

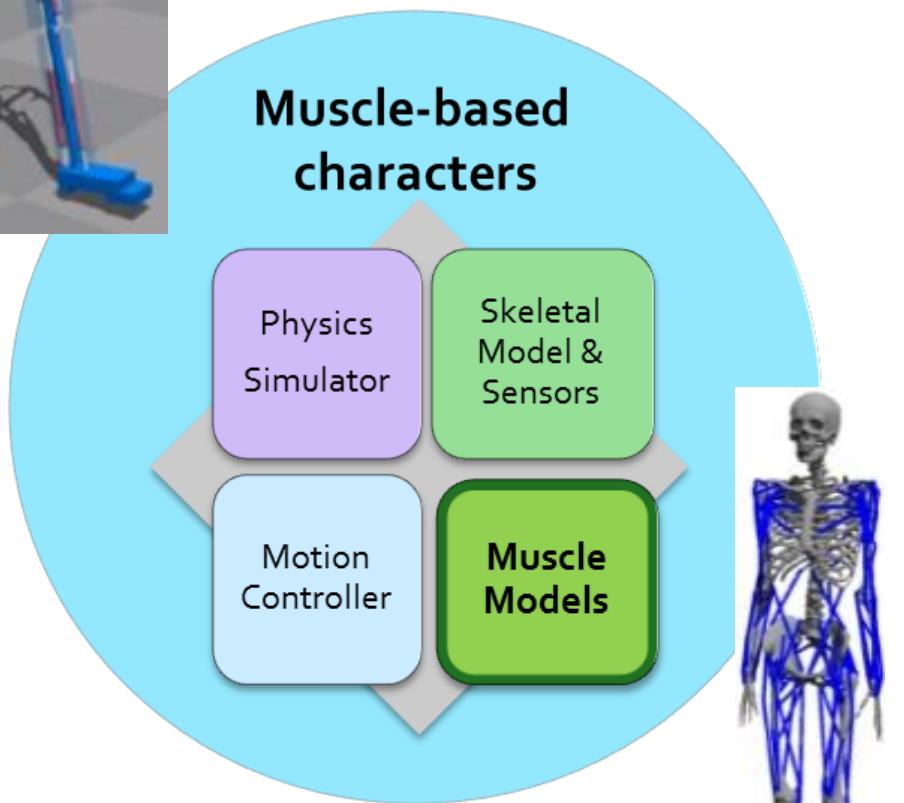
Low-Dimensional Motor Control Strategy of Throwing Motions

Ana Lucia Cruz Ruiz, Charles Pontonnier, Georges Dumont





Our interest



Characters actuated by muscles

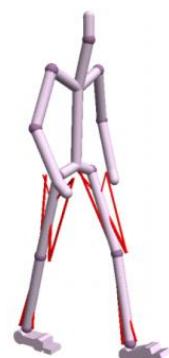
- Muscles generates forces
- Forces generates motions
- How do we control muscles ?

Our interest

Actuation redundancy

Muscles > # DoF

6 DoF
16 Muscles



(Wang et al. 2012)

39 DoF
120 Muscles



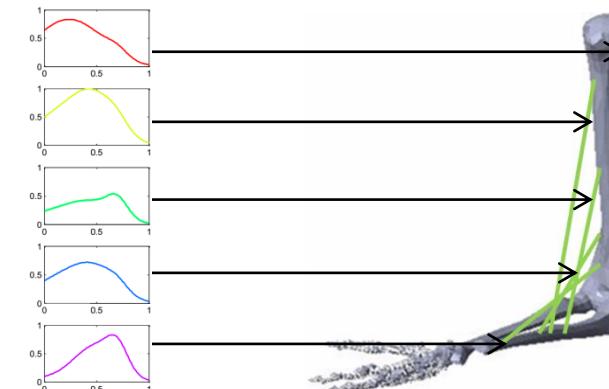
(Lee et al. 2014)

Control redundancy

Control signals = # Muscles

5 control signals

5 Muscles, 1 DoF



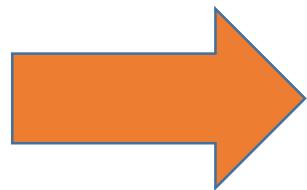
(Cruz Ruiz et al. 2016a)

Numerous combinations of control signals achieve the same motor task:
One combination should be selected

Goal of this work

Can we find a reduced muscle motor control strategy usable for motion synthesis in a acyclic, dynamic motion ?

