Cardiac-Respiratory–Locomotor coupling

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Objectives

- Coupled systems
- Pathophysiology of Cardiac- Respiratory and Locomotor interactions
- Gait and balance
- Clinical Implications

Entrainment phenomena

Entrainment phenomena

Biological rhythms generated in oscillating networks exhibit entrainment phenomena that can be triggered internally or in response to external periodic inputs.

- Central autonomic and locomotor networks exhibit oscillatory patterns at different time-scales. True oscillators e.g. cardiac and respiratory networks interact “on demand” with locomotor central pattern generators and sensory inputs.
- Coupling entrainment or “ synchronization” by chance?

Rhythm generation

a. Patterns of neuronal responses

b. Rhythm generation by endogenous rhythmic bursts in pacemaker cells coupled with “ follower” cells

Activation vs. inhibition coupling

Synaptic coupling- Reciprocal inhibition

Network oscillator of 2 neurons that fire independently when uncoupled

but fire in alternating bursts when **coupled**

Marder E. Current Biology 2001,11:R986-R996

Central pattern generators

a. Reflex chain model – alteration of activation and inhibition (left)

b. Central pattern generator (right)

Pattern generated by both models may appear similar

Coupling vs. Chance?

Marder E. Current Biology 2001,11:R986-R996

Interaction between central pattern generator and sensory inputs

a. Rhythmic pattern – the cycle period, burst duration, duty cycle, firing phase

b. Measurement set up of locust wing movements in wind

c. Intact recordings from depressor and elevator motor neuron-phase shift

d. De-afferented recording show de-phasing

Marder E. Current Biology 2001,11:R986-R996.

Cardio-Respiratory coupling

Cardio-Respiratory coupling

- RSA- respiratory modulation of heart beat and sympathetic outflow (Lyon 1862, Traube-Hering 1865)
- Central cardio-respiratory networks (Langhorst, Koechen 1981)
- Feedback- central & peripheral connections
- Baroreflexes and chemoreflexes
- Respiratory muscles and lung movements
- Mechanical effects

Brain stem

- Brain stem-the oldest part of the brain that connects it the spinal cord.

- Respiratory, vasomotor and cardiac centers, as well as many mechanisms for controlling reflex activities such as coughing, gagging, swallowing and vomiting.

- Vital neurological functions necessary for survival (breathing, digestion, heart rate, blood pressure) and for arousal (being awake and alert).

Brain Stem cont'd

- Midbrain - The midbrain serves as the nerve pathway of the cerebral hemispheres and contains auditory and visual reflex centers.

- Pons - is a bridge-like structure which links different parts of the brain and serves as a relay station from the medulla to the higher cortical structures of the brain. It contains the respiratory centers, cardiac vagal and motor centers.

- Medulla Oblongata - primarily as a relay station for the crossing of motor and sensory tracts between the periphery, spinal cord and the brain, all ascending and descending pathways.

Respiratory centers – set the automatic breathing patterns of inspiration, expiration and pause

- Connect with autonomic centers (nc. X vagus) and nc. VI (ambiguus), other cranial nerves, sympathetic centers in medulla and central autonomic network and locomotor networks and many cortical areas

Ponto-medullary transection

- Eliminates respiratory modulation of cardiac rhythm and sympathetic effectors
- Creates a breathing pattern with apnea (breath holds)
- Small amplitude BP modulation present

Dick TE et al. Respiratory Physiology&Neurobiology 168, 76-85; 2009

Cardio-Respiratory Coupling

• Respiration modulates heart beat over a wide range of frequencies from

0.01- 2 Hz

The effects of RSP on R-R internals increases exponentially at slower breathing frequencies

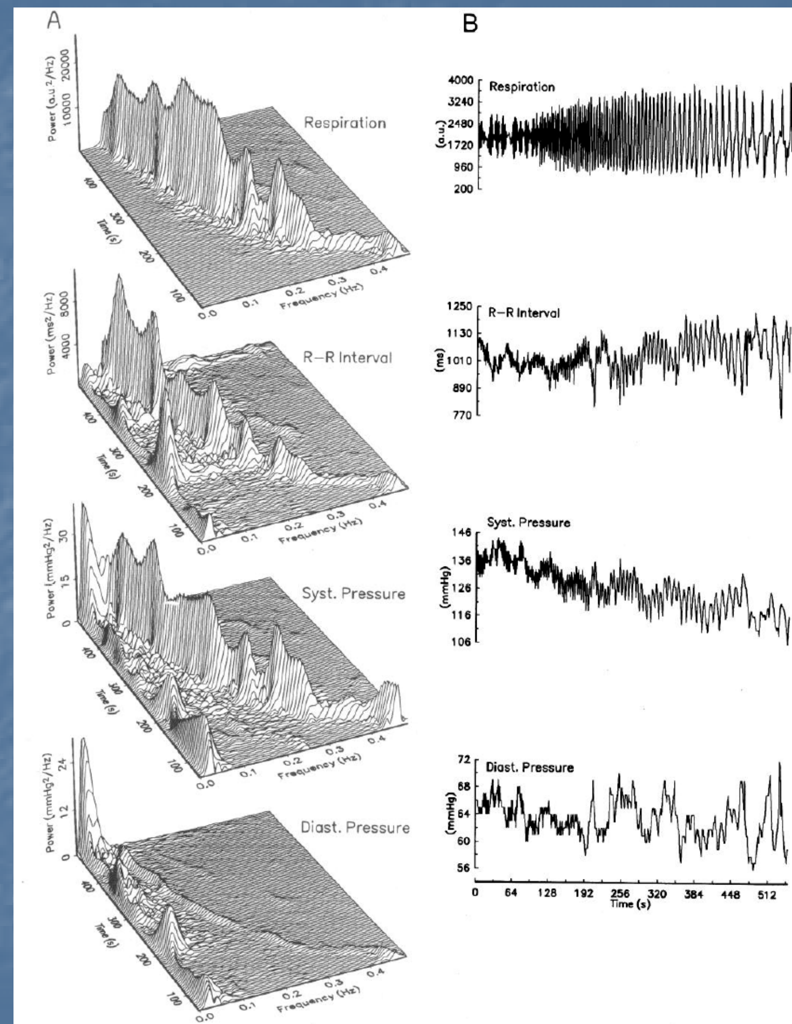
-increased RSP volume

- increased vagal modulation

-increased CO2

• Beat-to-beat SBP/DBP are also modulated by respiration

• Amplitude of respiration, R-R intervals, blood pressure also modulated by very slow rhythms < 0.01 Hz



