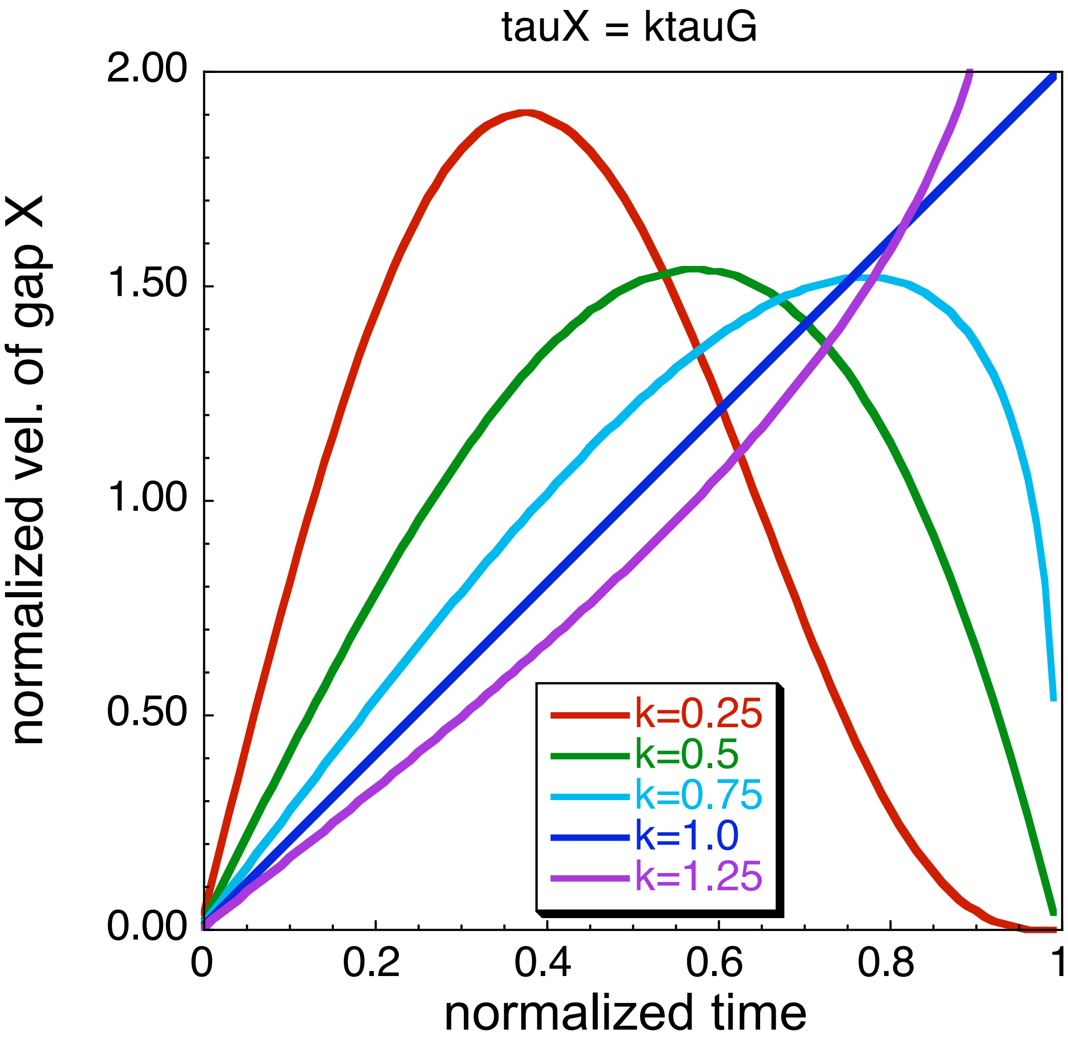
Prescriptive Rhos

A hypothesised prescriptive rho is founded on the ecological invariant gravity. It is $\lambda\rho_G$, which equals the rho of the gap between an object falling from rest to the ground, multiplied by an 'oomph' factor, λ. That is

$$\rho(X) = \lambda\rho_G = 2\lambda t / (t^2 - T^2)$$

where *T* is the total movement duration and time *t* = 0 to *T.*

Effect of the oomph factor k (=1/λ) on the velocity of closure of a gap X



Activities found to use RhoG/TauG-coupling

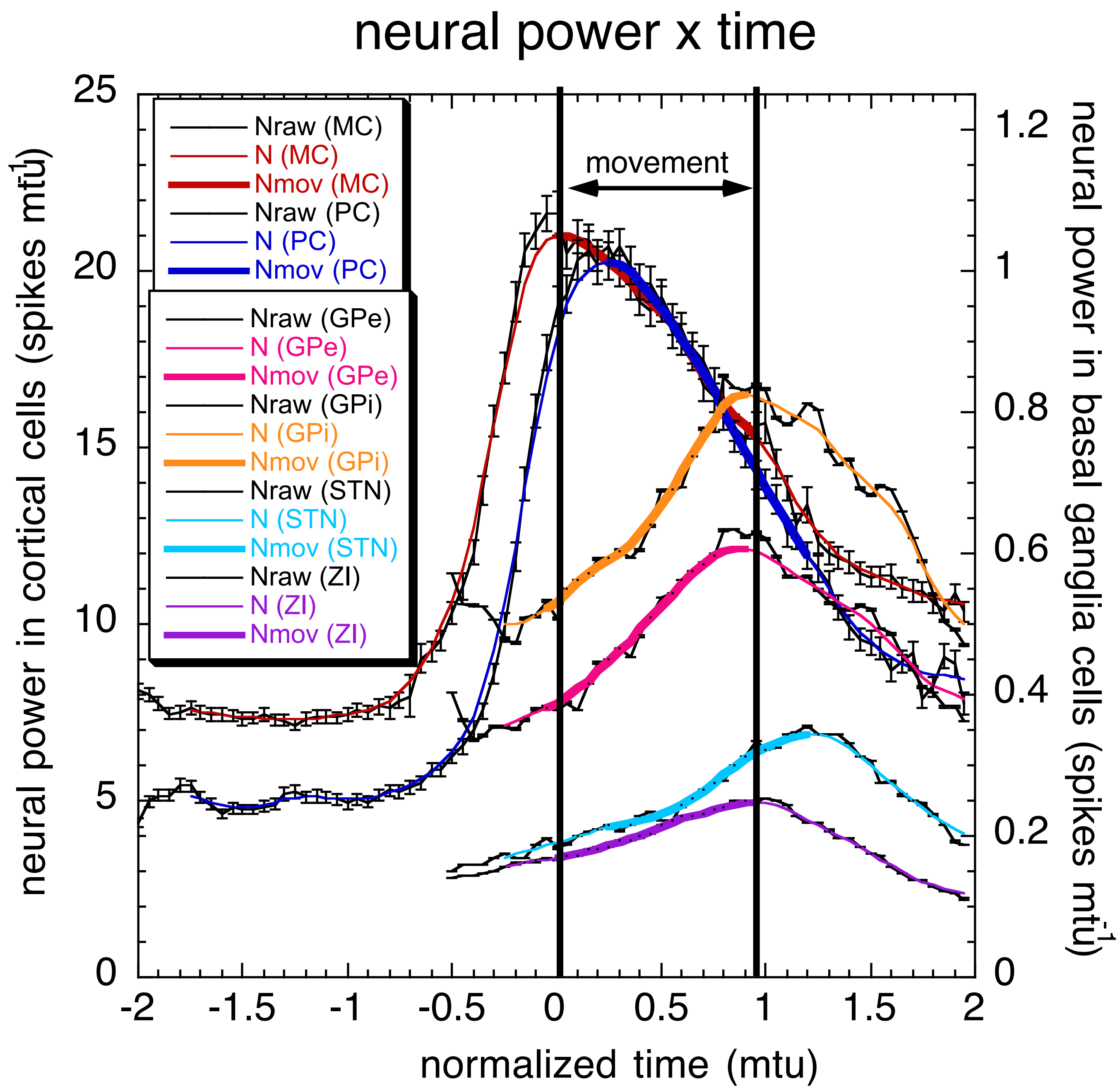
- Flying (bats, birds, humans)
- Gesturing (babies)
- Hitting (golf)
- Intercepting and catching
- Playing musical instrument
- Reaching
- Running
- Singing
- Suckling (babies)
- Swimming (cells)

Function of Basal Ganglia in Controlling Action

- Single unit and movement recording from rhesus monkeys reaching to targets.