Is this strategy consistent across subjects ?



Let's try on overhead throwing motions !

Muscle synergy theory

Muscle synergy theory

Synergy = “working together”

The central nervous system (CNS) generates motions by controlling muscles in groups via synergies.

Evidence of muscle synergies:

Walking

(Ivanenko et al. 2003, 2004)

Running

(Cappellini et al. 2006)

Pedaling

(Hug et al. 2011)

Reaching

(d'Avella et al. 2007, 2008)

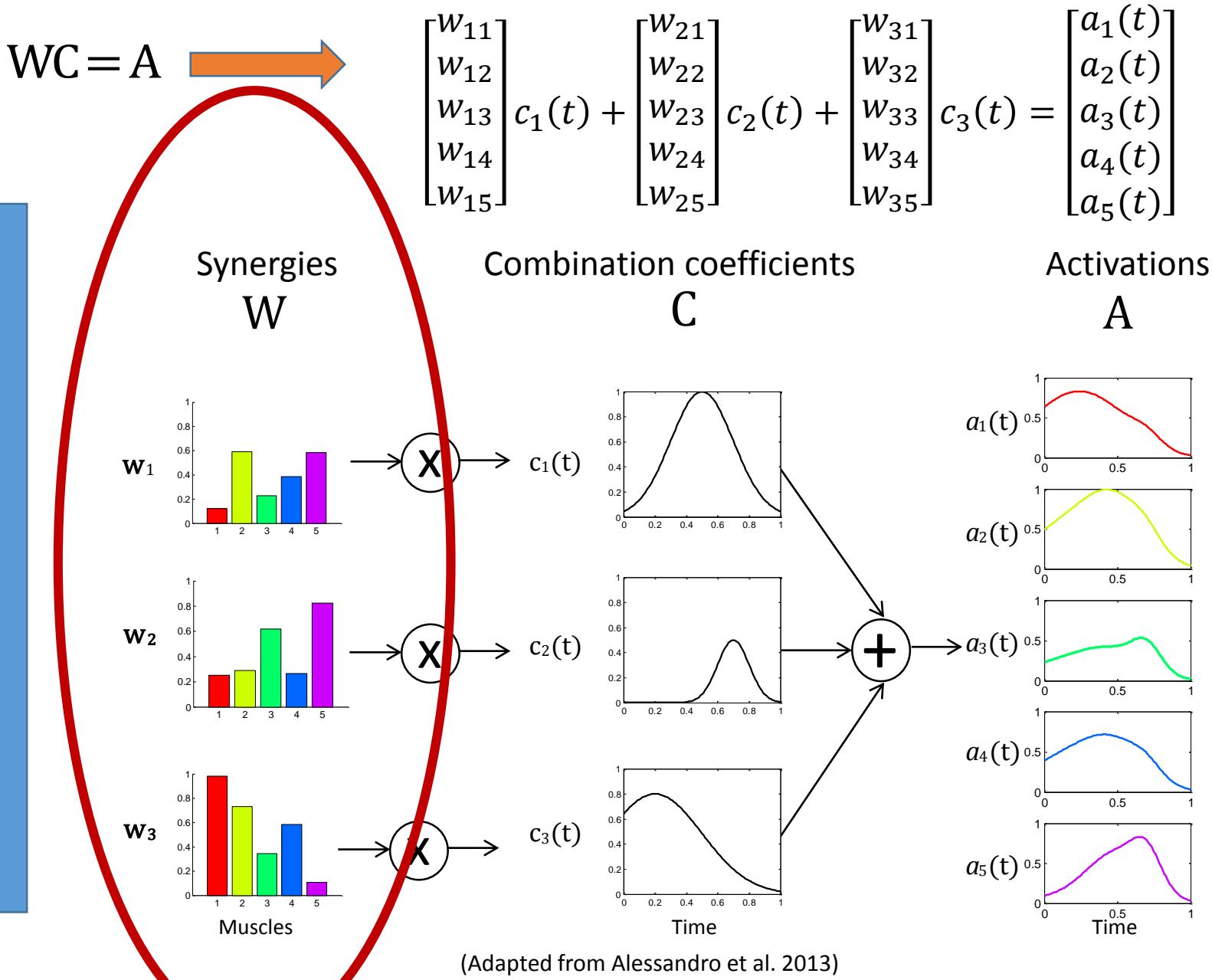
Force generation tasks

(Roh et al. 2012)