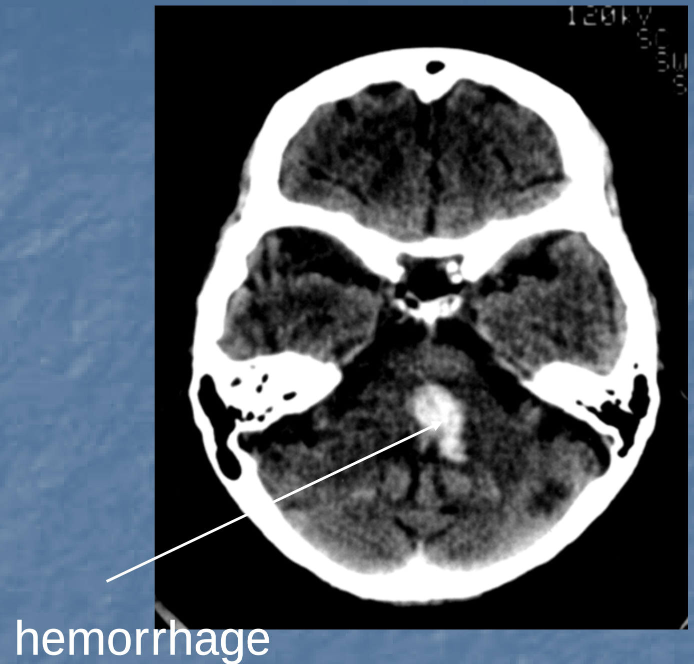
Novak V et al. J. Appl. Phys. 1993; 74: 617-26.

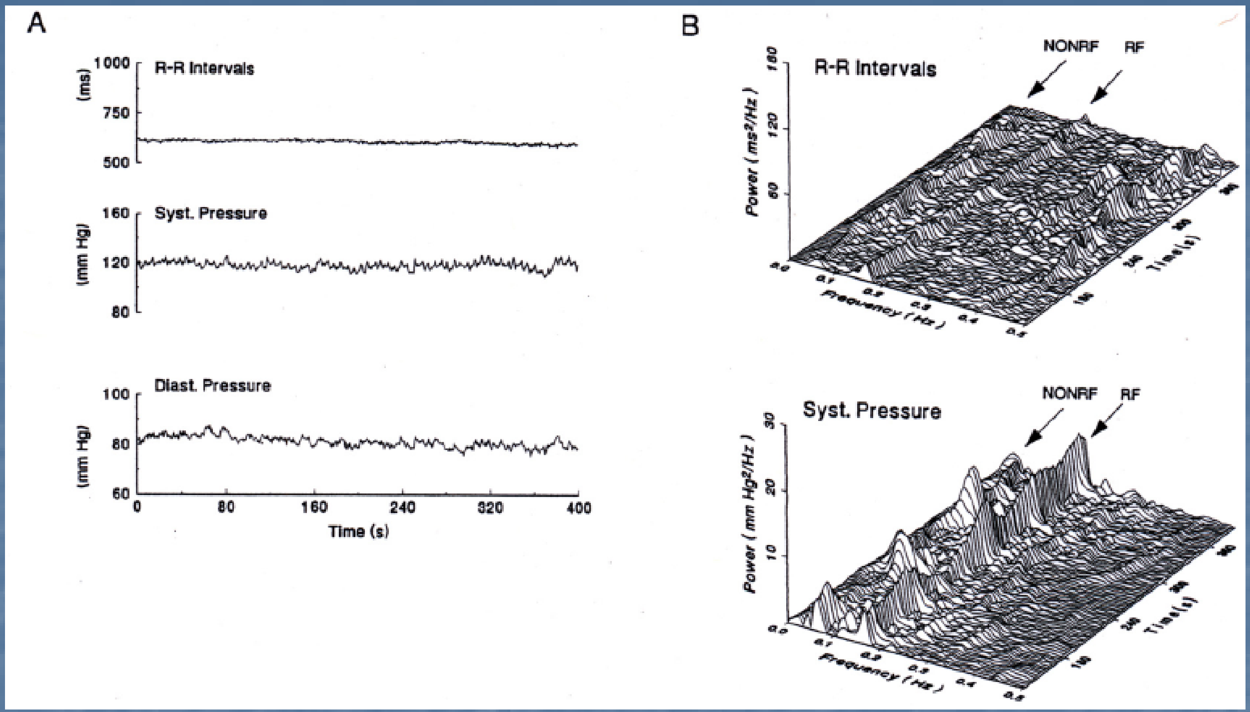
Eckberg et. Al. J. Appl. Phys. 1993;74:

Brain stem lesions

- Death
- “Lock in “ syndrome
- Dysautonomia-hypertension/hypotension
- “Ondine’s curse”

Pontine hemorrhage- Brain Stem death





- 81yr old F with pontine hemorrhage, unconscious
- Artificially ventilated at 0.15 Hz
- R-R oscillations abolished (only minimal amplitude)
- Systolic BP oscillations both respiratory and slow oscillations (Mayer waves) present

Novak V et al. Clin. Autonom. Res. 1995; 5: 24-30

Cardiac-Locomotor Coupling

Cardio-locomotor coupling (CLC)

- Coupling between locomotor, respiratory and cardiac rhythms has been reported in humans during walking and running, cycling, in response to periodical thigh pressure and finger tapping, (Kirby 1989, Niizeki 1993,Nomura 2001, Niizeki 2005).

- Respiratory-locomotor coupling- wheelchair propulsion (Lou, 2003) and in animals.

- Cardio-locomotor coupling was enhanced during periods when cardio-respiratory coupling (RSA) decreased.

- Coupling is short lasting and typically occurred during walking or running at faster speeds.

