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OMICS Group International is a pioneer and leading science event organizer, which publishes around 400 open access journals and conducts over 300 Medical, Clinical, Engineering, Life Sciences, Phrama scientific conferences all over the globe annually with the support of more than 1000 scientific associations and 30,000 editorial board members and 3.5 million followers to its credit.

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"Multi-muscle control of postural muscles: Manifolds and Frequencies"

Alessander Danna-dos-Santos, PT PhD

Motor Control Laboratory

School of Physical Therapy and Rehabilitation Science

Outline

- **Topic**: Human Posture / Mechanisms of multi-muscle control.

- **Objectives of Research**: Recognition, quantification, and understanding of neurophysiological mechanisms involved on multi-muscle control.

- **This presentation**

    - Comprehensive overview
    - Operational definition of "Synergy"
    - Recognition and quantification of muscle synergies
    - Uncontrolled Manifold Hypothesis
    - Frequency domain analysis

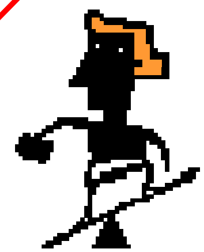
Axial Skeleton

Inherently unstable:

- Large number of joints
- Vertically positioned segments while standing
- High center of gravity
- Relatively small base of support

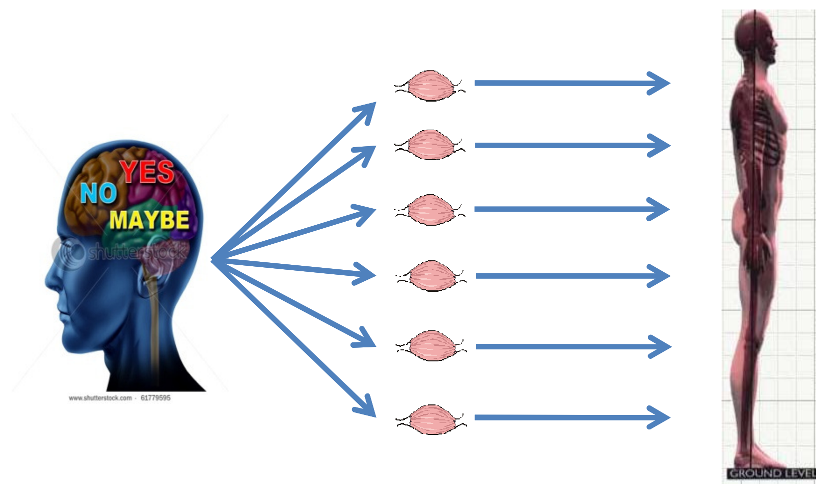
- Large number of muscles
- Presence of uni- and poli- articular muscles
- Non-linear force production features
- Dynamic interactions of joint torques generated by polyarticular muscles
- Interaction of internal forces across segments
- Response to external perturbations

Large number of effectors



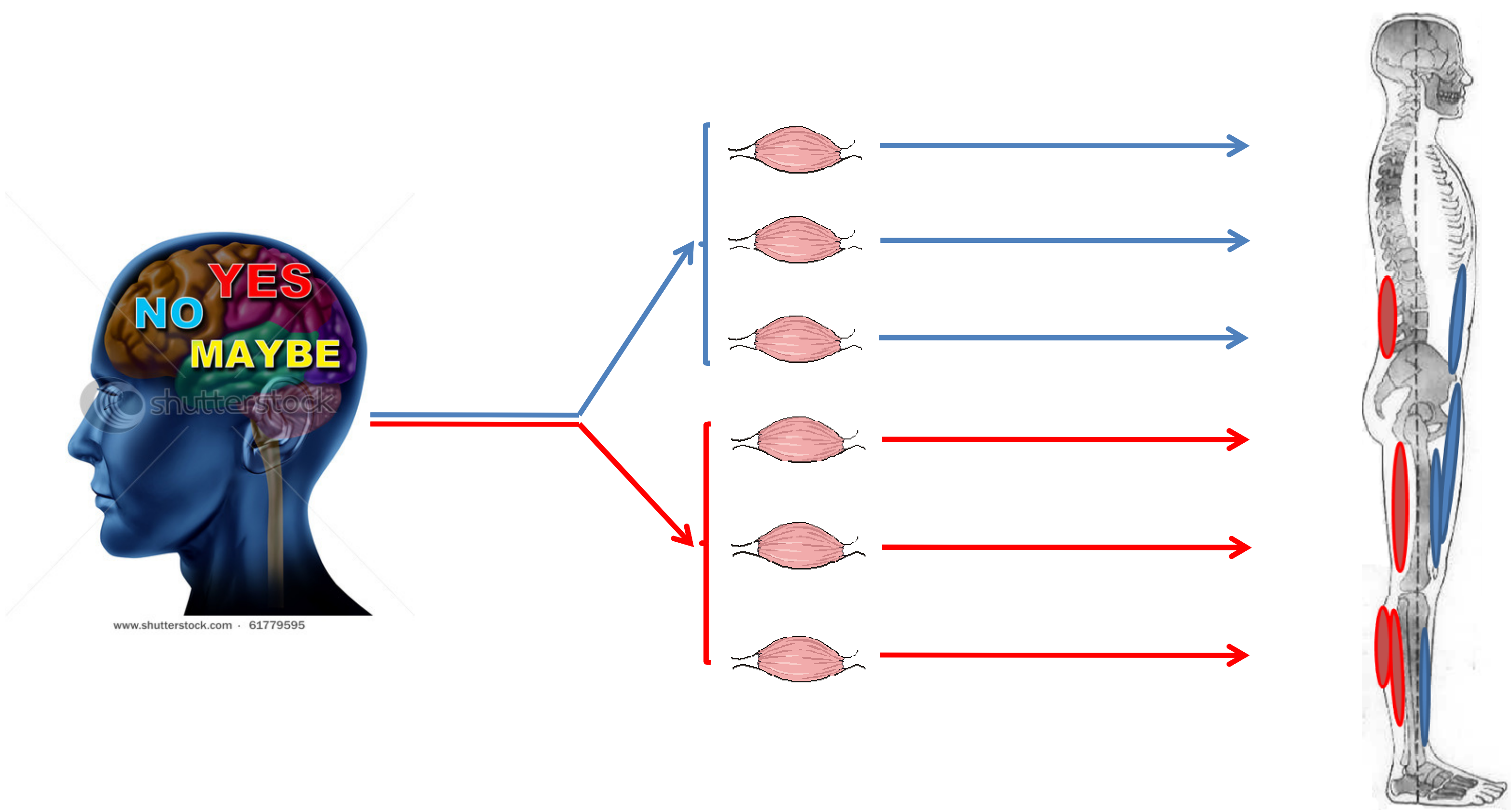
Large repertoire of postures
(system flexibility)

Complex system of control



A possible solution

Creation of functional groups ("Synergies")



Bernstein 1967, reviewed in Latash ML 2002

The use of the term “synergy”

To study the topic we need an

OPERATIONAL DEFINITION

What is synergy ?

How do we find it ?

How do we quantify it?

The use of the term "synergy"

To study the topic we need an

OPERATIONAL DEFINITION

What is synergy ?

How do we find it ?

How do we quantify it?

The use of the term "synergy"

Synergy = Working together ????

Gerald J. Furnkranz for The Examiner.com 2012

The use of the term “synergy”

To study the topic we need an

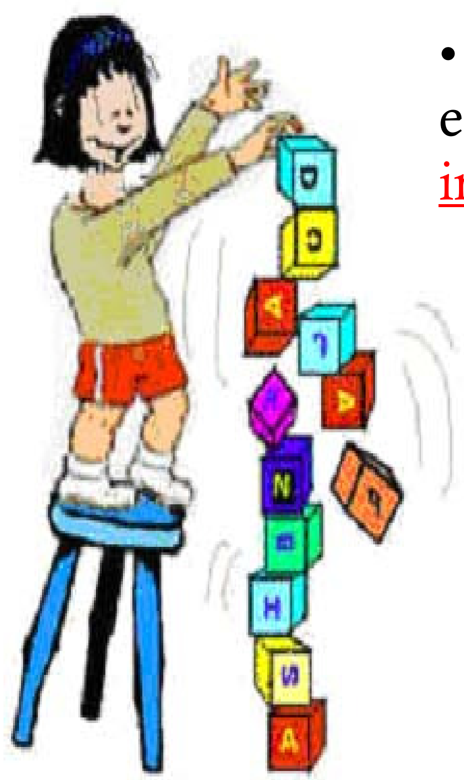
OPERATIONAL DEFINITION

What is synergy ?

How do we find it ?

How do we quantify it?