Regions recorded:

- Gpe: globus palidus ext.
- Gpi: globus palidus int
- STN: sub-thalamic nucleus
- ZI: zona inserta



neural power x time
Nraw (MC)
N (MC)
Nmov (MC)
Nraw (PC)
N (PC)
Nmov (PC)
Nraw (GPe)
N (GPe)
Nmov (GPe)
Nraw (GPi)
N (GPi)
Nmov (GPi)
Nraw (STN)
N (STN)
Nmov (STN)
Nraw (ZI)
N (ZI)
Nmov (ZI)
movement
neural power in cortical cells (spikes mtu-1)
neural power in basal ganglia cells (spikes mtu-1)
normalized time (mtu)
25
20
15
10
5
0
1.2
1
0.8
0.6
0.4
0.2
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Conclusions: Functions of Basal Ganglia

- GP involved in creating the prescriptive neural power for rhoG.
- STN involved in monitoring the perceptual neural power about the action.
- ZI involved in combining the prescriptive and perceptual neural powers to create a performative neural power to the muscles.

Summary 1
Body-environment-coupling law

$$\rho(NP) = \lambda\rho(EP)$$

NP = power flowing in neurons

EP = power flowing from environment to body

Summary 2
Neural Information for Creating Actions

$$\rho(NP_{perceptual})$$

$$\rho(NP_{prescriptive}) = \rho_G$$

$$\rho(NP_{performatory})$$

<u>Note</u>: All are <u>vectors</u>

RhoG/TauG-coupling makes possible coordination and coupling of movements

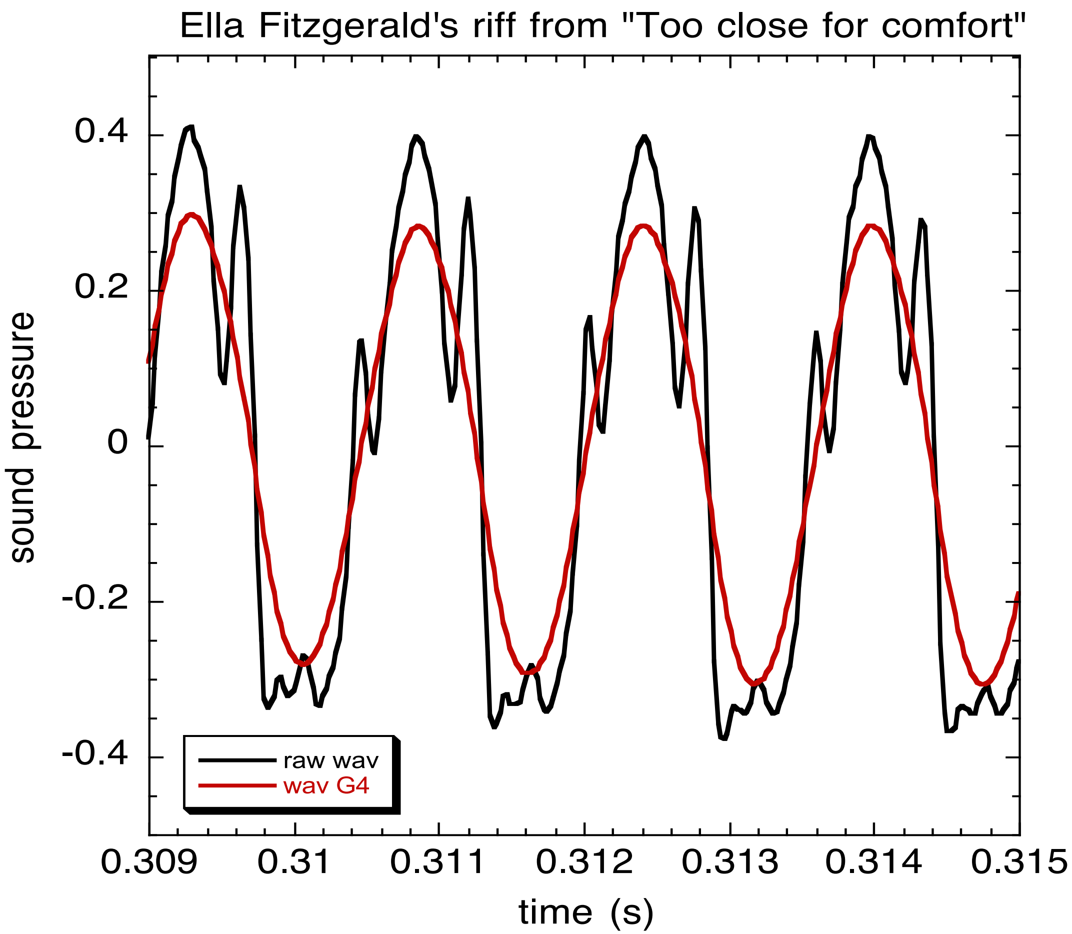
Some examples follow

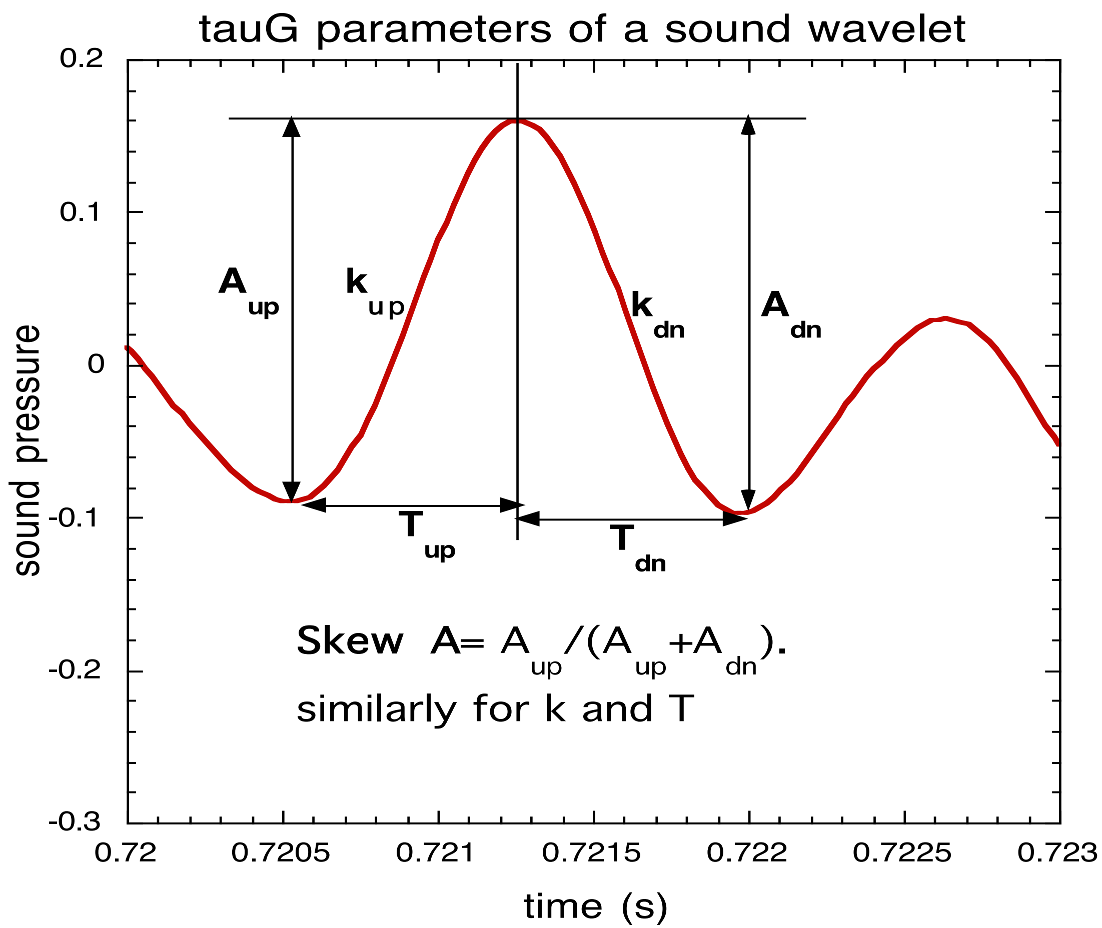
Ella Fitzgerald and one-day-old baby in duet