- Kirby (1989) - heart and step rate within 1% of closest ratio
- Niizeki (1993) - duration 1 min phase relationship within 10%

Locomotor circuits

- Voluntary control
- Central pattern generator circuit-basal ganglia-sensory-motor cortex
- Sensory inputs
- Spinal reflexes
- Feedback

Goulding M. nature Reviews neuroscience 10,2009

CLC-Central Theory

- Central coupling between locomotor activity and heart rate was demonstrated by stimulation of the locomotor mesencephalic area in decerebrated vagotomized cats (Kawahara, 1993).
- “ Fictive gait” – coherences an entrainment between EMG discharges in gastrocnemius m., phrenic nerve activity and ECG.
- Locomotor circuits generating patterns and timing of the gait cycle interact with cardiac and respiratory centers in the brainstem and upper medulla (Guadagnoli, 2000).
- A hierarchical model of central command was proposed, based on temporary synchronization from locomotor to respiratory to cardiac rhythms.

CLC- Peripheral theory

- Changes in intramuscular pressure, muscle tone and blood flow in exercising muscle provide periodical inputs to cardiovascular system.
- The peripheral concept of cardiac-locomotor coupling was based on phase dependency between active muscle contraction and cardiac cycle (Nomura 2003, Niizeki 1999)
- CLC occurs because the afferent signal from active muscle by via sensory group III afferent activity to parasympathetic cardiac centers.
- Positive slope between EMG and RRI in the first ¼ of cardiac cycle and negative slope for remaining 3/4 of cardiac cycle (Niizeki and Miamoto 1999).

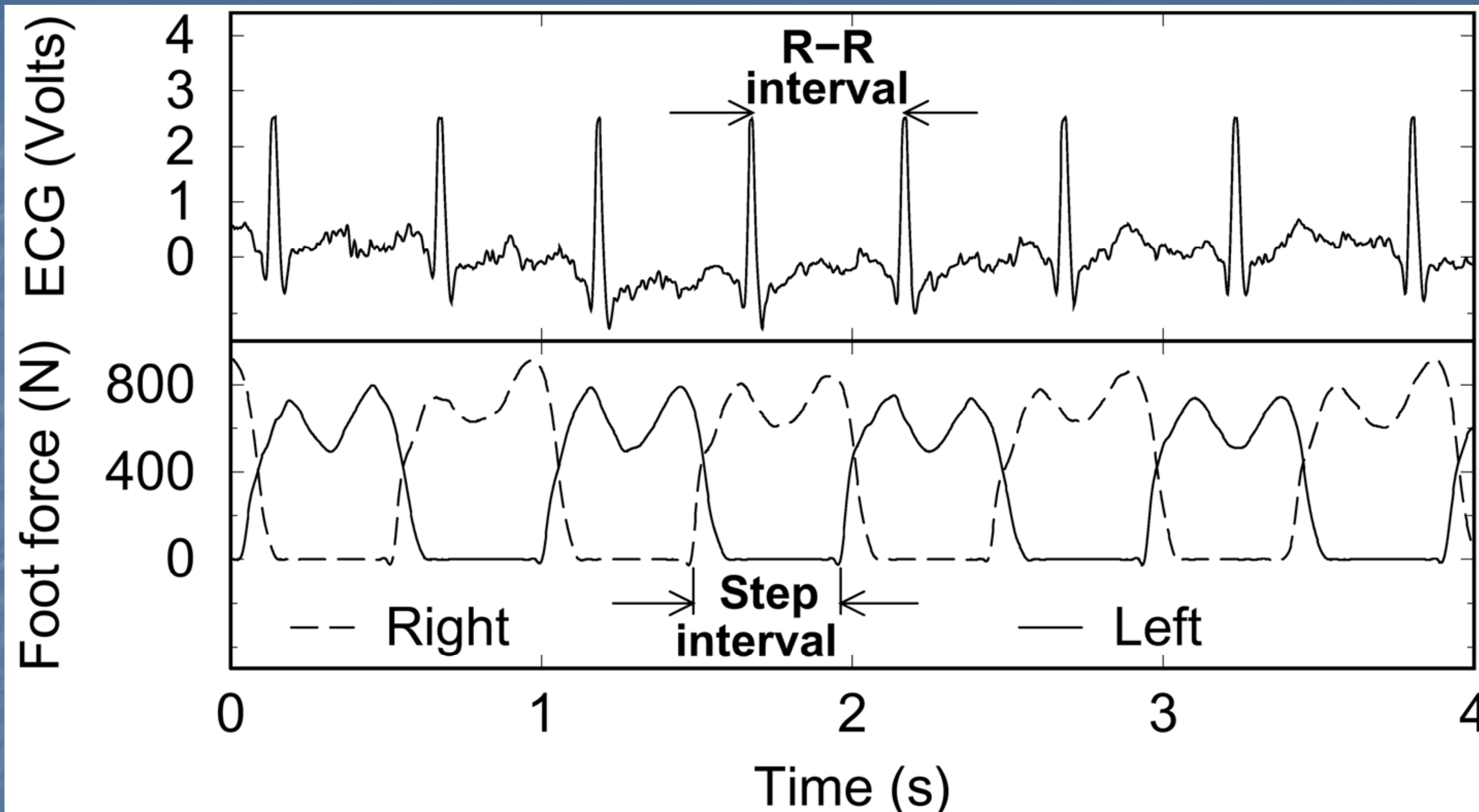
- Walking speed

a marker of an overall functional state, hallmarks frailty in the elderly

- Central command
- Rhythmic pattern
- Muscle strenght
- Sensory inputs
- Cardiovascular response