The Uncontrolled Manifold Hypothesis (UCMh)



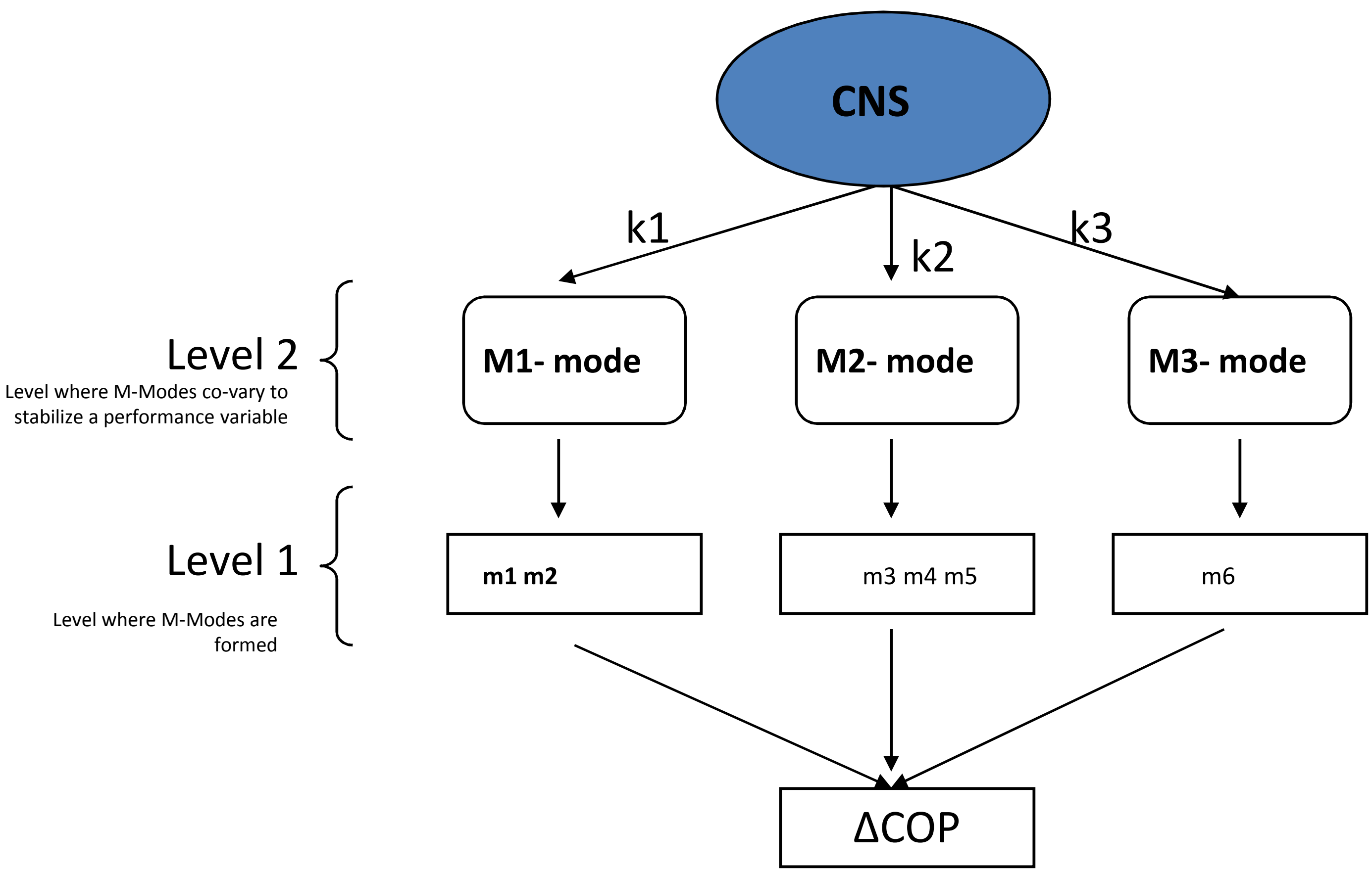
- It offers a computational method to estimate synergies quantitatively <u>using an index of structure of the variance</u>.

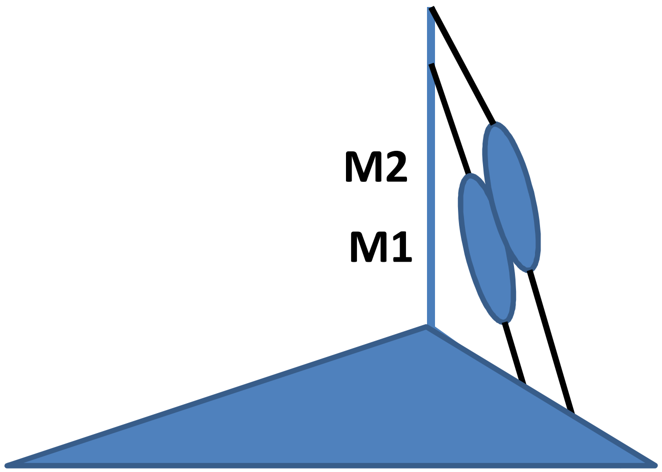
- The controller computes a subspace (a manifold, UCM) within the space of elemental variables and limits variability orthogonal to the UCM while allowing more variability within the UCM.

(Scholz and Schoner 1999; Latash et al 2002)