Ella

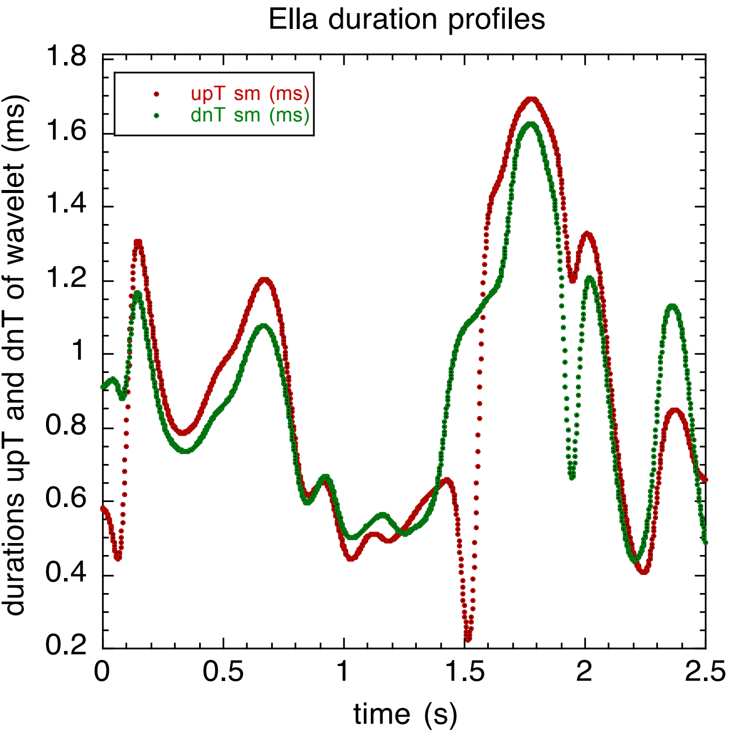
baby

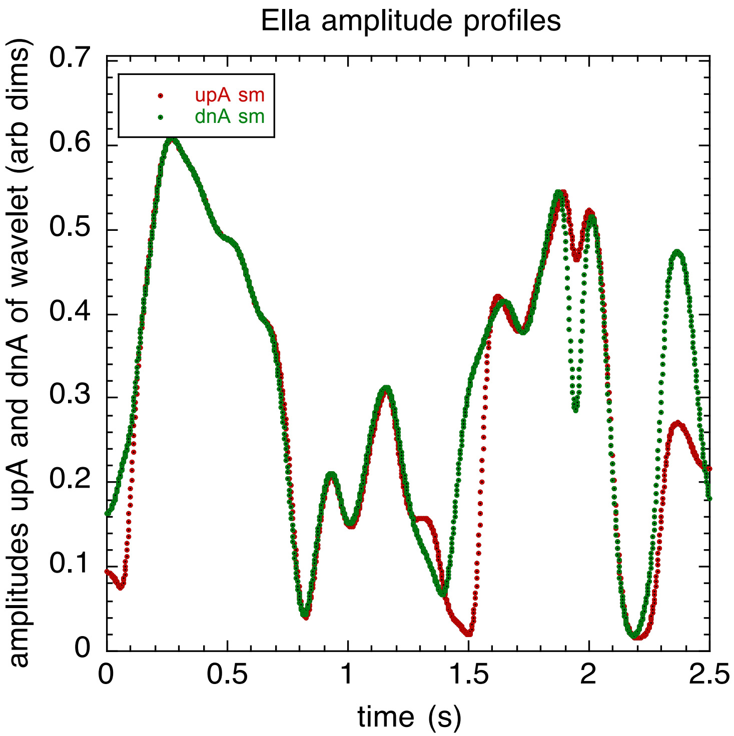
Acoustic motion wavelets

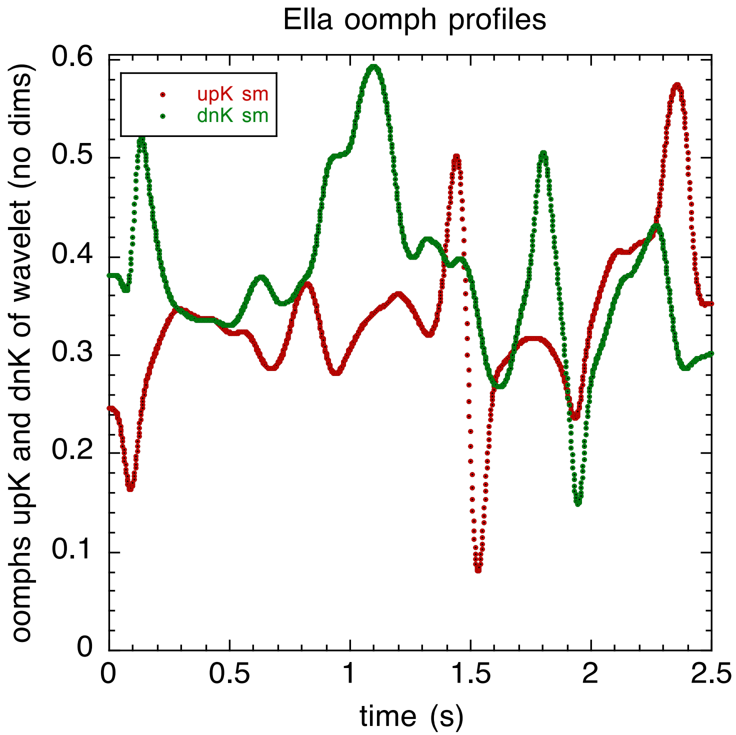




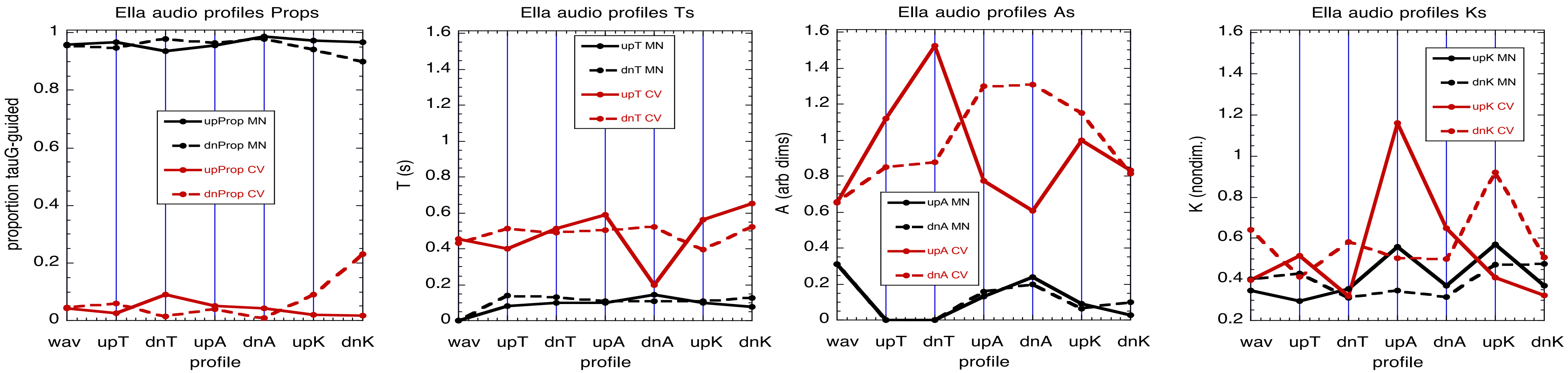
Acoustic motion parameter profiles





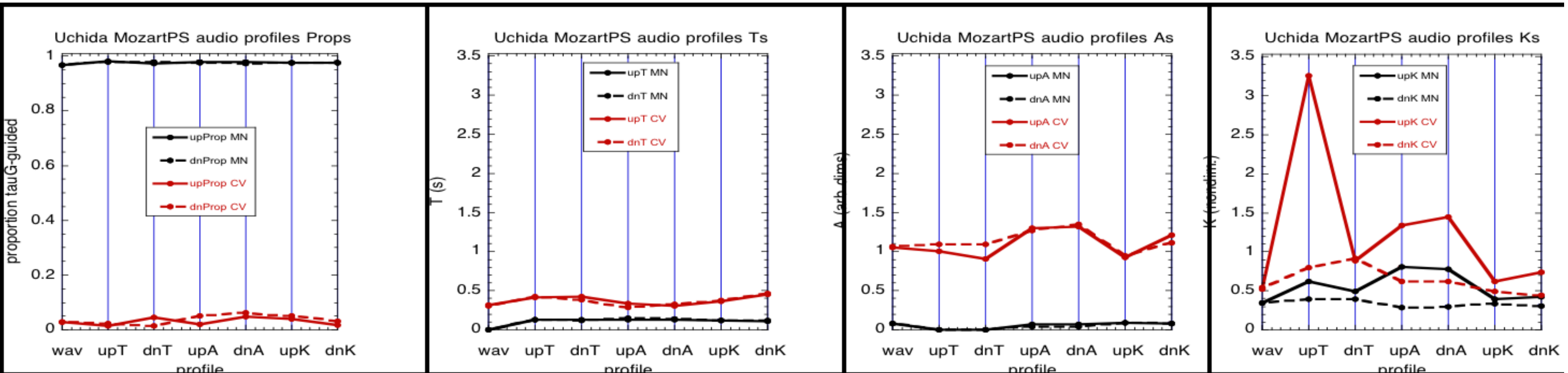


Measures on acoustic motion wavelets & profiles