Postural control

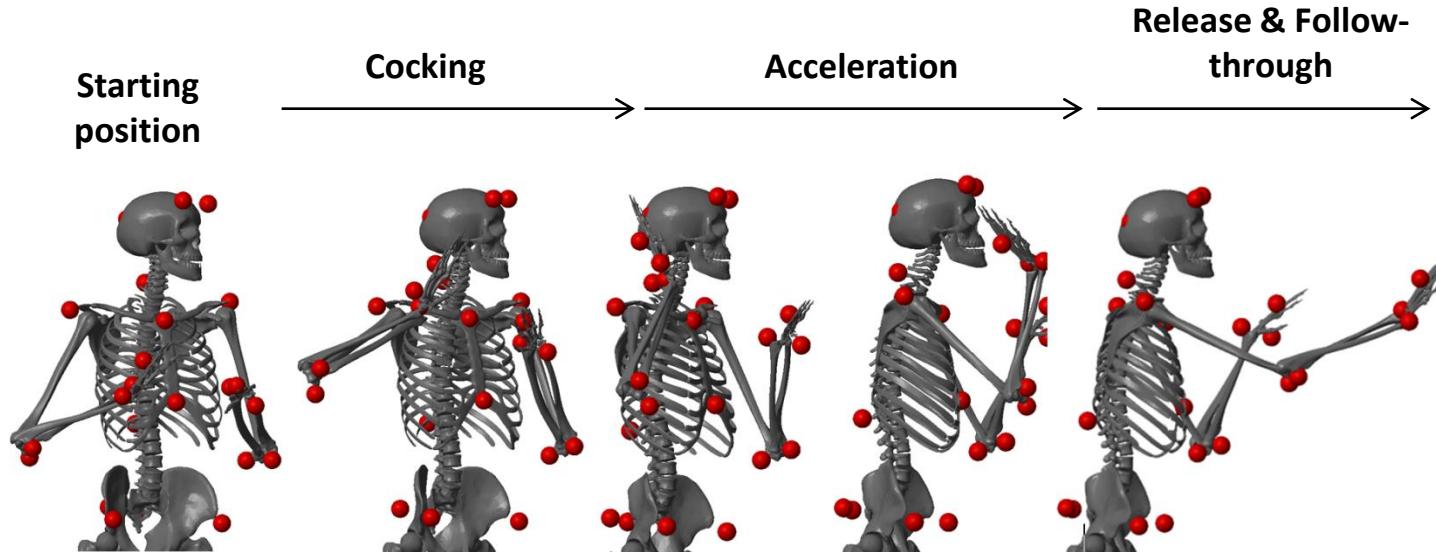
(Torres Oviedo and Ting 2007,
Safavynia and Ting 2011)

Task-independent... Across subjects ?



Experimentation

Overhead throwing motion description

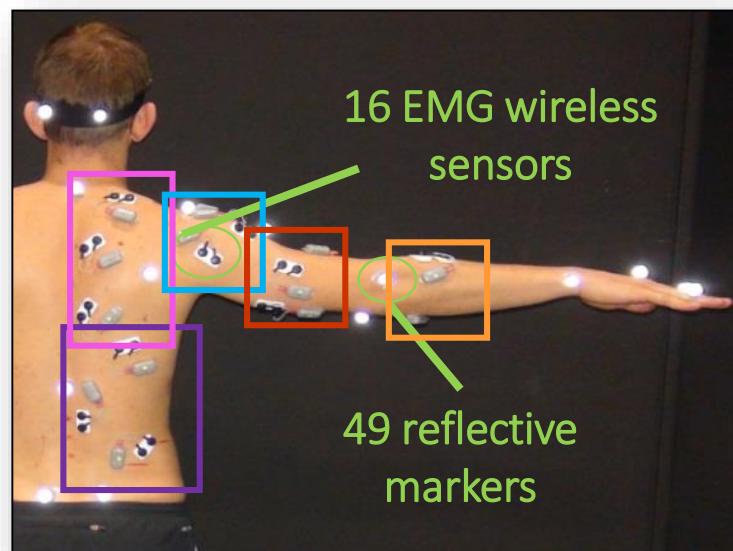


An overhead throwing motion and its main phases
(Phases based on Kelly et al. 2002)