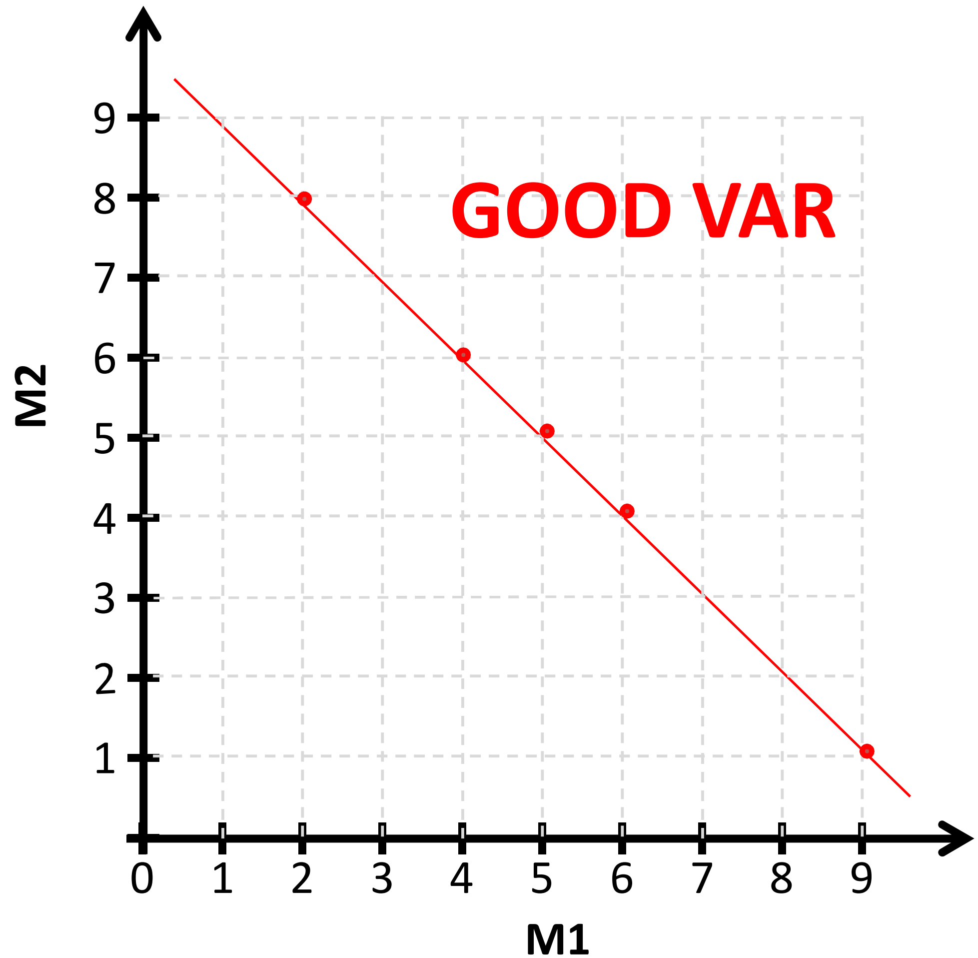
Main assumption

Existence of at least 2 levels of control

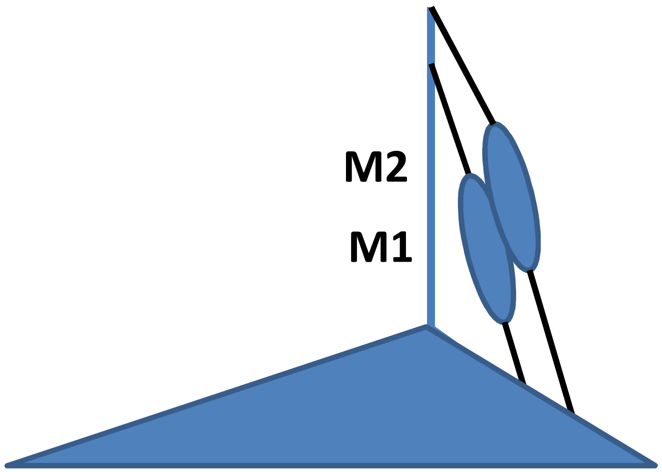




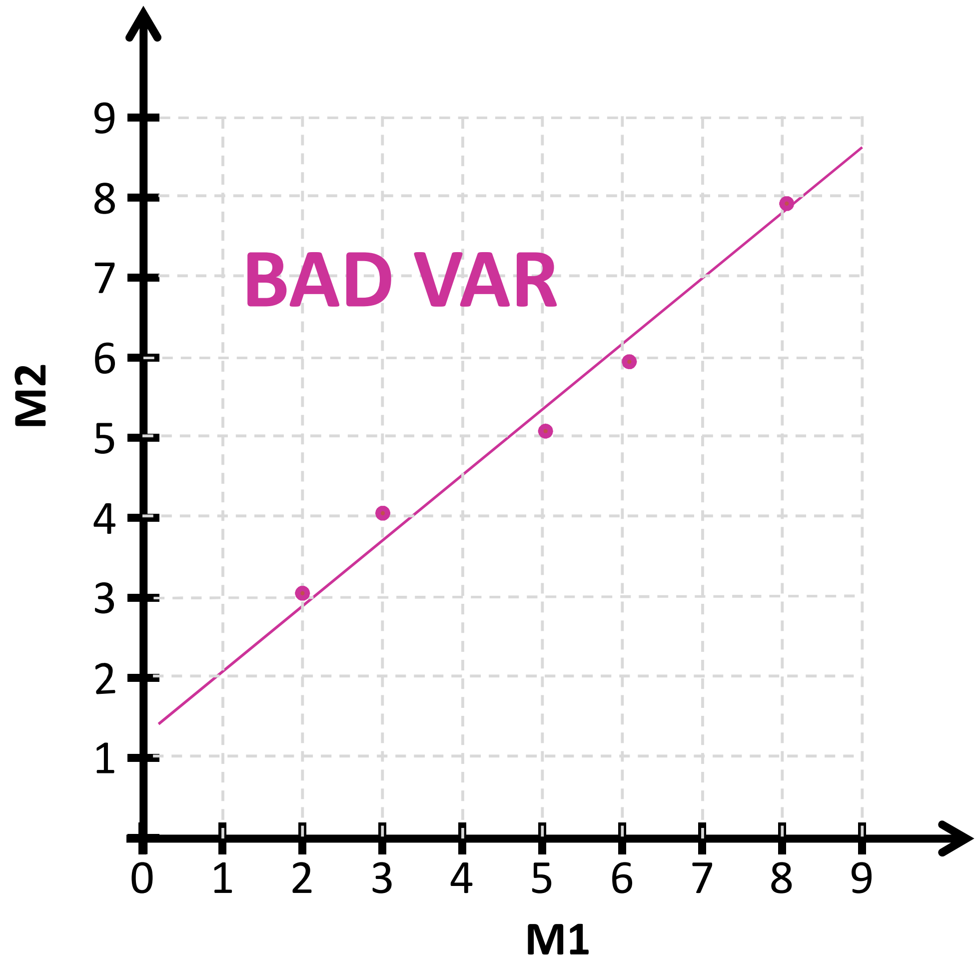
M1	M2
2	8
4	6
5	5
6	4
9	1



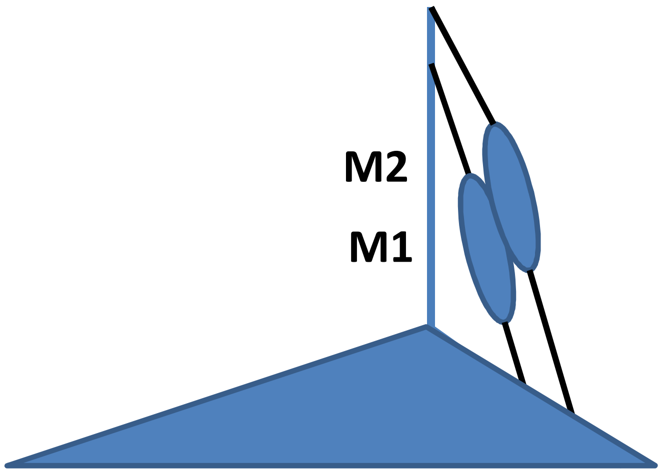
$$M1 + M2 = 10\ N/m$$



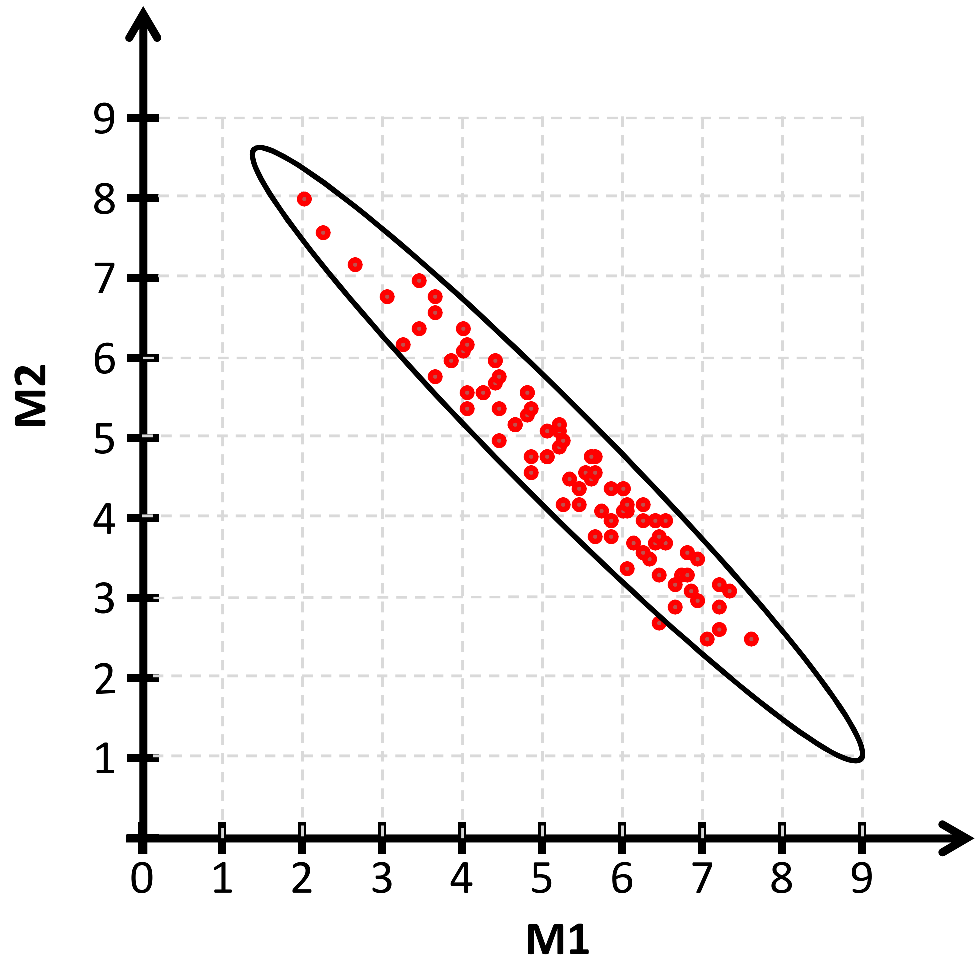
M1	M2
2	3
3	4
5	5
6	6
9	1



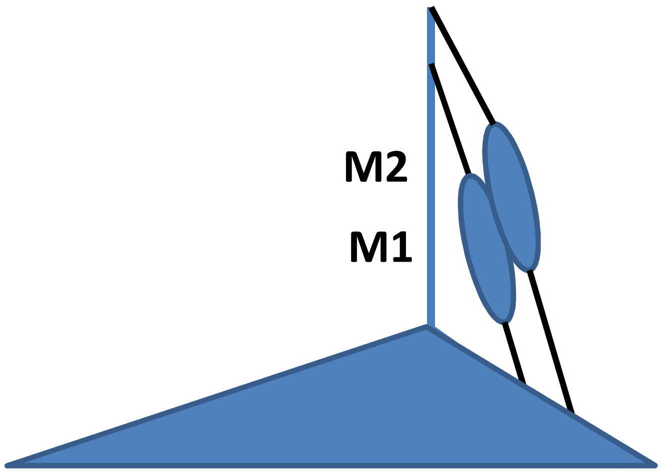
$$M1 + M2 = 10\ N/m$$



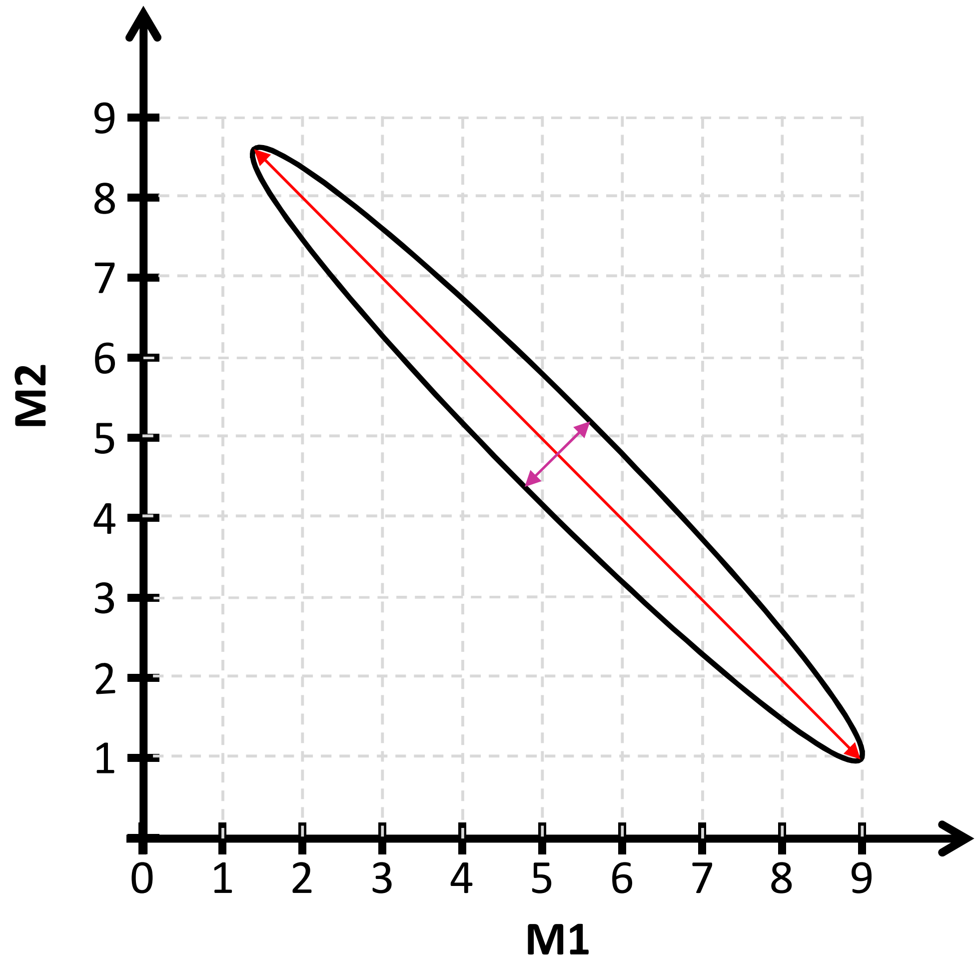