Walking in Aging

- Walking is a complex act that requires the coordination among locomotor, cardiovascular and autonomic systems. Aging may affect each of these systems and alters physiological mechanisms regulating interactions between them.
- The processing speed and sensitivity of end-organs to central and peripheral stimuli decline with age.
- Degradation of feedback mechanisms contributes to diminished responses to stress.
- Gait abnormalities - slow speed, unsteady patterns and falls predict development of vascular dementia and adverse outcomes in elderly people (Verghese, NEJM 2002).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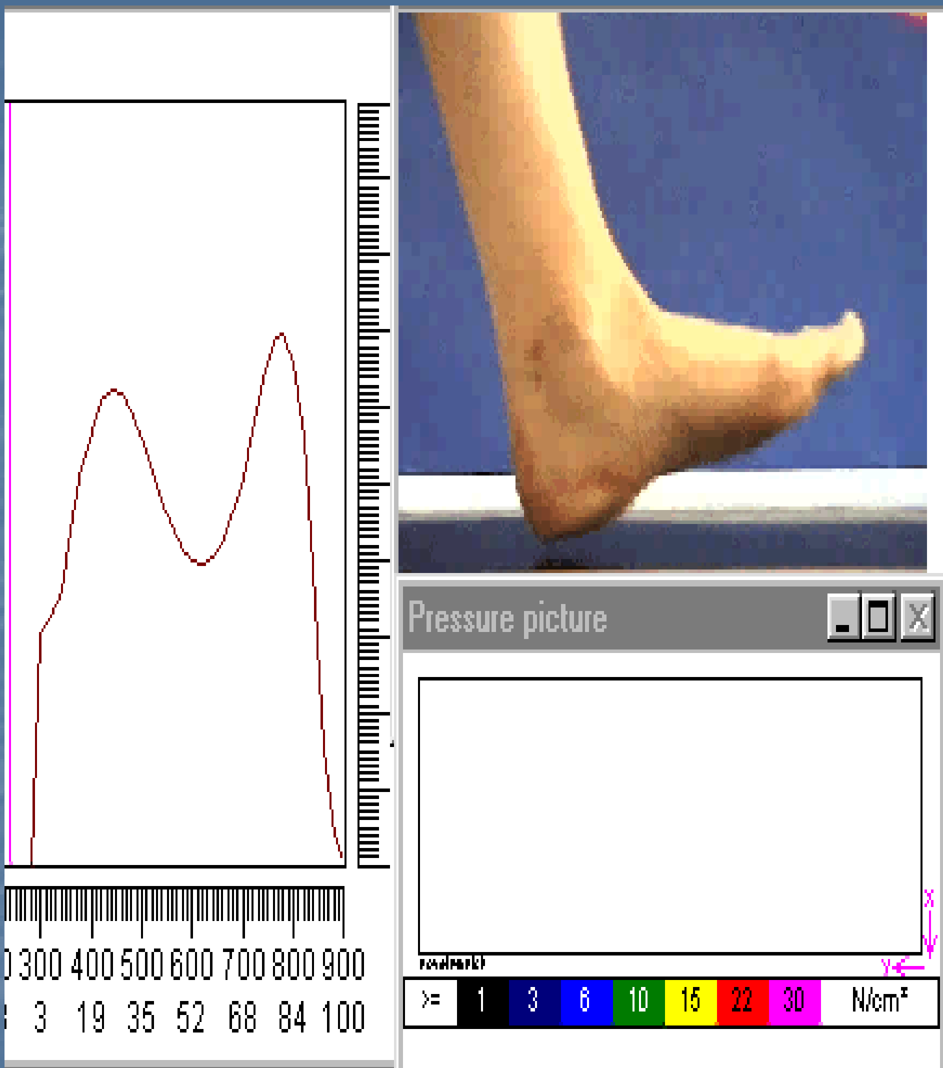
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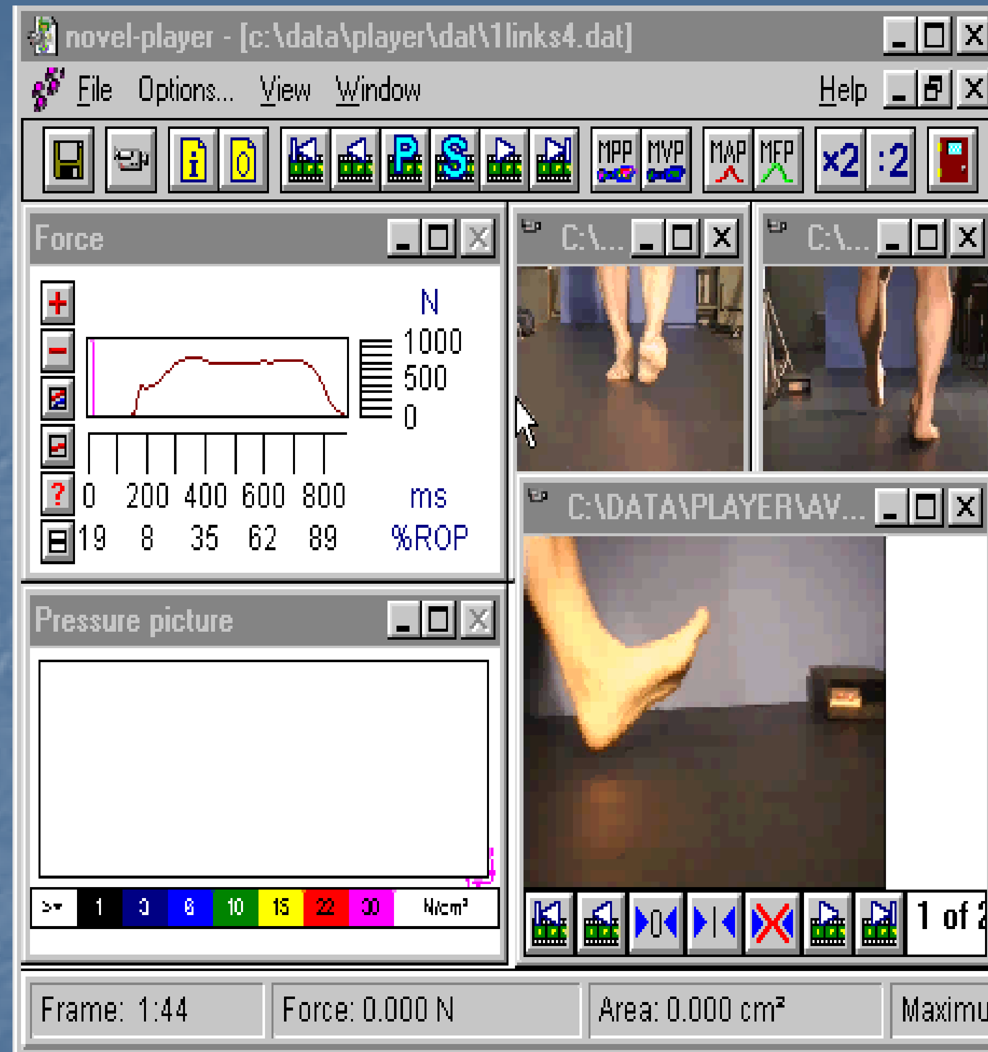
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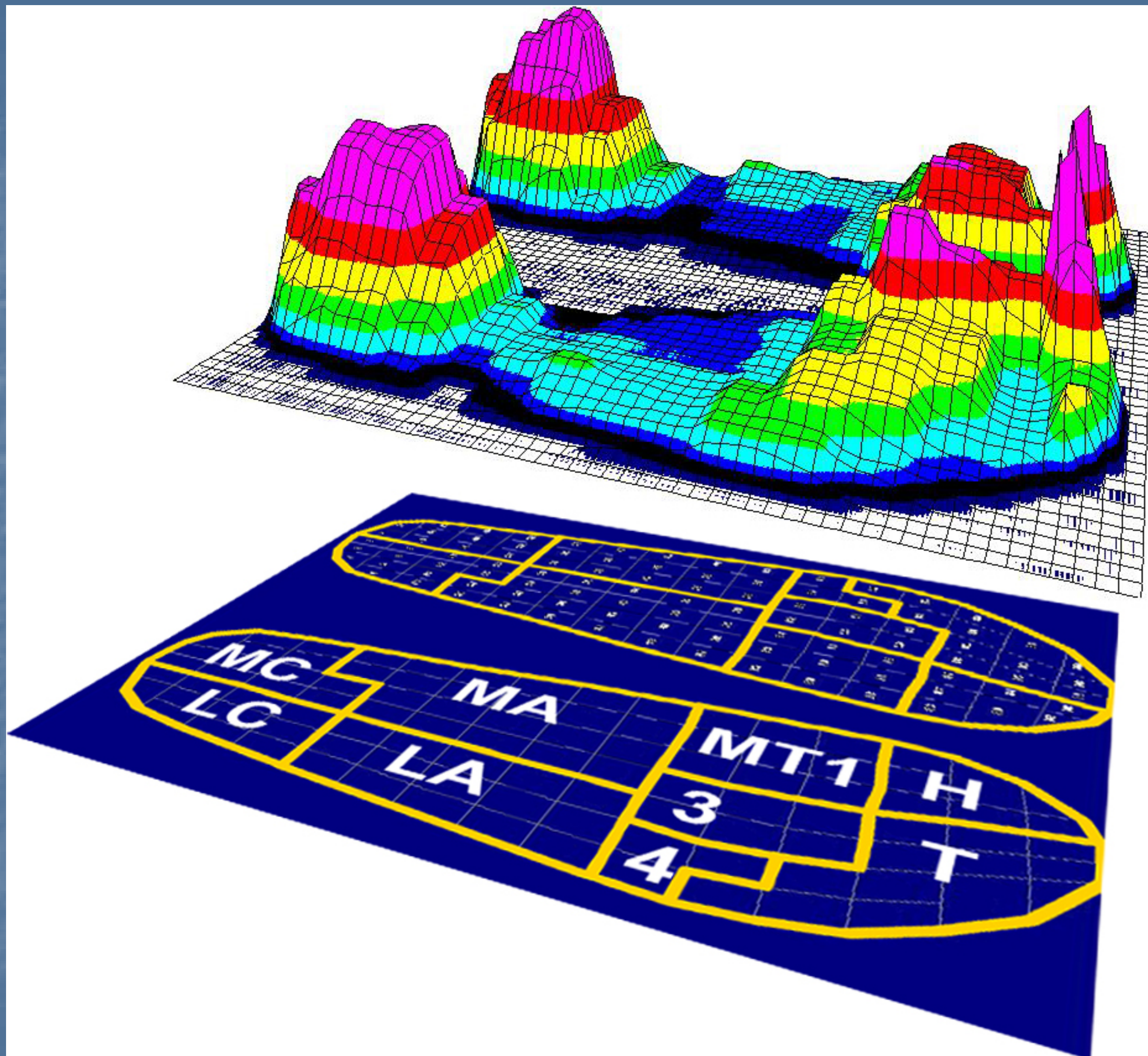
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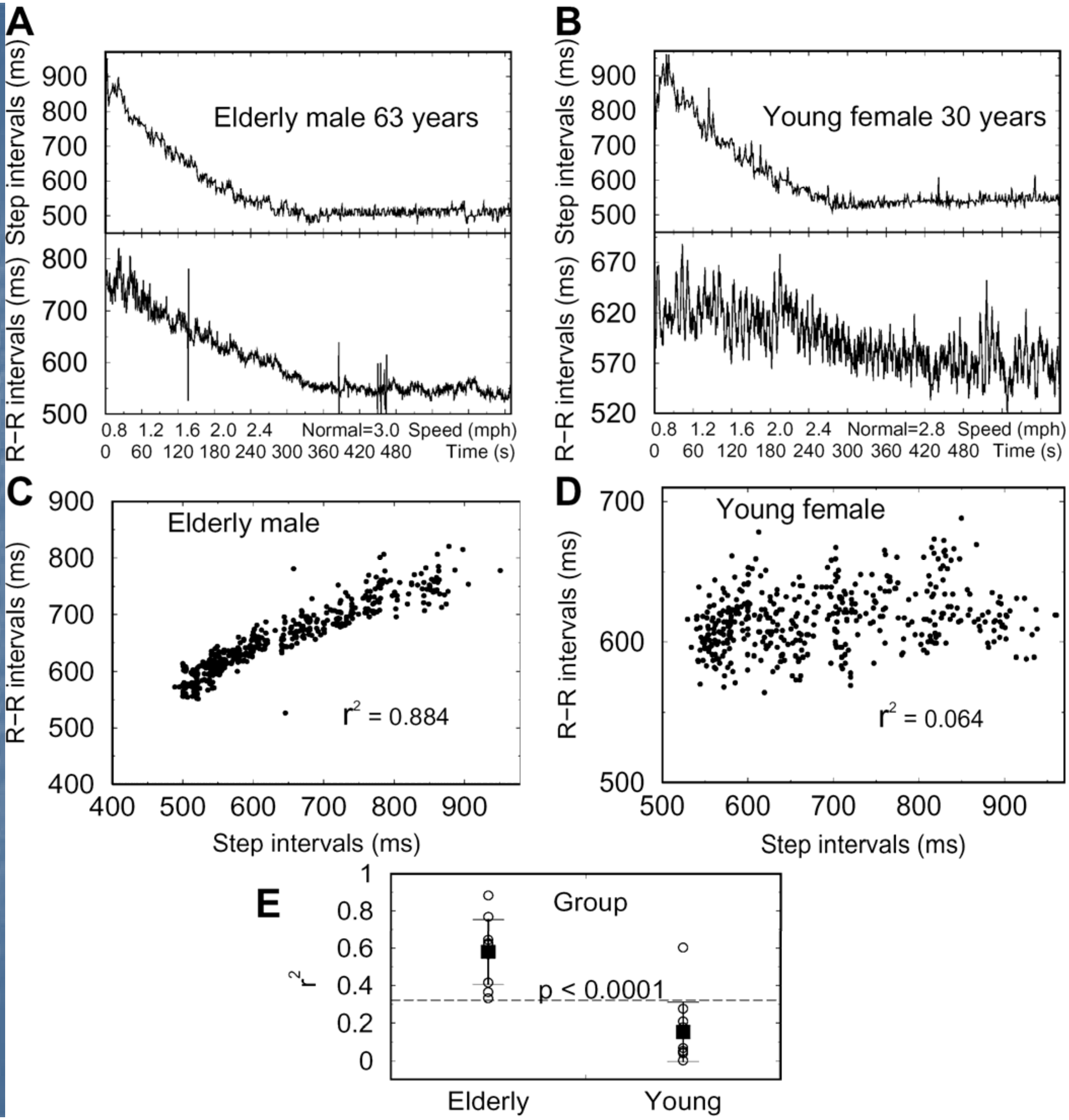