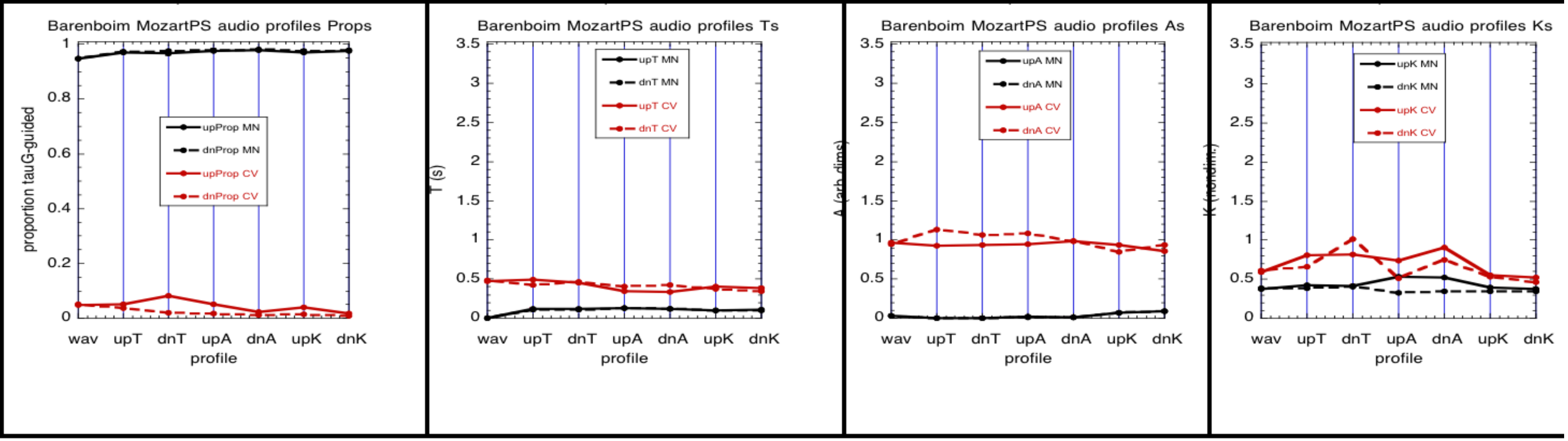


2 pianists playing same piece, different expression

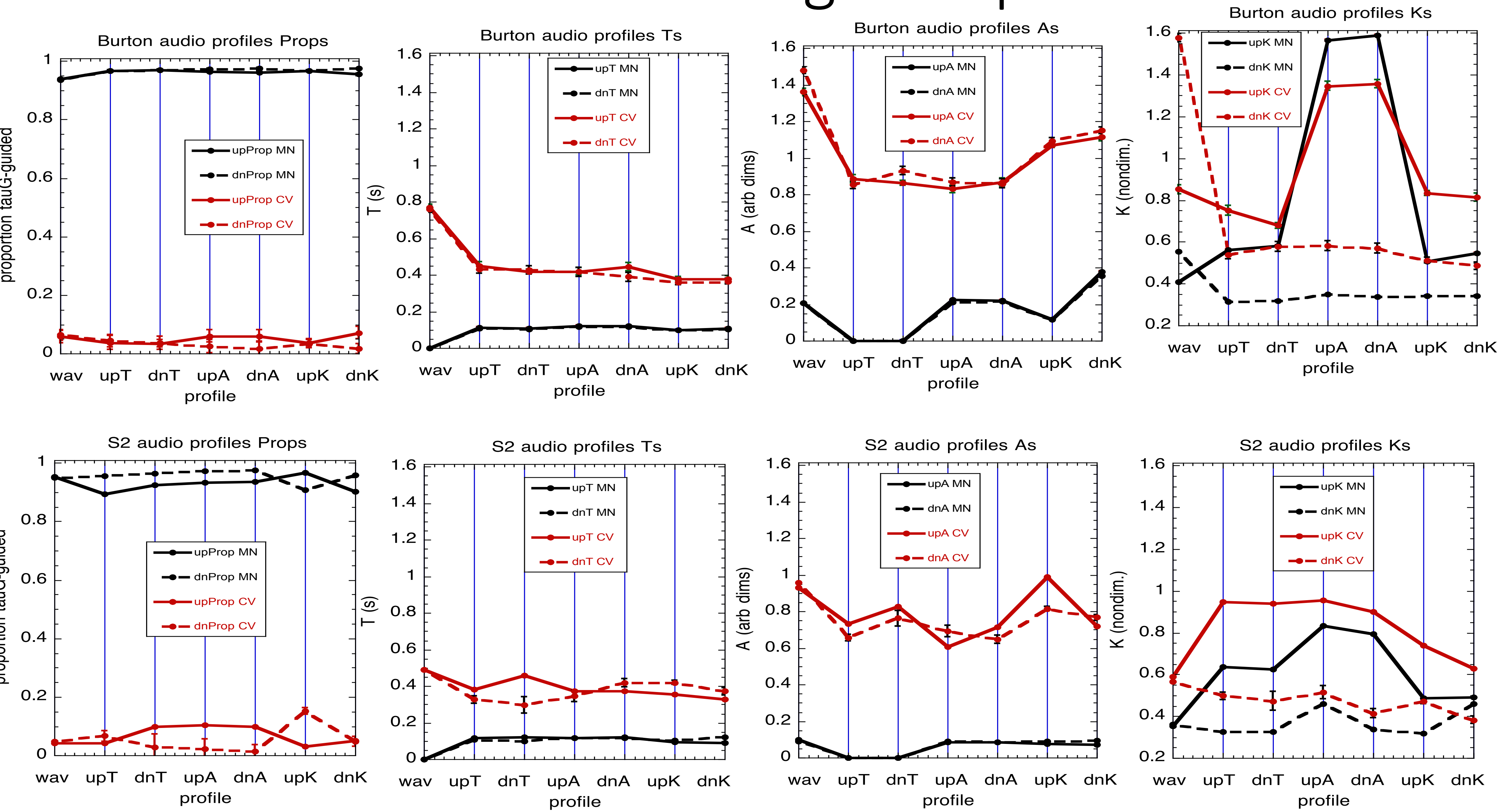
60s clip from Mozart piano sonata K545 andante



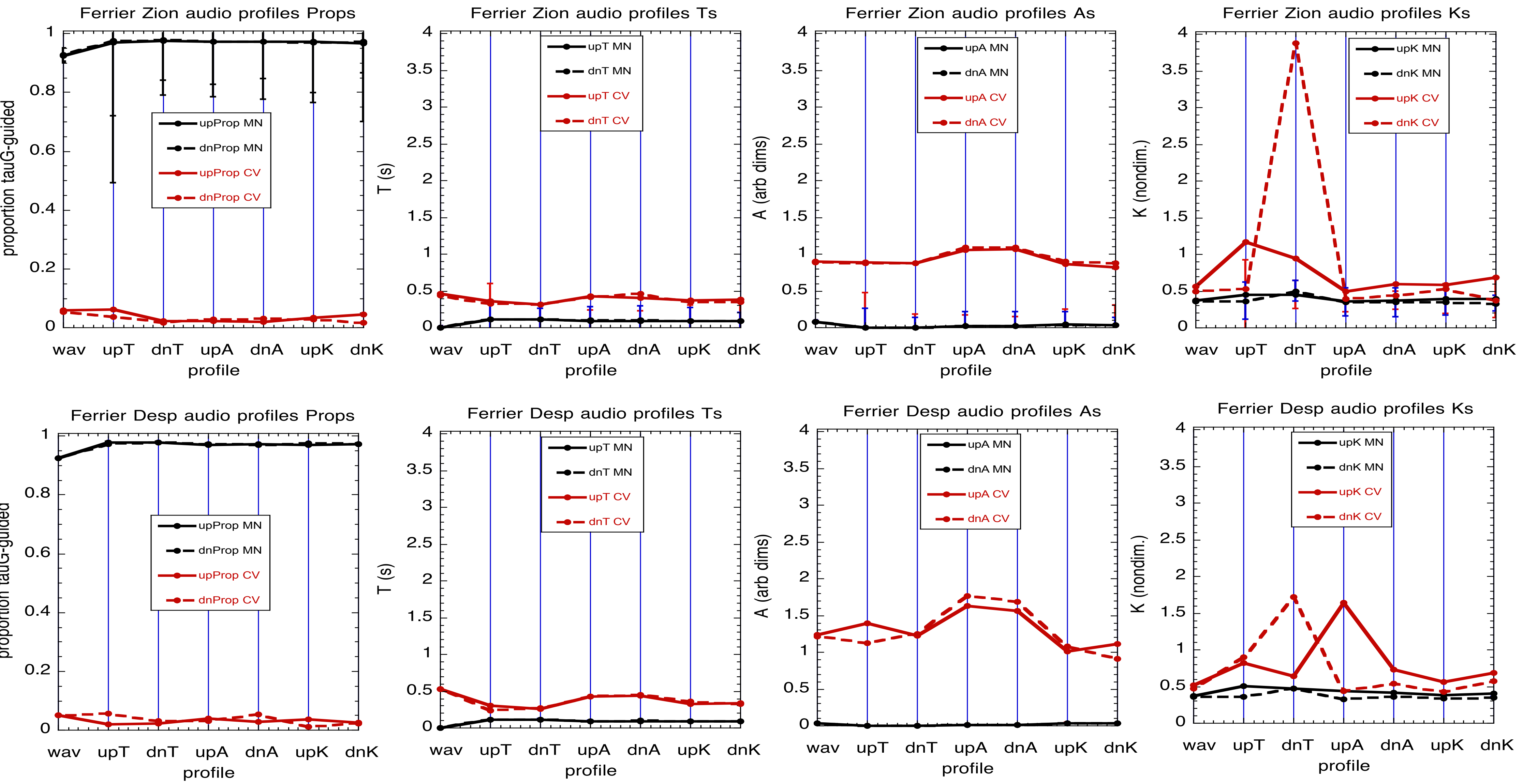
Result: the flexibility (cv) in use of *K* is higher for the upper more expressive pianist