M1	M2
x_1	y_1
x_2	y_2
x_3	y_3
...	...
x_n	y_n



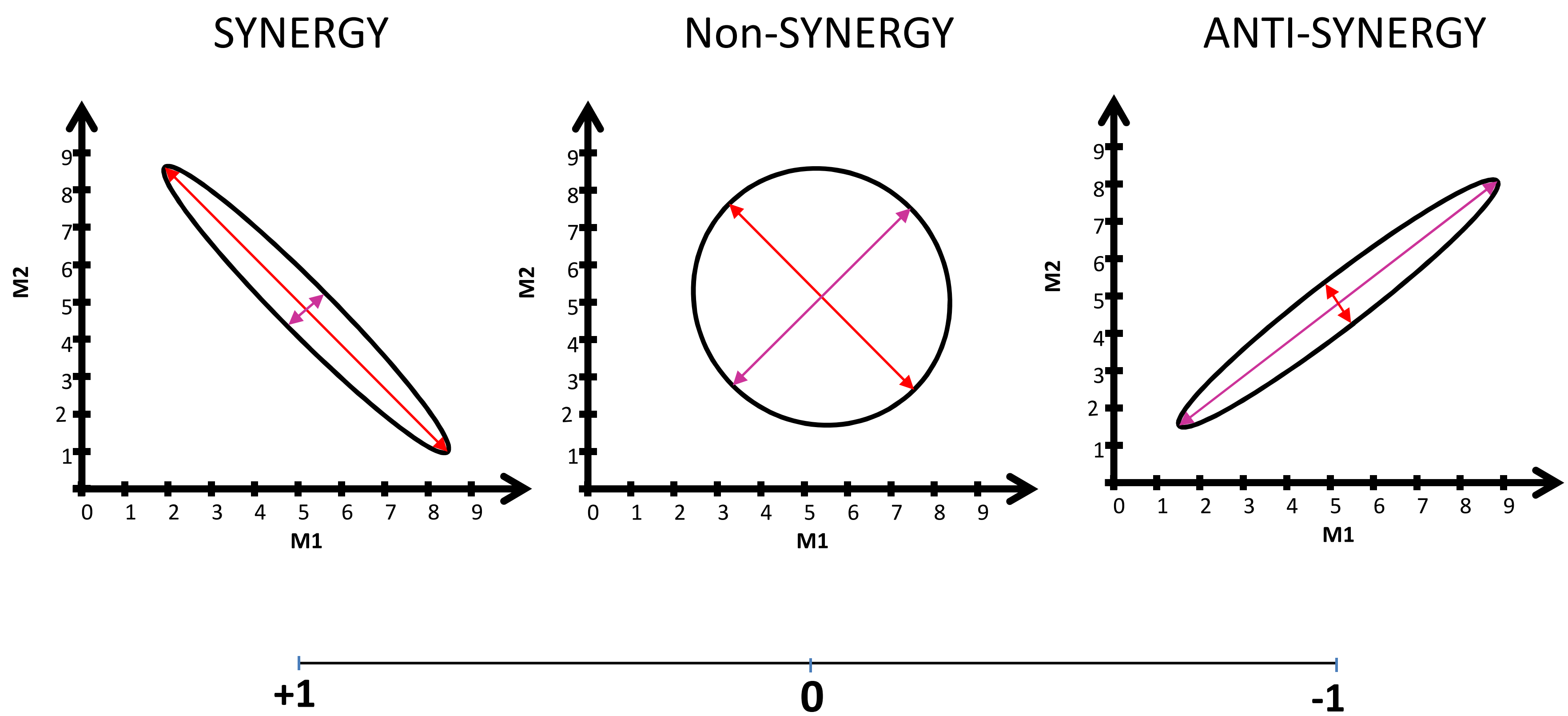
$$M1 + M2 = 10\ N/m$$



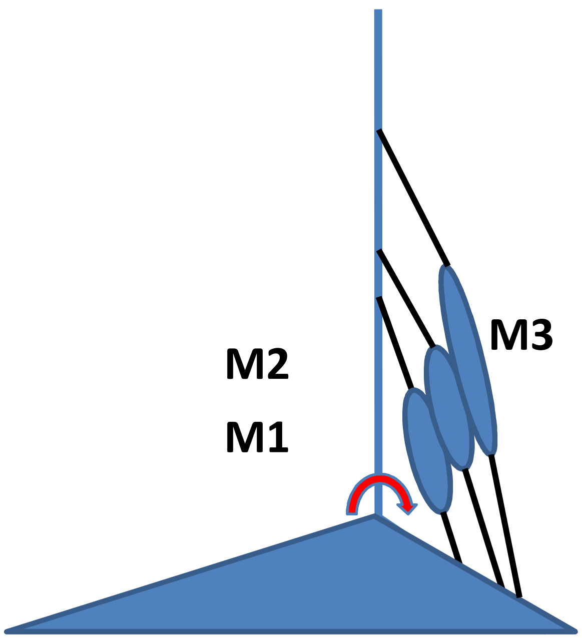
$$\text{Index} = \frac{\text{GOOD}}{\text{BAD}}$$

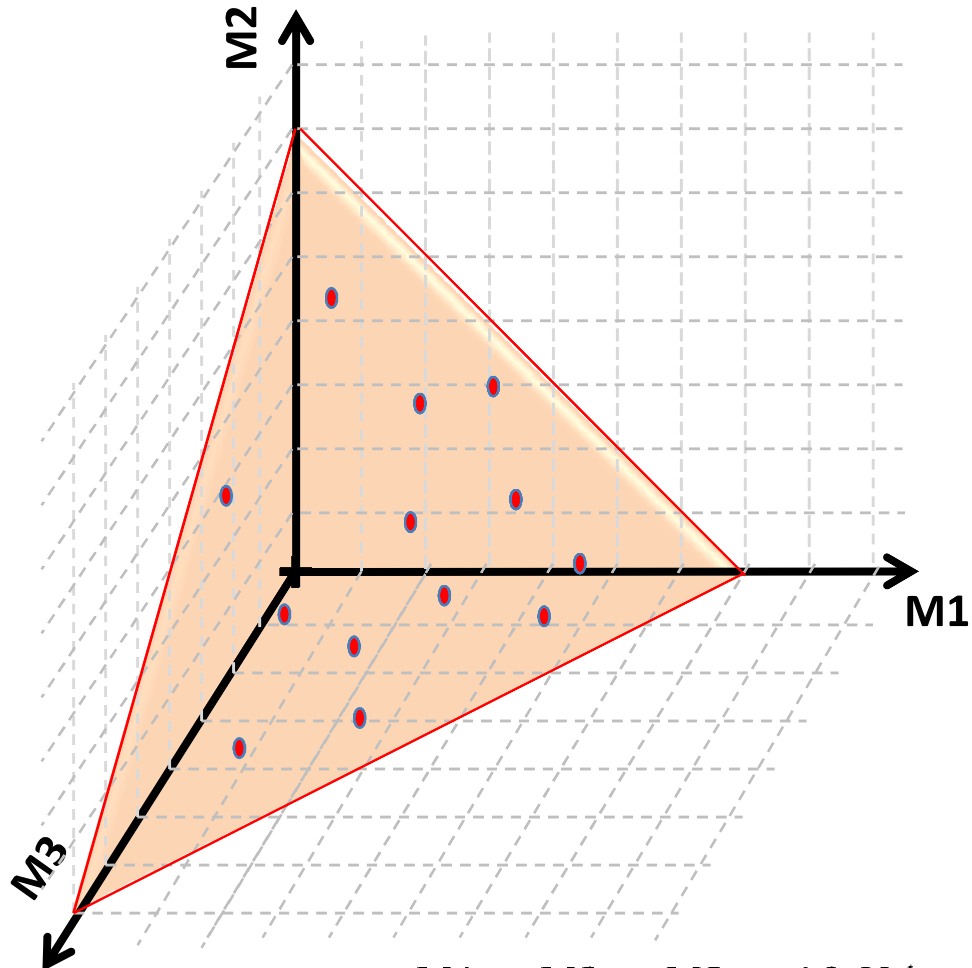


$$M1 + M2 = 10\ N/m$$



$$\text{Index } (\Delta var) = \frac{\text{GOOD}_{/dfg}}{\text{BAD}_{/dfd} + \text{GOOD}_{/dfg}} = \frac{\text{GOOD}_{/dfg}}{\text{Total}_{/(dfg+dfb)}}$$