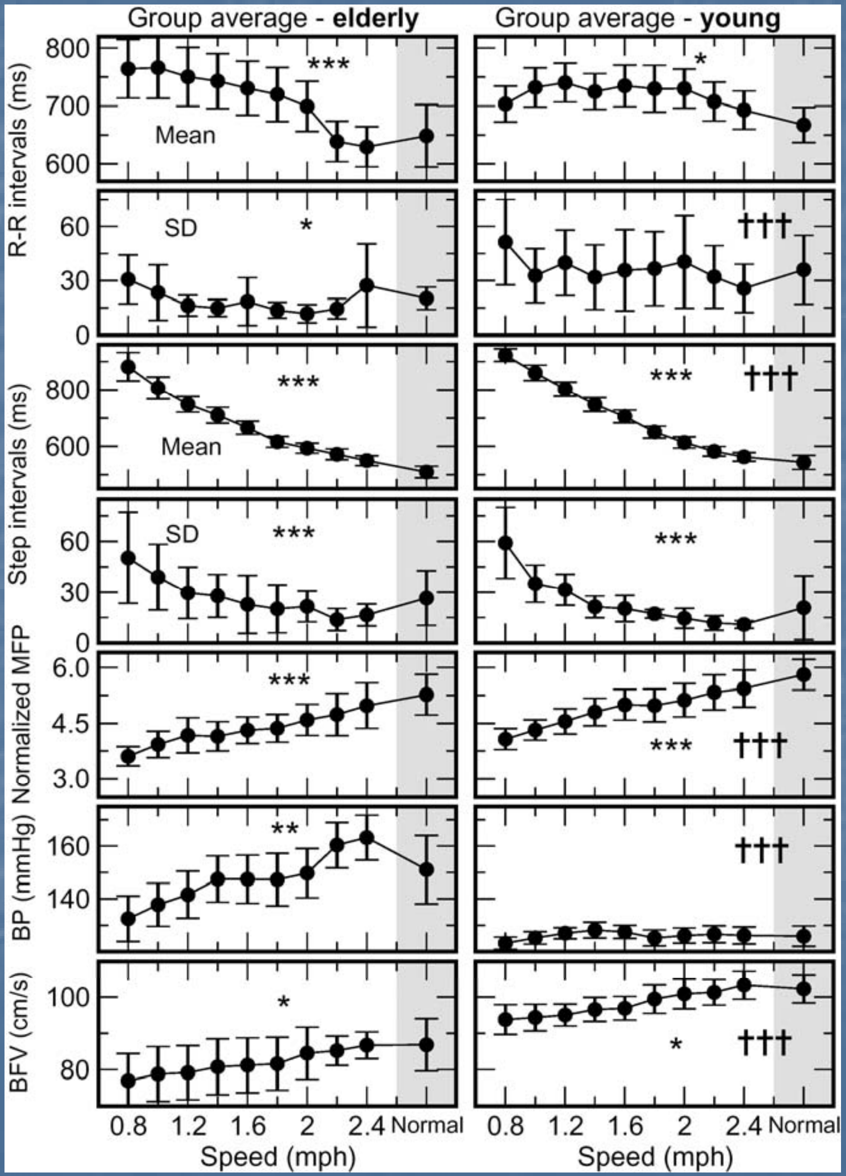
Novak J. Geront, 2007

CLC in Aging

- For similar walking speed and heart rate, old adults showed lower HR and step interval variability, lower force, greater blood pressure and lower blood flow velocity.

- In young subjects, beat-to-beat increases in systolic BP are dampened by the baroreflexes, leading to R-R interval prolongation and increased R-R interval variability, stable BP and cerebral blood flow.

- Cardio-locomotor coupling and periodic increases of blood pressure may improve adaptation to exertion and may have positive effects on brain perfusion in old people.