An unconstrained and dynamic motion,
requiring coordination, accuracy, and skill

Data collection: Throwing experiments

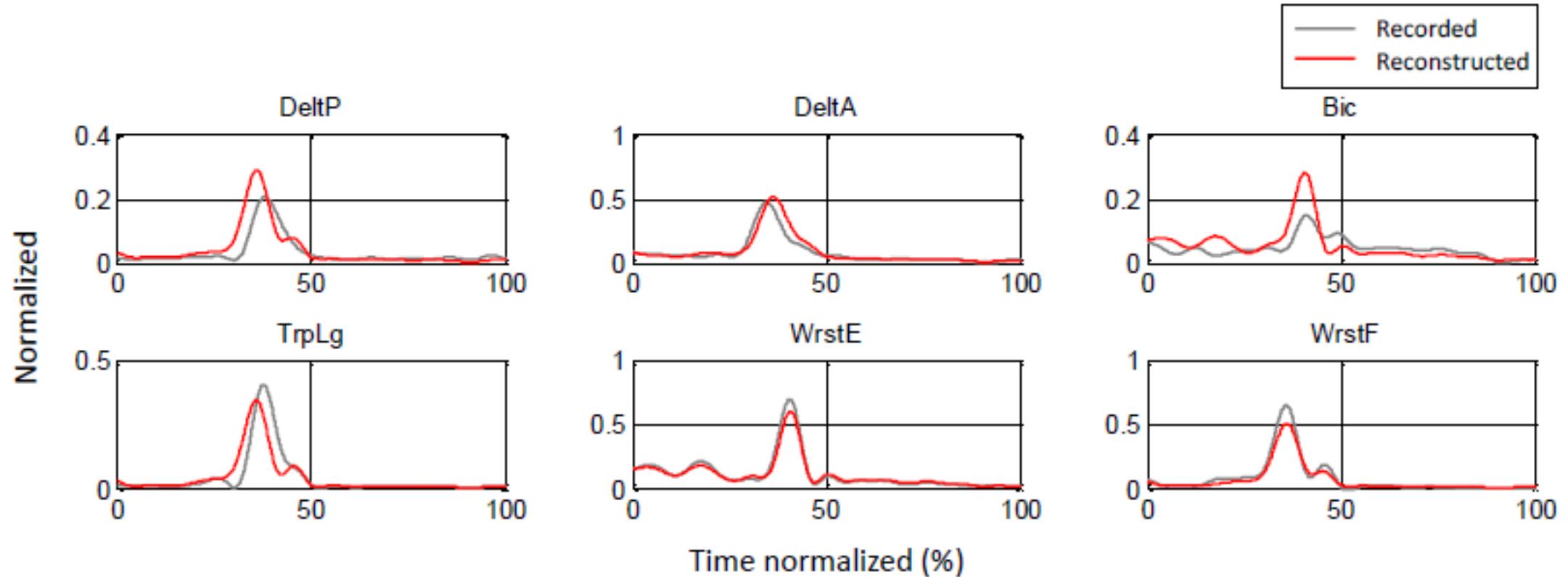
10 subjects * 3 distances * 6 trials



EMG electrodes and reflective marker placement
(Hermens et al. 1999, Criswell 2010)

- Back muscles
 - Erector spinae longissimus
 - Erector spinae iliocostalis
 - Lastissimus dorsi
- Scapula
 - Upper trapezius
 - Middle trapezius
 - Lower trapezius
- Glenohumeral
 - Posterior deltoid
 - Anterior deltoid
 - Middle deltoid
 - Pectoralis major (Clavicular)
 - Pectoralis major (Sternocostal)
- Elbow/forearm
 - Biceps
 - Triceps long
 - Triceps lateral
- Wrist and hand
 - Forearm extensor bundle
 - Forearm flexor bundle

Collected data: Muscle activations



Muscular strategy

Nonnegative matrix factorization (NMF)