$$M1 + M2 + M3 = 10\ N/m$$

Exp Brain Res (2007) 179:533–550
DOI 10.1007/s00221-006-0812-0

RESEARCH ARTICLE

Muscle modes and synergies during voluntary body sway

Alessander Danna-dos-Santos · Kajetan Slomka · Vladimir M. Zatsiorsky · Mark L. Latash

Received: 6 September 2006 / Accepted: 18 November 2006 / Published online: 13 January 2007

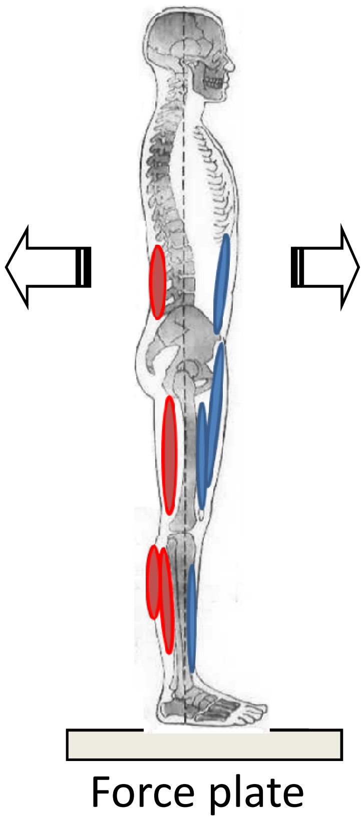
Abstract We studied the coordination of muscle activity during voluntary body sway performed by human subjects at different frequencies. Subjects stood on

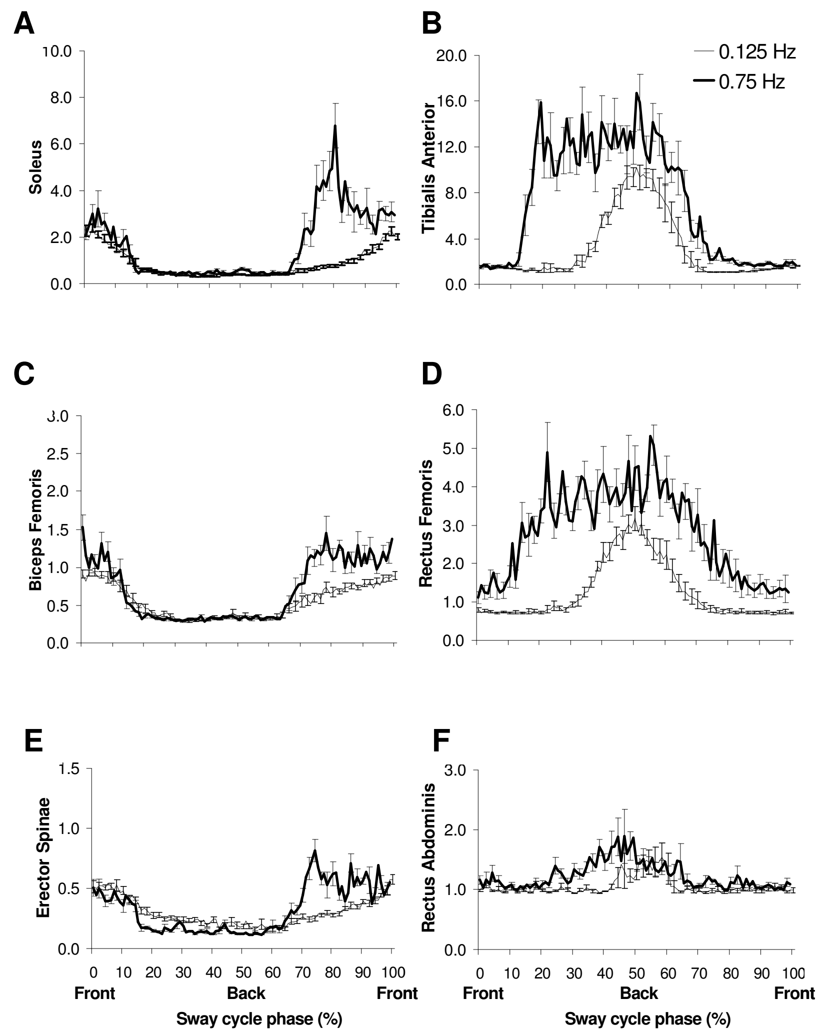
tions in the “good variance”. We conclude that muscle modes and their mapping on COP shifts are robust across a wide range of rates of COP shifts. Multi-*M*-

Study #1

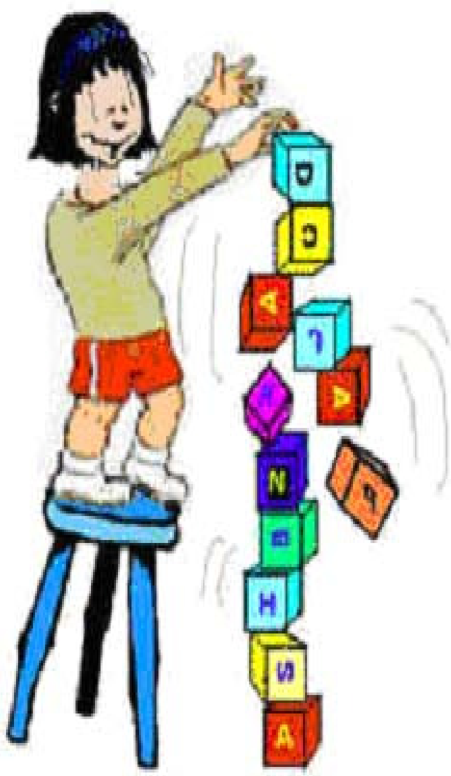
Muscles recorded: SOL, GL, GM, BF, ST, ERE, TA, VL, RF, RA

- 5 conditions: Bipedal stance at five frequencies (0.125, 0.25, 0.5, 0.75 and 1 Hz)





Steps of Data Processing



1- IEMG matrix (1200x11) is submitted to PCA and Varimax rotation

- Output: loading matrix
  - 3-5 first PCs were taken into account for further analysis
    - Modes are computed by IEMG matrix x 'loading matrix' (eigenvector)

2- Multiple regression is performed to obtain the Jacobian matrix (J) between M-modes and COPap.

- ΔCOPap= *k1**ΔM-mode1 + *k2**ΔM-mode2 + *k3**ΔM-mode3 +…+ *kn**ΔM-mode n
- J = [*k1 k2 k3 … kn]*.