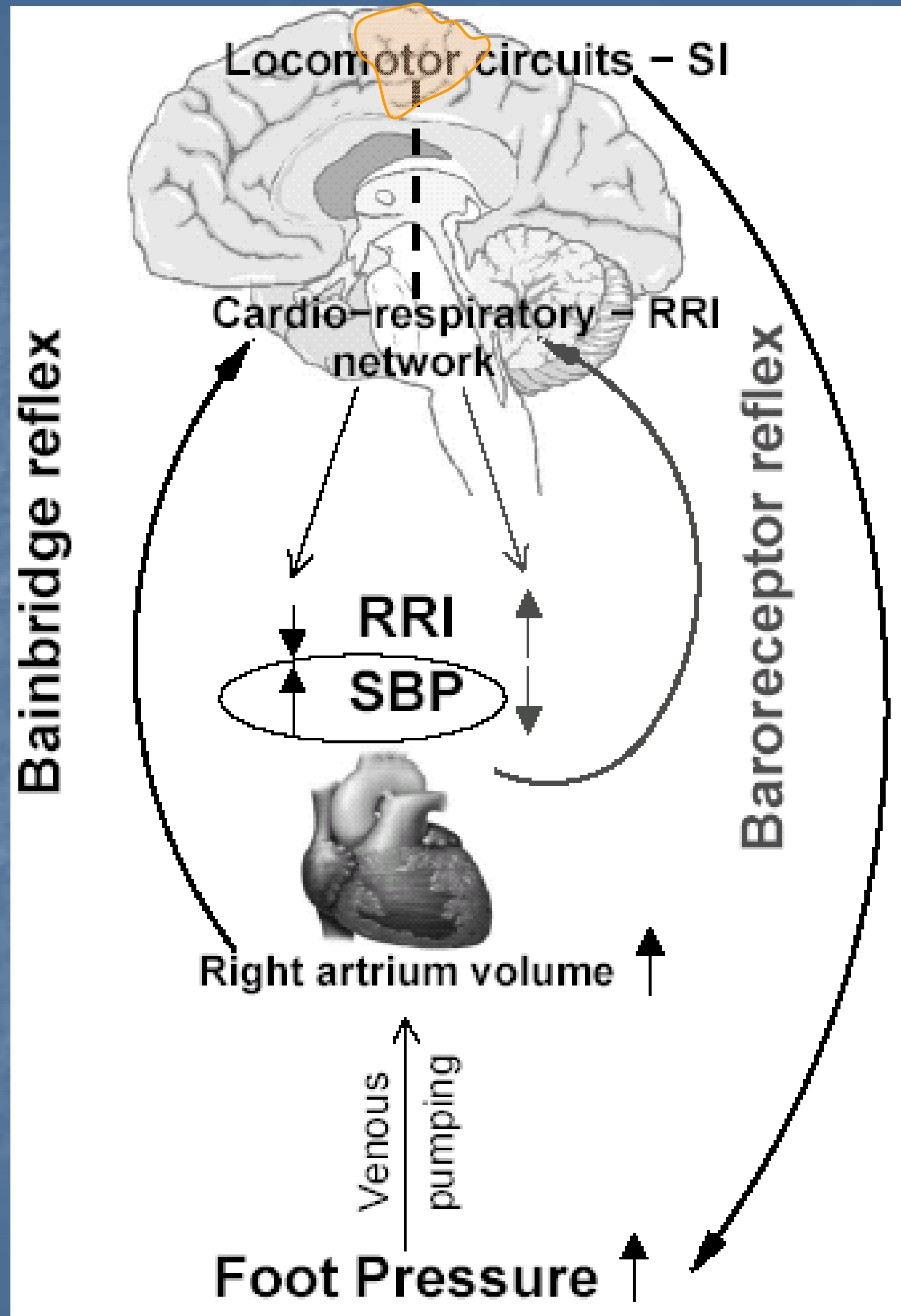
Central Command

Regional perfusion autoregulation

Locomotor

Respiratory

Cardiac



Cardio-locomotor coupling

- Cardio-locomotor coupling that becomes manifest with aging may optimize cardiovascular adaptation to walking. In elderly people, forces generated during the gait cycle may be transmitted to arterial pressure and thus synchronize the central cardiovascular network with the stepping rhythm.

Postural-Respiratory Coupling

Postural Control

Postural control is regulated by a complex system comprised of somatosensory, visual and vestibular sensory elements, ascending and descending neural pathways, numerous brain regions, and the musculo-skeletal system.

- Voluntary-central command
- Body position-vestibulo-sympathetic reflex
- Motor response
- Priopriocepteptive inputs (sensory, joints, tendons etc..)
- Cardiovascular response- blood pressure, HR
- Brain Perfusion
- Feedback

Posturo-Respiratory Coupling

- The dominant oscillatory mode of respiration and the corresponding oscillatory mode of anterioposterior center-of-pressure dynamics were extracted from each signal using empirical mode decomposition (Huang et al 1998).

- Instantaneous phase shifts between the two extracted oscillatory signals were calculated over the entire trial using Hilbert transform, and were used to obtain the degree of posturo-respiratory coupling using an entropy-based synchronization analysis.