Recitation vs regular speech



Joyful vs Sad Handel’s Messiah



Sprinting
(red lines - tauG-coupled movements)

Principal collaborators

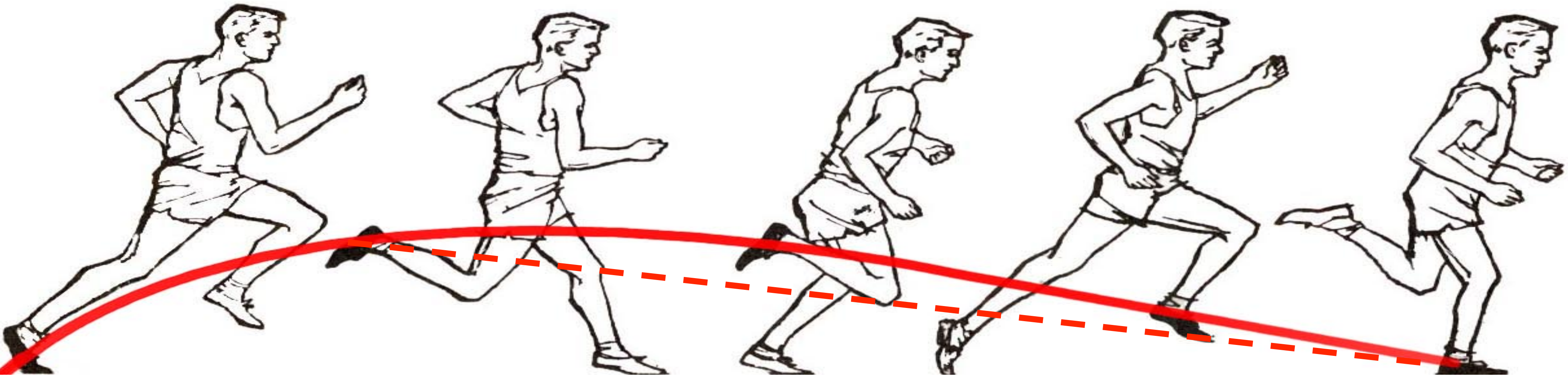
Malcolm Fairweather

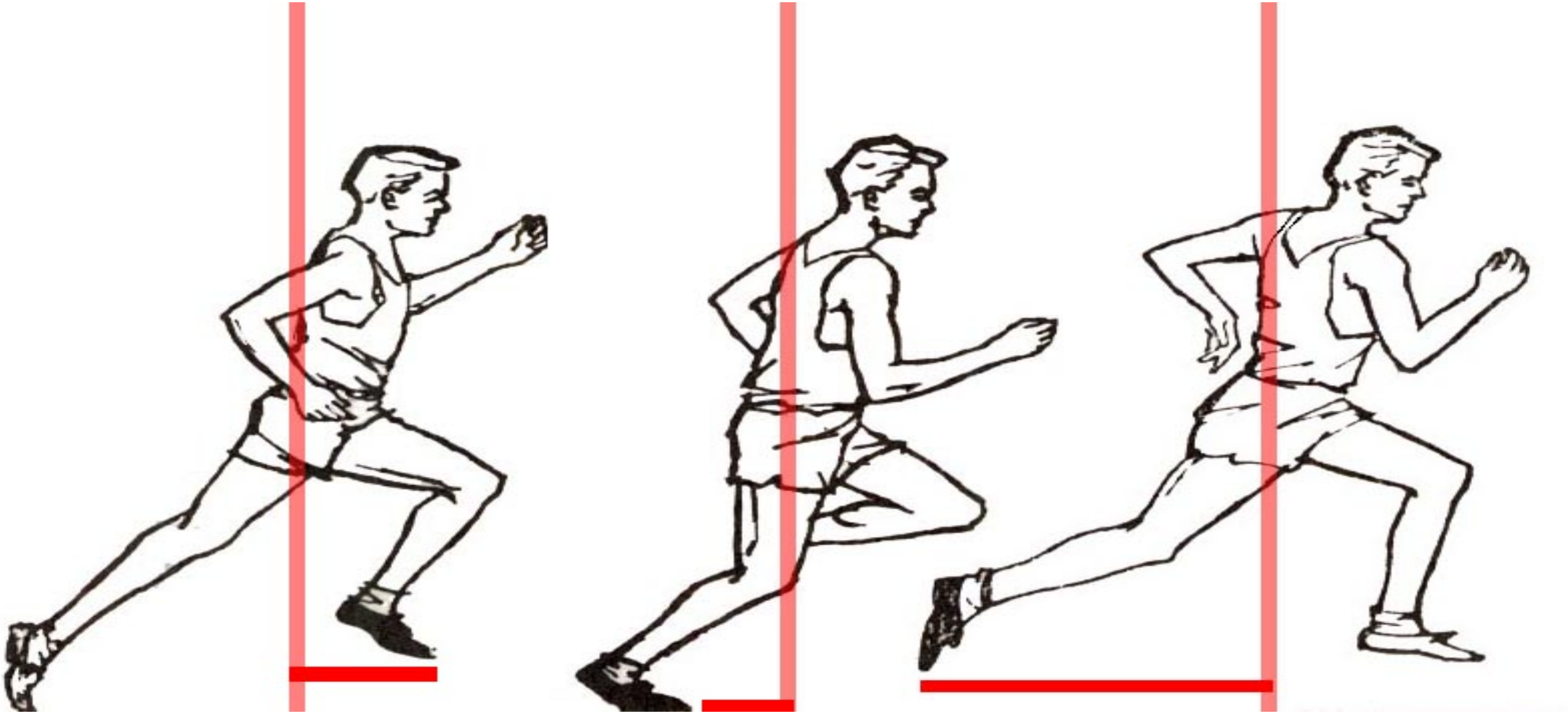
Madeleine Grealy

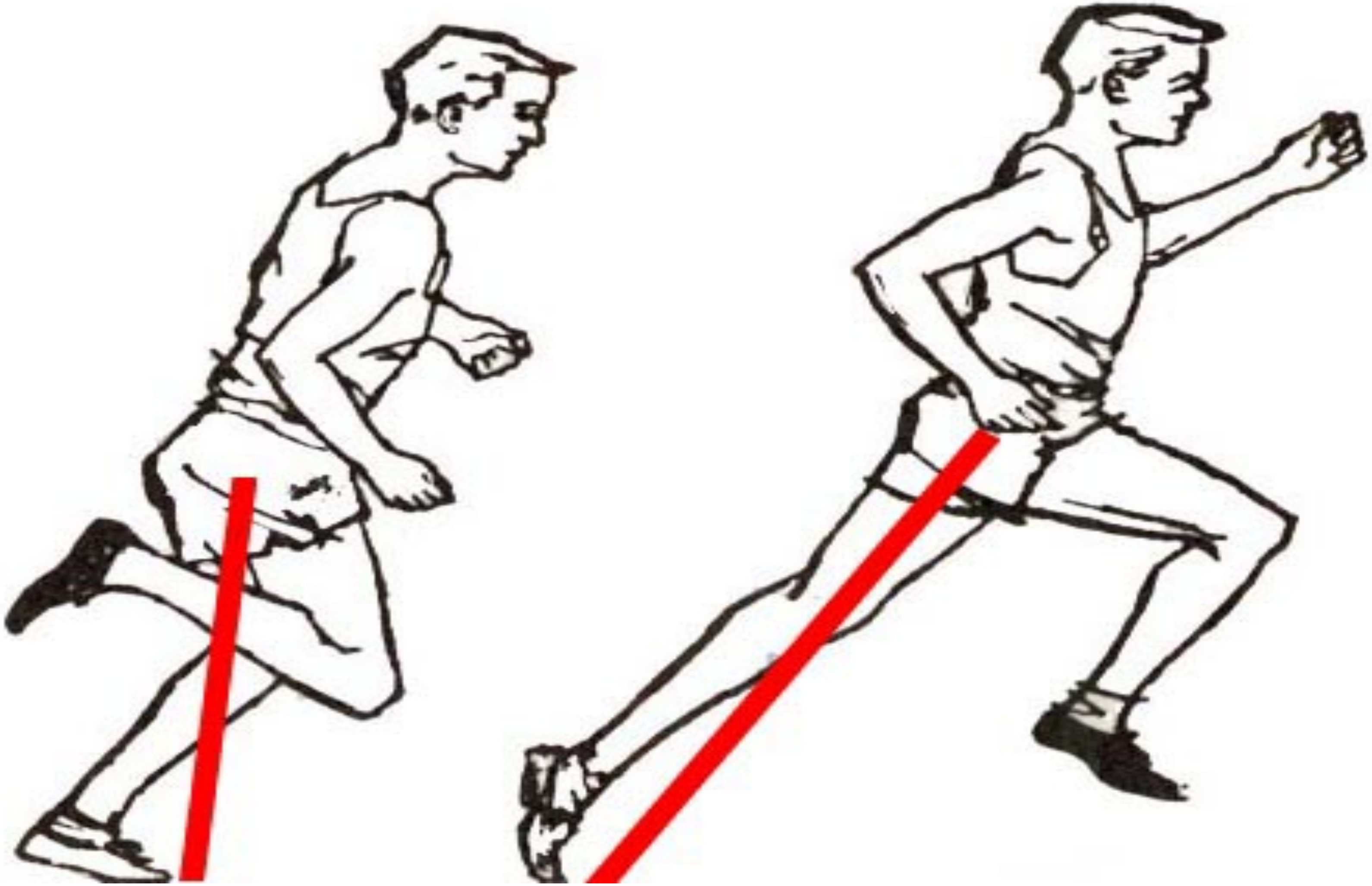
Gert-Jan Pepping

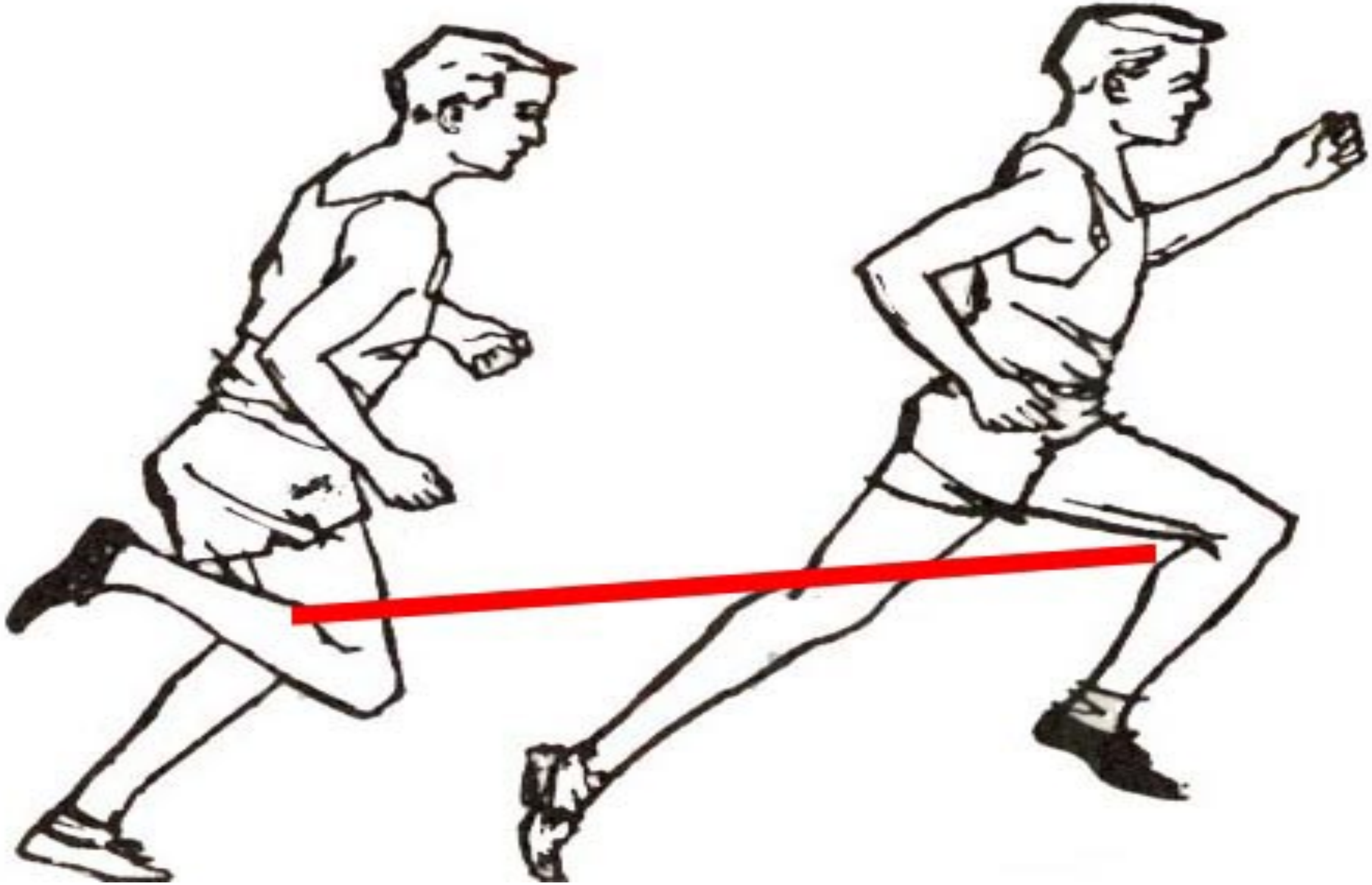
Dennis Rewt