3- UCM analysis is performed

- Vort and Vucm
- ΔV (index of synergy) =

$$\frac{(Vucm/dof\_ucm) - (Vort/dof\_ort)}{Total\ Var/dof\_total}$$

Results – Study #1

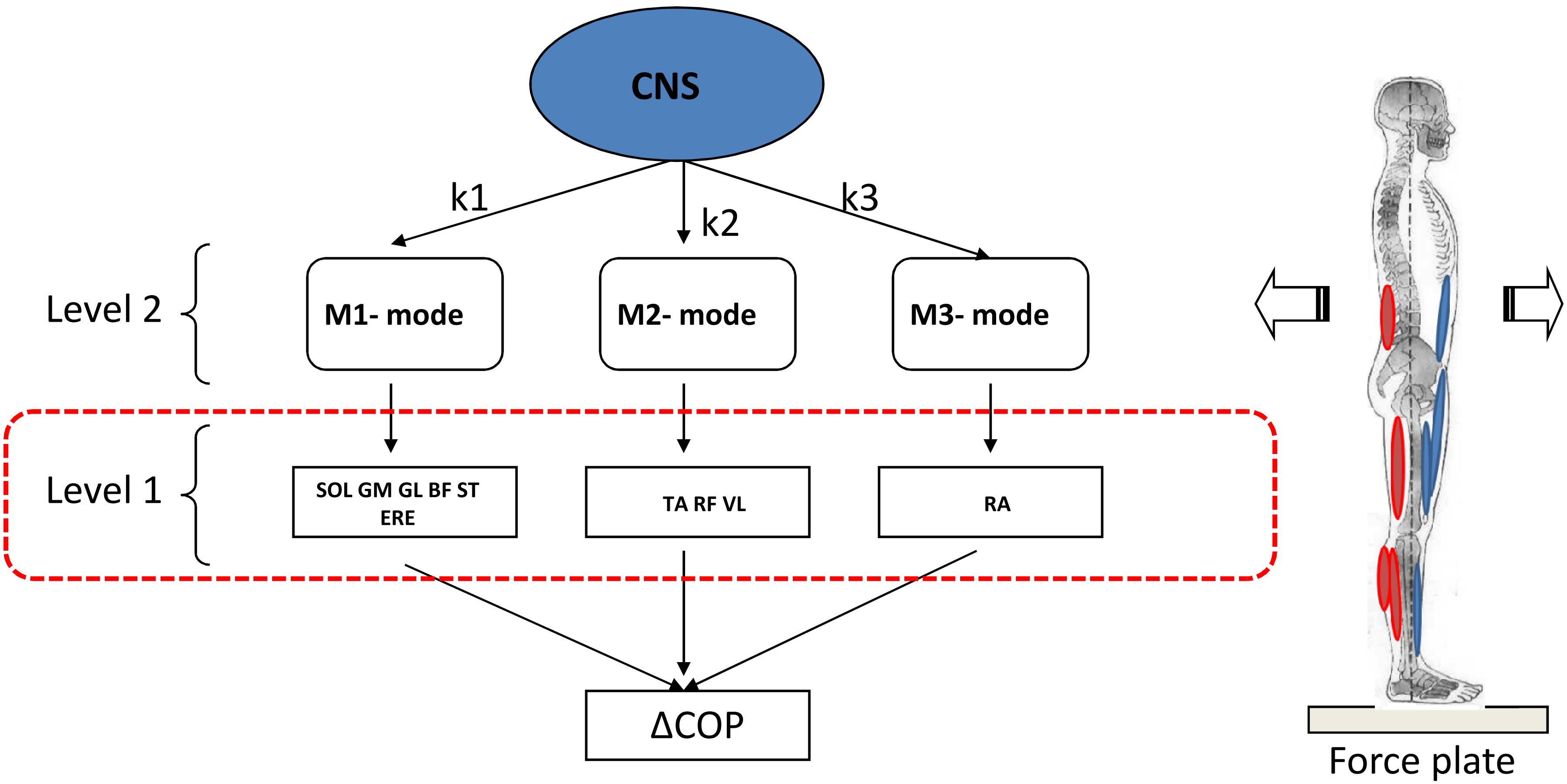
Muscle	0.125 Hz			0.25 Hz			0.50 Hz		
	PC1 M_1-mode	PC2 M_2-mode	PC3 M_3-mode	PC1 M_1-mode	PC2 M_2-mode	PC3 M_3-mode	PC1 M_1-mode	PC2 M_2-mode	PC3 M_3-mode
SOL	0.86 ± 0.07	−0.26 ± 0.16	0.08 ± 0.17	0.84 ± 0.06	−0.27 ± 0.10	0.02 ± 0.03	0.70 ± 0.24	−0.30 ± 0.13	0.15 ± 0.31
GL	0.88 ± 0.04	−0.13 ± 0.13	0.08 ± 0.15	0.84 ± 0.05	−0.22 ± 0.14	0.04 ± 0.04	0.72 ± 0.25	−0.23 ± 0.17	0.17 ± 0.32
BP	0.80 ± 0.14	−0.17 ± 0.13	0.12 ± 0.29	0.79 ± 0.05	−0.12 ± 0.25	−0.03 ± 0.11	0.77 ± 0.10	−0.19 ± 0.13	0.03 ± 0.23
ST	0.54 ± 0.46	0.13 ± 0.51	0.16 ± 0.32	0.42 ± 0.45	0.27 ± 0.55	−0.01 ± 0.09	0.51 ± 0.41	0.25 ± 0.42	0.05 ± 0.31
ES	0.75 ± 0.10	−0.25 ± 0.12	0.09 ± 0.14	0.70 ± 0.11	−0.22 ± 0.14	0.04 ± 0.08	0.58 ± 0.12	−0.20 ± 0.16	0.07 ± 0.16
TA	−0.08 ± 0.28	0.84 ± 0.05	0.14 ± 0.17	−0.19 ± 0.17	0.77 ± 0.09	0.16 ± 0.22	−0.21 ± 0.24	0.69 ± 0.13	0.03 ± 0.24
VL	−0.19 ± 0.10	0.90 ± 0.03	0.01 ± 0.06	−0.27 ± 0.07	0.84 ± 0.02	0.05 ± 0.05	−0.20 ± 0.14	0.80 ± 0.06	0.01 ± 0.07
VM	−0.18 ± 0.11	0.91 ± 0.03	0.07 ± 0.10	−0.27 ± 0.12	0.83 ± 0.10	0.10 ± 0.08	−0.23 ± 0.07	0.84 ± 0.05	0.00 ± 0.09
RP	−0.23 ± 0.10	0.91 ± 0.04	0.07 ± 0.09	−0.31 ± 0.10	0.82 ± 0.08	0.10 ± 0.10	−0.24 ± 0.09	0.84 ± 0.04	0.02 ± 0.12
RA	0.13 ± 0.21	0.27 ± 0.2[illegible]	0.71 ± 0.50	0.05 ± 0.05	0.12 ± 0.08	0.97 ± 0.03	0.08 ± 0.10	0.14 ± 0.2[illegible]	0.61 ± 0.61

Muscle	0.75 Hz			1.00 Hz		
	PC1 M_1-mode	PC2 M_2-mode	PC3 M_3-mode	PC1 M_1-mode	PC2 M_2-mode	PC3 M_3-mode
SOL	0.76 ± 0.23	−0.21 ± 0.11	0.16 ± 0.3	0.70 ± 0.30	−0.17 ± 0.09	0.28 ± 0.39
GL	0.77 ± 0.22	−0.19 ± 0.11	0.18 ± 0.32	0.68 ± 0.32	−0.16 ± 0.10	0.30 ± 0.40
BP	0.62 ± 0.25	−0.14 ± 0.19	0.17 ± 0.48	0.57 ± 0.30	−0.19 ± 0.19	0.38 ± 0.35
ST	0.38 ± 0.33	0.20 ± 0.47	0.22 ± 0.44	0.40 ± 0.40	0.14 ± 0.36	0.37 ± 0.43
ES	0.59 ± 0.06	−0.22 ± 0.14	0.04 ± 0.32	0.52 ± 0.23	−0.24 ± 0.19	0.29 ± 0.30
TA	−0.31 ± 0.15	0.54 ± 0.12	0.12 ± 0.33	−0.19 ± 0.24	0.60 ± 0.17	−0.13 ± 0.14
VL	−0.20 ± 0.11	0.76 ± 0.06	0.00 ± 0.14	−0.19 ± 0.18	0.72 ± 0.07	−0.03 ± 0.19
VM	−0.23 ± 0.11	0.76 ± 0.15	0.07 ± 0.25	−0.22 ± 0.06	0.78 ± 0.09	−0.07 ± 0.12
RP	−0.24 ± 0.11	0.77 ± 0.11	0.07 ± 0.26	−0.24 ± 0.10	0.78 ± 0.05	−0.08 ± 0.12
RA	−0.03 ± 0.11	0.23 ± 0.25	0.52 ± 0.52	−0.04 ± 0.12	0.46 ± 0.25	0.12 ± 0.56

Averaged across subjects data are shown with standard deviations

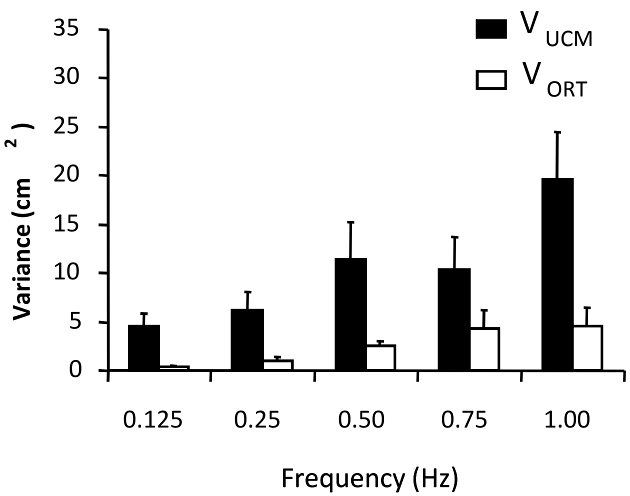
Conclusion

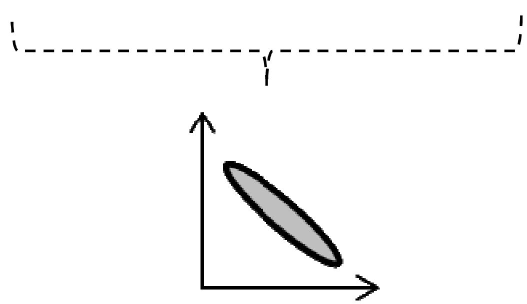
- M-mode composition does not depend on sway frequency;