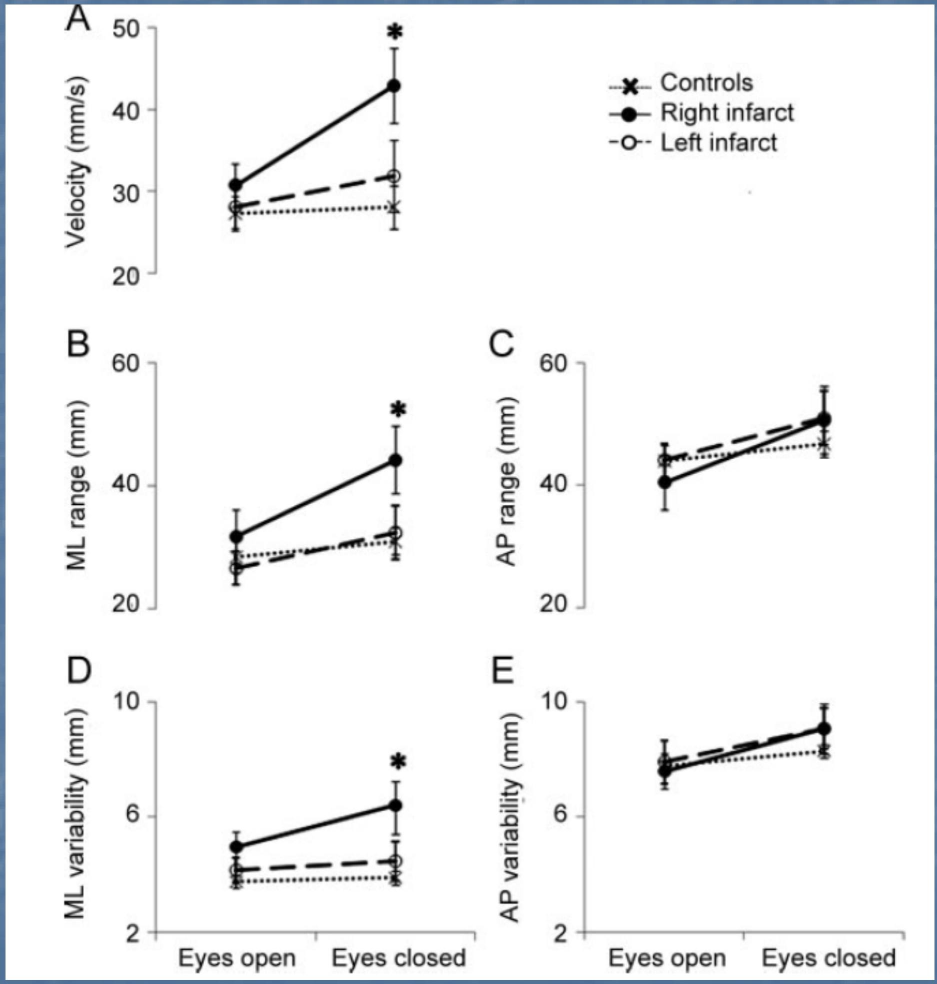
Postural-Respiratory coupling

- Degradation of the control system, as might occur in aging and neurological diseases, may reduce compensatory control and lead to increased "posturo-respiratory coupling."

- We hypothesized that both aging and stroke are associated with increased posturo-respiratory coupling during upright stance.

Stroke effects on Balance

a. Sway velocity
b. Mediolateral range
c. Anteroposterior range
d. Mediolateral variability
e. Anteroposterior variability



Stroke patients had worse balance with

Only right-sided infarctions

Only with eyes closed

Manor et. al. Neurology 2010;74:458-464

Posturo-respiratory coupling

- Evidenced by increased posturo-respiratory coupling, the control system responsible for dissipation of respiratory perturbations is dependent upon vision and degrades with advancing age and stroke.

- Future studies outlining the central and/or peripheral pathways involved in this control system are therefore warranted.

Posturo-respiratory coupling & improved balance

- Enhancement of sensory feedback
- Vibration stimulation of the soles improves gait and balance in Parkinson’s Disease
- Posturographic training
- Tai-chi- combines deep breathing with postural control – improves balance

Cardiac-Postural Coupling

Clinical implications of cardiovascular control failure

- Falls
- Syncope
- OH
- Strokes

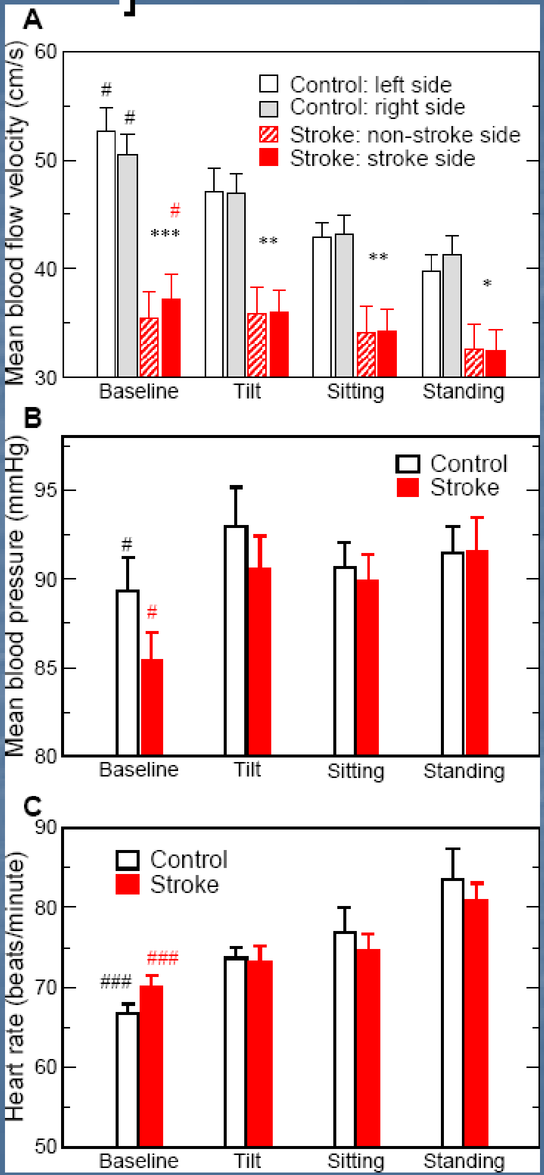
Cerebro- cardiovascular responses to upright posture

•Heart rate and blood pressure increaseas in responses to sitting, standing and tilt

•Cerebral blood flow velocities, decline in upright posture in older adults

• Decline in blood flow velocities is more prominent after a stroke

• Flow velocities post-stroke become dependent on perfusion pressure



Novak et. Al. Stroke 2010

Falls/hypotension prevention

- Engaging muscle pump can improve cardiovascular response to upright posture.

- Cardiac-lomocotor coupling thus may be beneficial to maintain/improve cardiovascular adaptation to walking and standing up.

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Smit AAJ et al. Ann. Neurol, 42, 1997

Conclusions

- Coupling and entrainment phenomena represent signaling among multiple organ systems.
- As signaling and processing speed declines with aging, coupling among other systems may be enhanced.
- Cardiac-respiratory and postural coupling may enhance performance during adaptation to daily living in older adults.

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