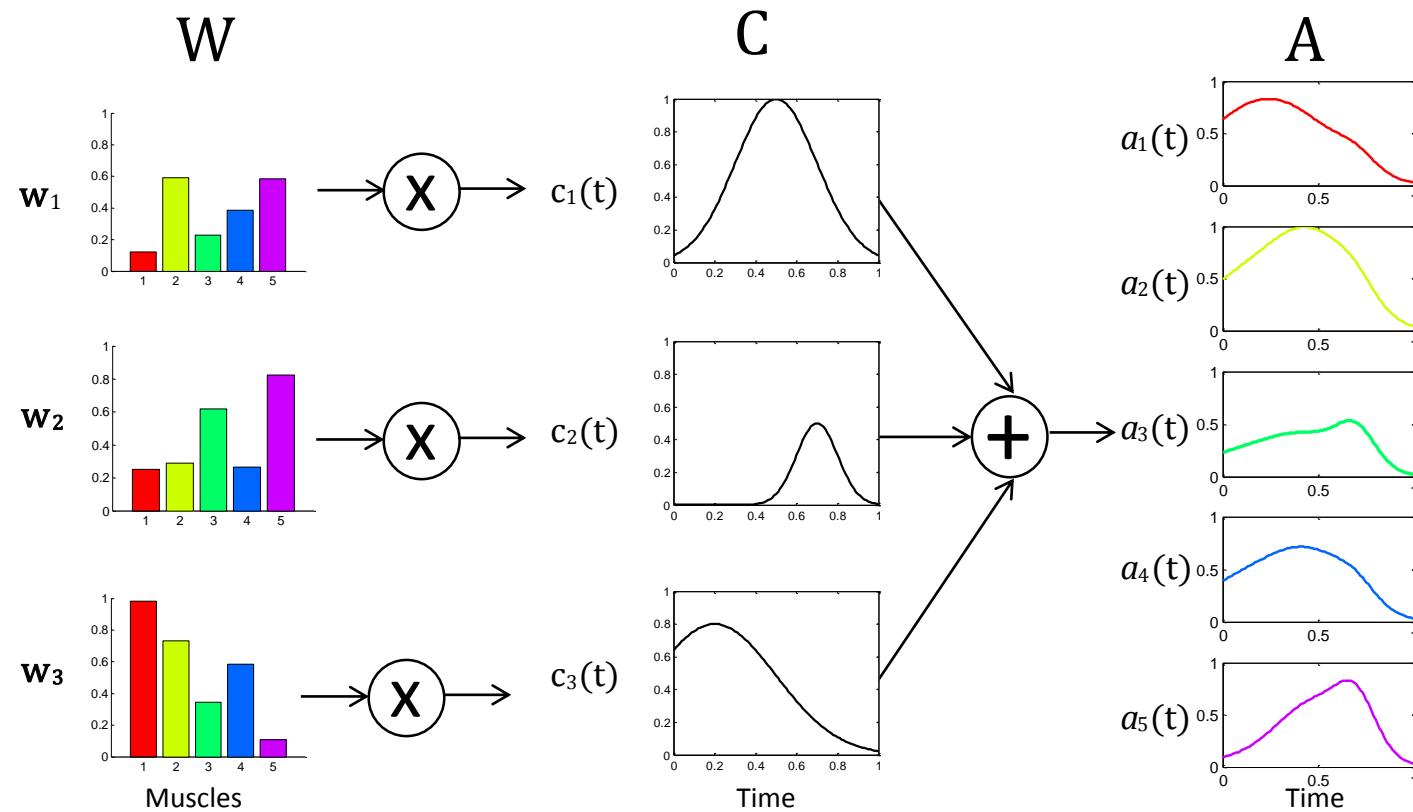
NMF →

$WC = A$

NMF (Kim & Park 2008)