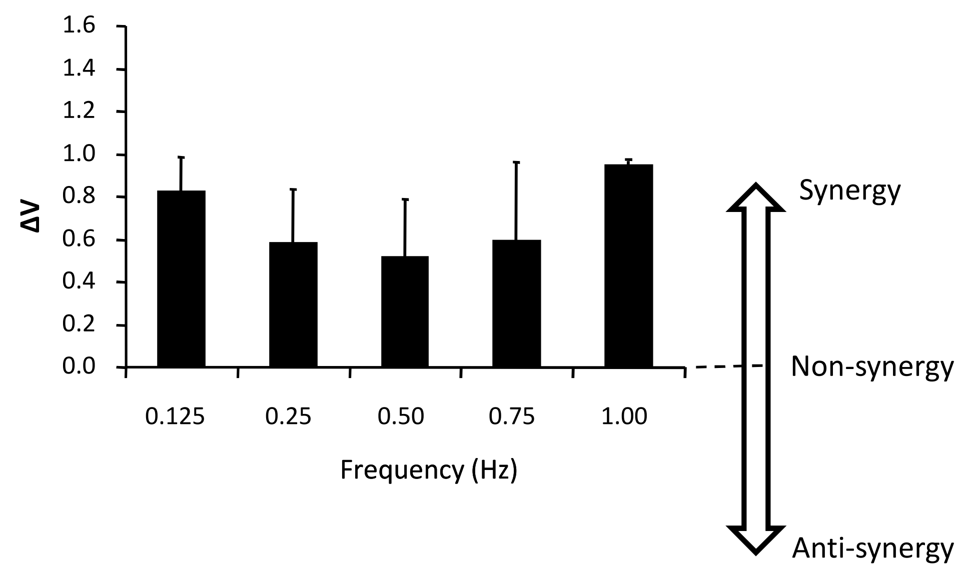

CNS
k1
k2
k3
Level 2
M1- mode
M2- mode
M3- mode
Level 1
SOL GM GL BF ST
ERE
TA RF VL
RA
ΔCOP
Force plate

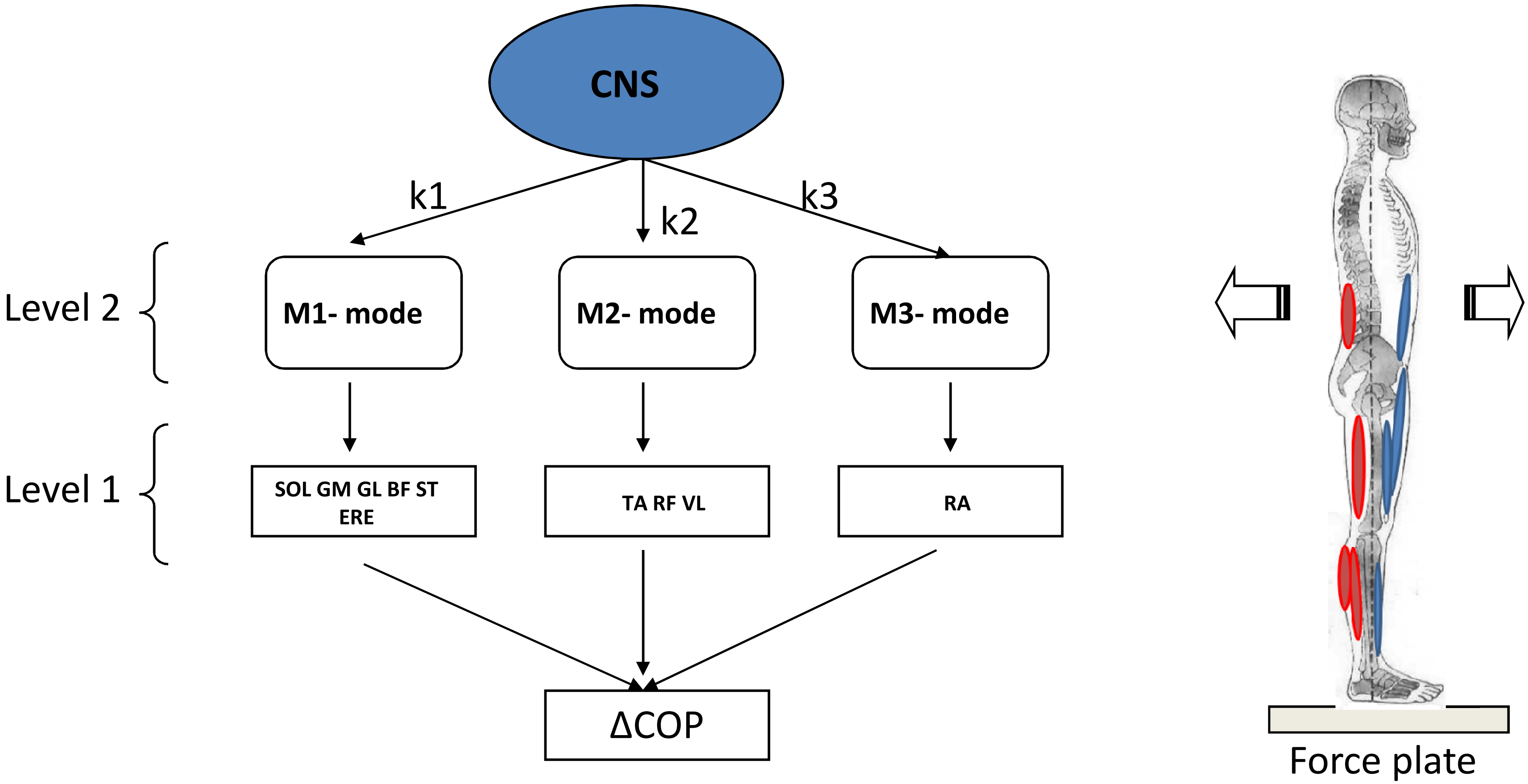
Results – Study #1

ΔV > 0 - a multi-M-mode synergy








CNS
k1
k2
k3
Level 2
M1- mode
M2- mode
M3- mode
Level 1
SOL GM GL BF ST ERE
TA RF VL
RA
ΔCOP
Force plate

Exp Brain Res (2008) 189:171–187
DOI 10.1007/s00221-008-1413-x

RESEARCH ARTICLE

Flexible muscle modes and synergies in challenging whole-body tasks

**Alessander Danna-dos-Santos ·
Adriana M. Degani · Mark L. Latash**

Exp Brain Res (2009) 193:565–579
DOI 10.1007/s00221-008-1659-3

RESEARCH ARTICLE

Postural control during upper body locomotor-like movements: similar synergies based on dissimilar muscle modes

Alessander Danna-Dos-Santos · Elena Yu. Shapkova · Alexandra L. Shapkova · Adriana M. Degani · Mark L. Latash

Exp Brain Res (2010) 202:457–471
DOI 10.1007/s00221-009-2153-2

RESEARCH ARTICLE

Multi-muscle synergies in a dual postural task: evidence for the principle of superposition

Miriam Klous · Alessander Danna-dos-Santos ·
Mark L. Latash

Conclusions

- The UCM hypothesis offers a fruitful framework for analysis of multi-muscle synergies involved in postural tasks.

- There are M-Mode synergies stabilizing the COPap trajectory

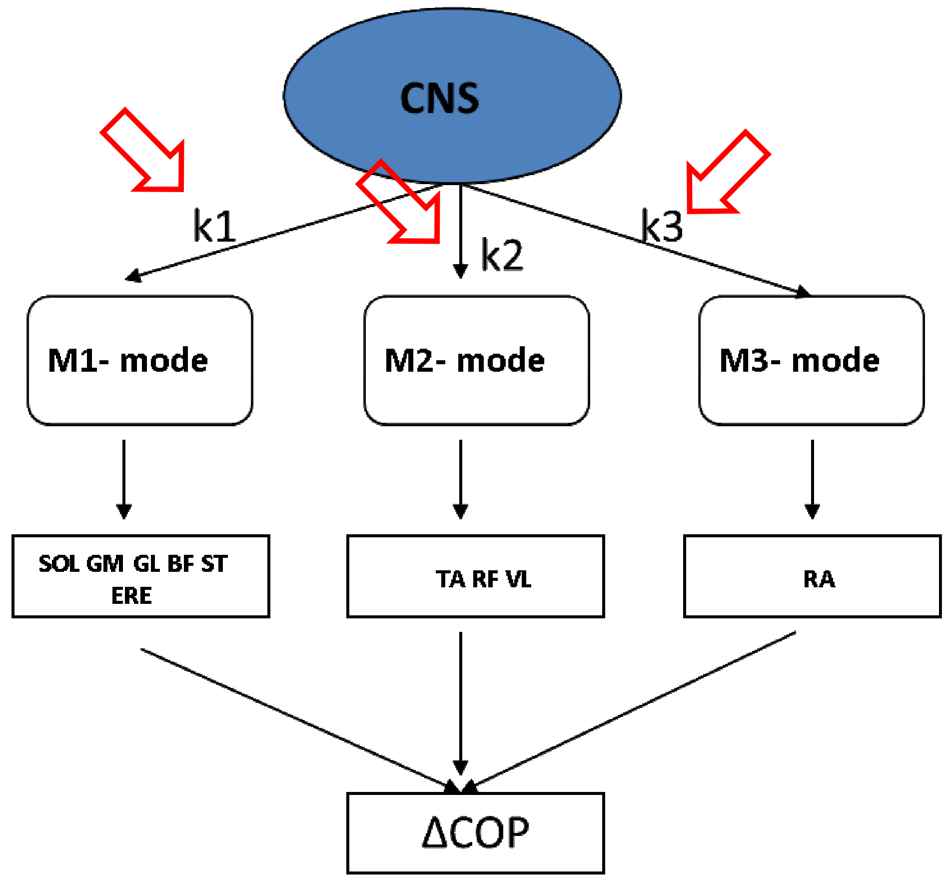
- M-mode composition are stable during routine whole-body actions