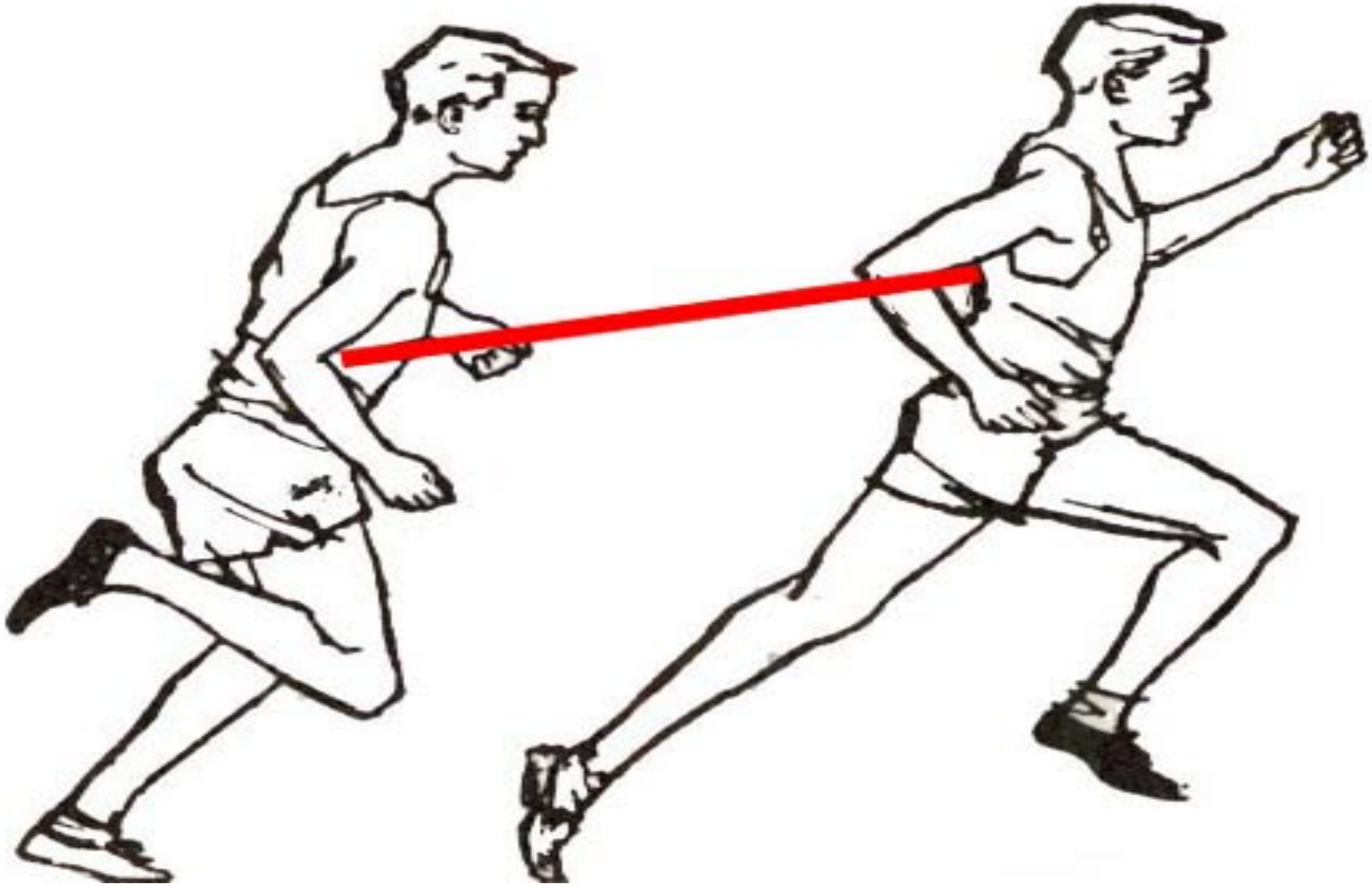
Benjaman Schogler

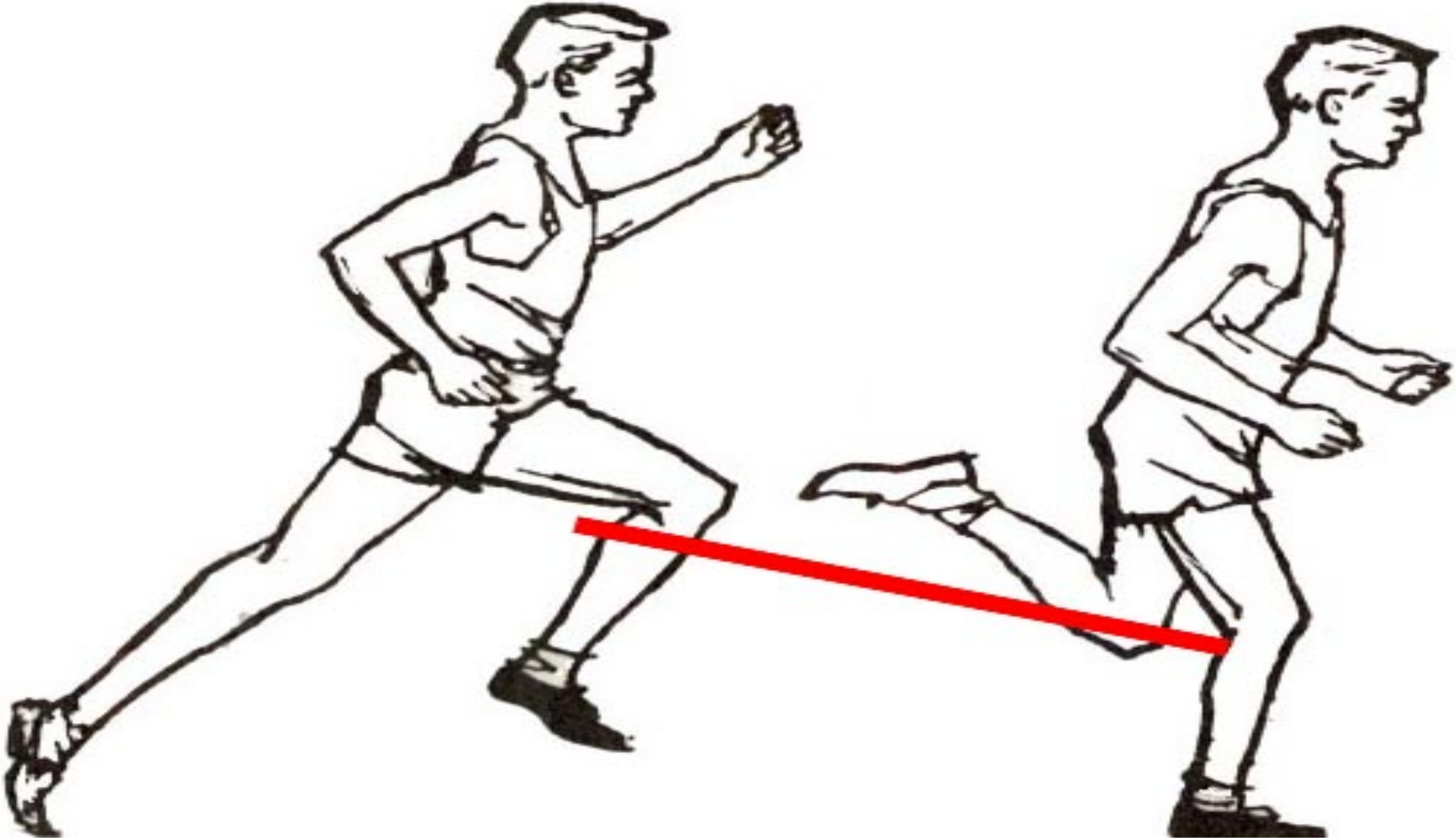


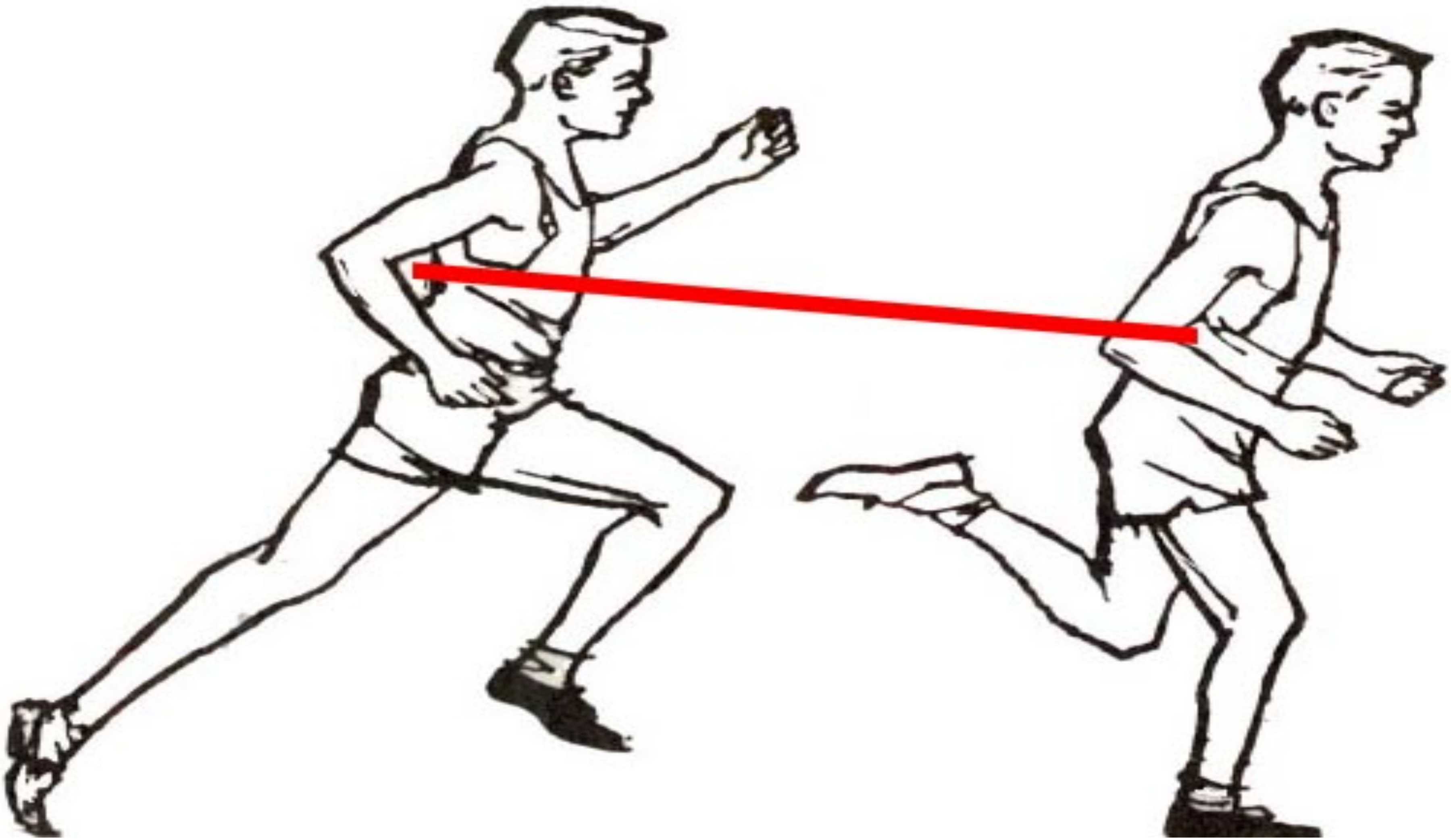












Pergolesi: Vanne, Vale, Dico Addio

Ella Fitzgerald
glissando

Rhapsody in Blue opening glissando

Humpback whale sounds

Amjad Ali Khan: Sarod
Pitch-glides

TauG-coupling of lip movements playing note on trombone (slowed down 40 times)