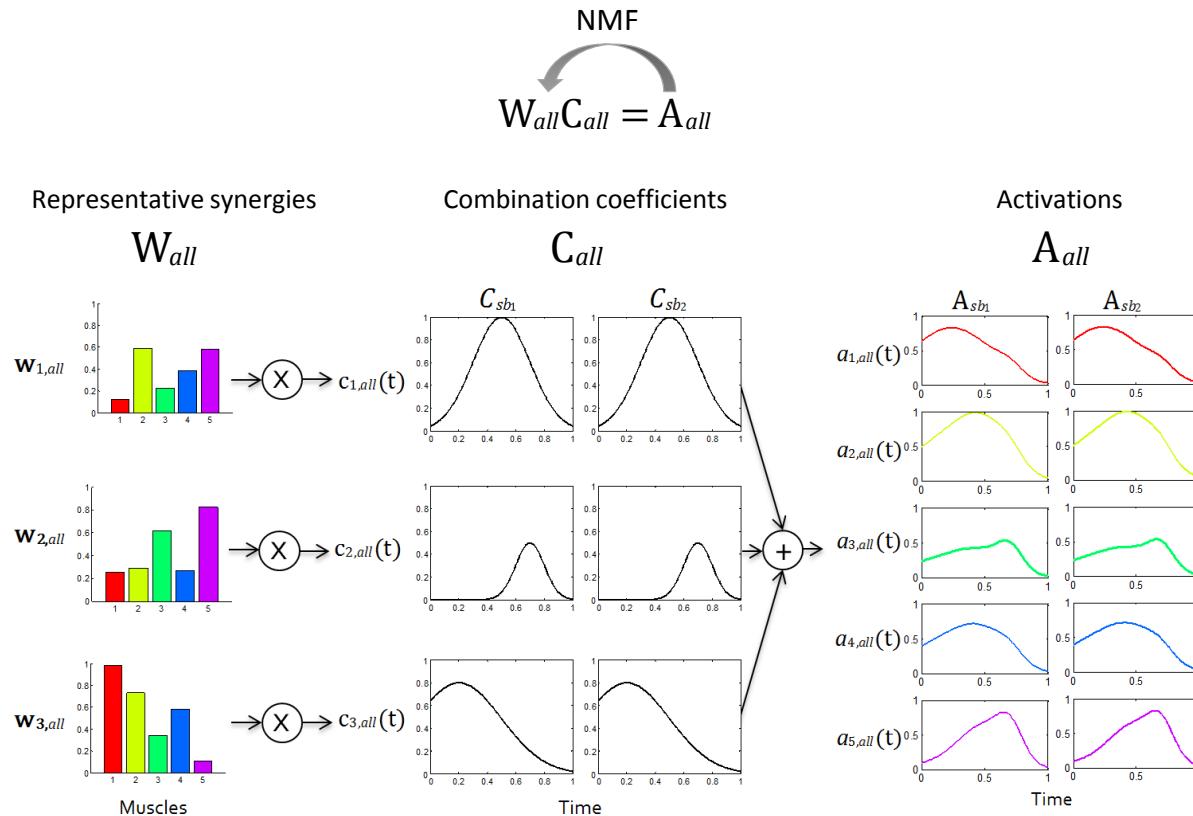
$$\min_{W,C} \frac{1}{2} \|A - WC\|_F^2$$