- M-mode composition changes under challenging conditions

Next Step

- The UCM hypothesis is still a behavioral analysis

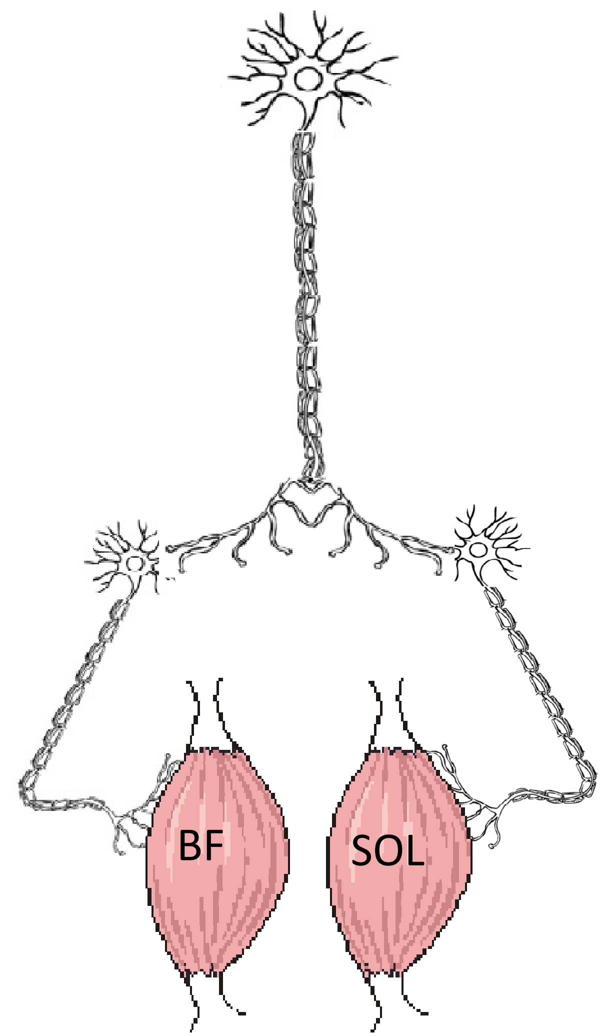
- What about the neural mechanisms generating the functional groups ?



Multi-Muscle Control: Frequencies

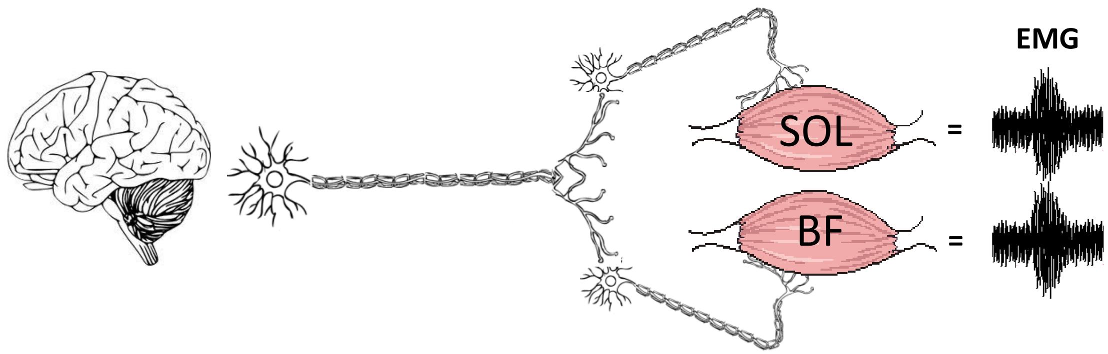
- Neurophysiological mechanisms responsible for the formation of these groups are still unclear and understanding these mechanisms is still one of the fundamental goals of motor control

- Common (correlated) neural inputs may be the mechanism used by the CNS to coordinate the activation of muscles forming a synergistic group
  (Farmer 1998; Semmler et al 2004; De Luca and Erim, 2002; Santello and Fuglevand 2004; Johnston et al 2005; Winges et al 2008)



Preliminary

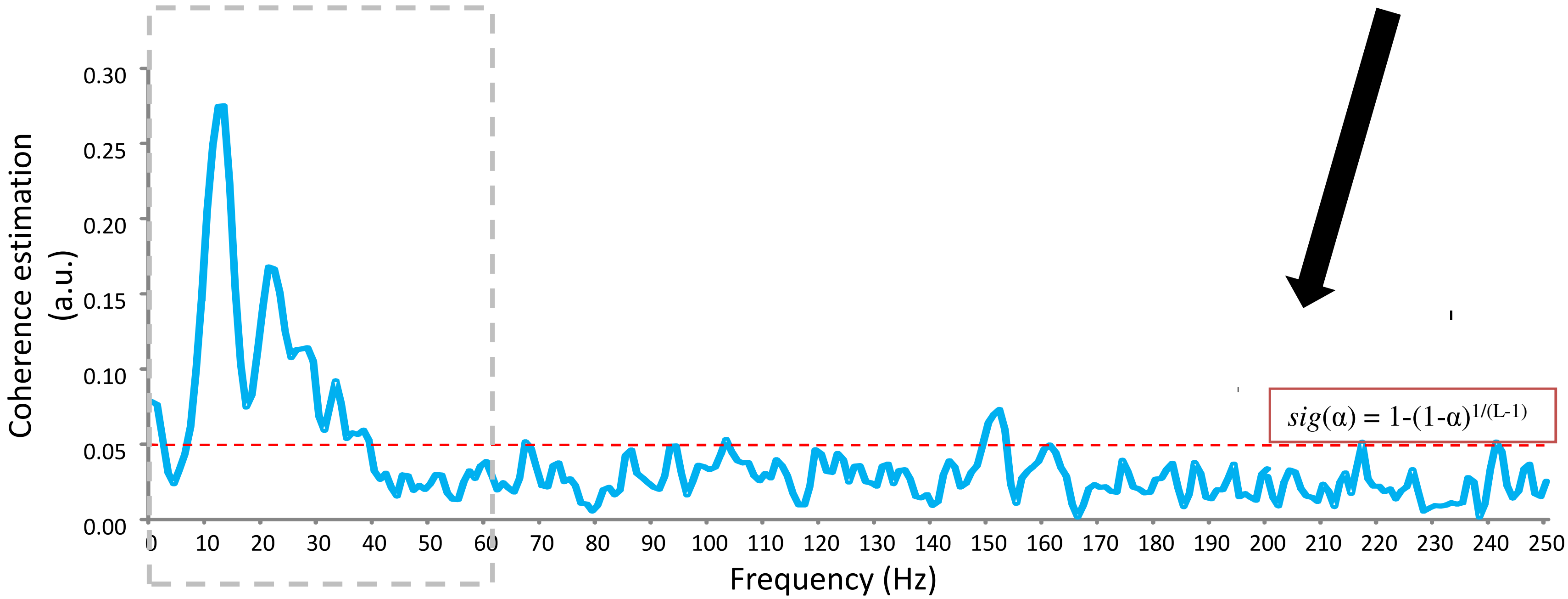
Procedures for quantification of correlated neural inputs



Coherence is estimated separately for pairs of EMG signals by using the cross-spectrum of two EMG signals (*fxy*) squared and normalized by the product of the autospectrum of each signal (*fxx* and *fyy*) at each frequency (λ)

$$|R_{xy}(\lambda)|^2 = |f_{xy}(\lambda)|^2 / (f_{xx}(\lambda) f_{yy}(\lambda))$$

f_{xy} : cross-spectrum
f_{xx} , f_{yy} : auto-spectra



$$sig(\alpha) = 1-(1-\alpha)^{1/(L-1)}$$

Coherence is a measure used to determine the linear relation between two signals in the frequency domain. Similar to the coefficient of determination (r^2) in linear statistics, the magnitude of coherence at a given frequency is bounded by 0 and 1, indicating that no linear relationship and a perfect linear relationship, respectively, exists at that frequency.

Rosemberg et al (1989)

Thank you !!!

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