Analysis of lip movements

	closing	**opening**
mn (sd) duration (ms)	**8** (1)	22 (15)
mn (sd) % tauG coupling	**100** (0)	74 (29)
mn (sd) r^2	**0. 999** (0.001)	0.981 (0.014)
mn (sd) k	**0.781** (0.136)	1.115 (0.638)

Parkinson’s disease

Paradoxical movement:

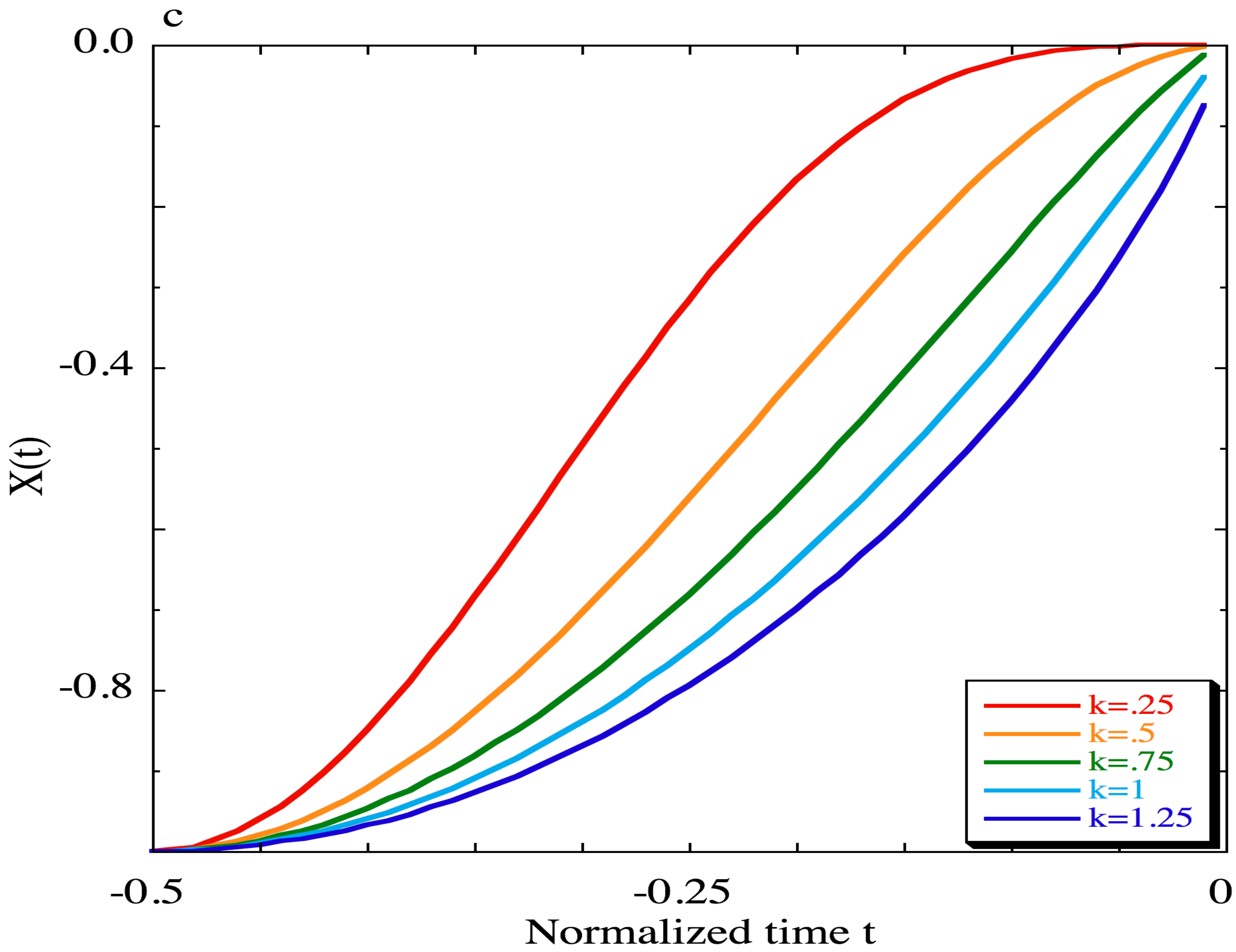
- Tau-coupled movements guided from without can be normal.
- TauG-coupled movements guided from within are less skillful.

Question:

Might coupling movement to tauG-coupled sound help?

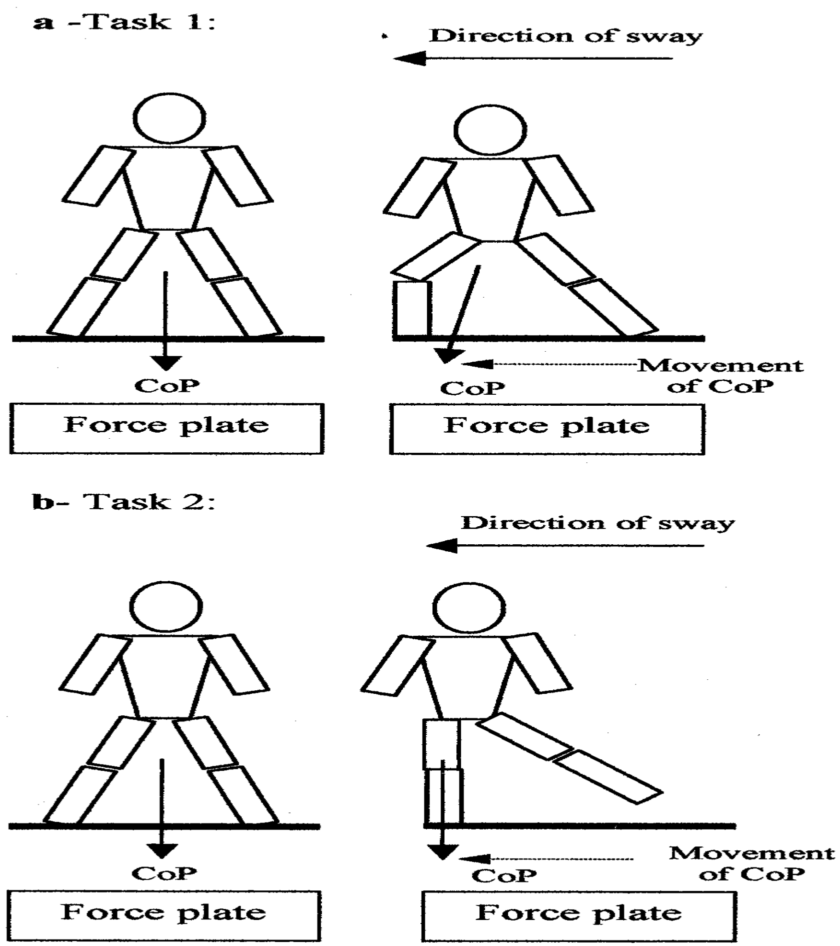
Upward ‘Whoop’

The shapes of tauG-coupled upward 'Whoops' ($X = f_0$)



Up and down pitch(f_0) ‘Whoop’

‘Whoops’ helped tauG-coupled sway in Parkinson’s



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