subject to $W \geq 0, C \geq 0$

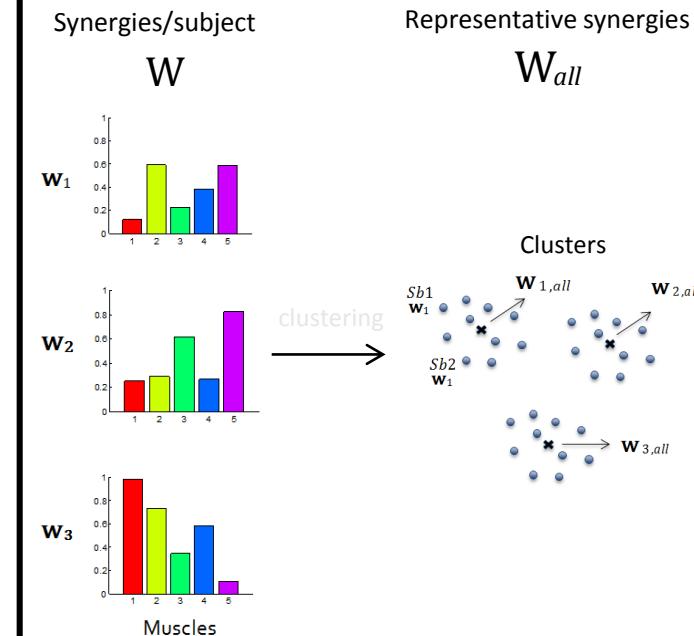


Synergy identification

Concatenation-based identification



Clustering-based identification



Representative synergies and coefficients W_{all}, C_{all}

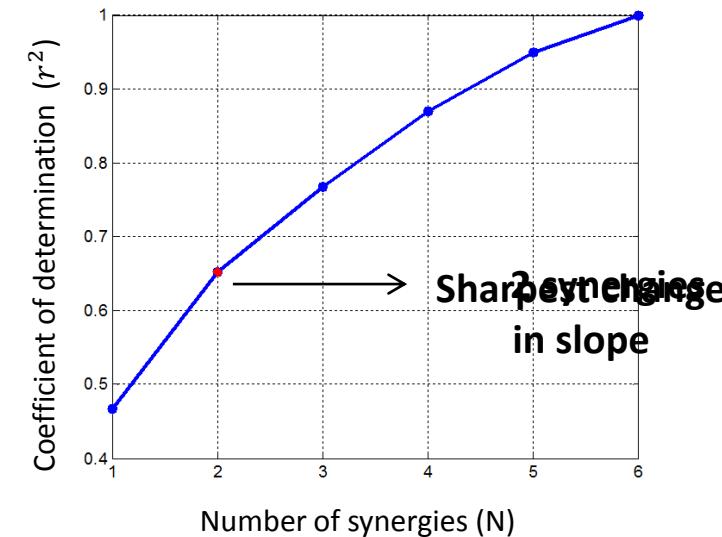
Synergy number selection

Criteria

N-synergies < D-muscles

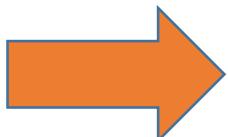
N-synergies encoding most relevant trends of the muscle activations

r^2 - curve



(d'Avella et al. 2003, Muceli et al. 2010)

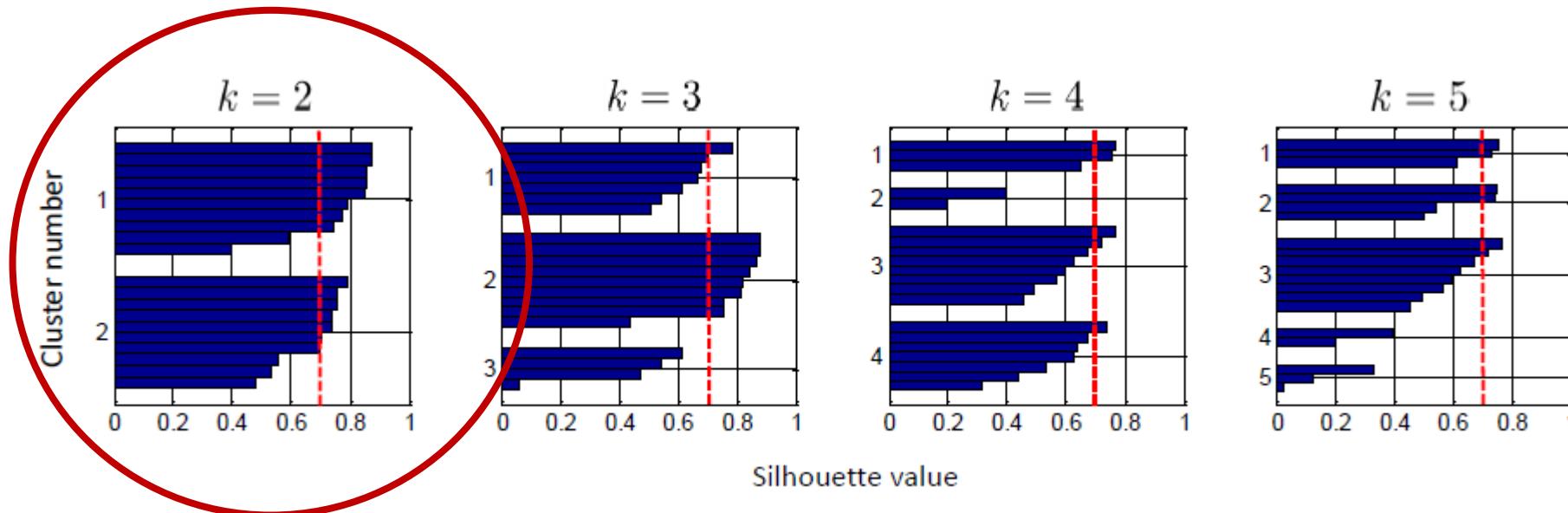
In our case: 2 synergies



Resulting synergies (W) → Clustering

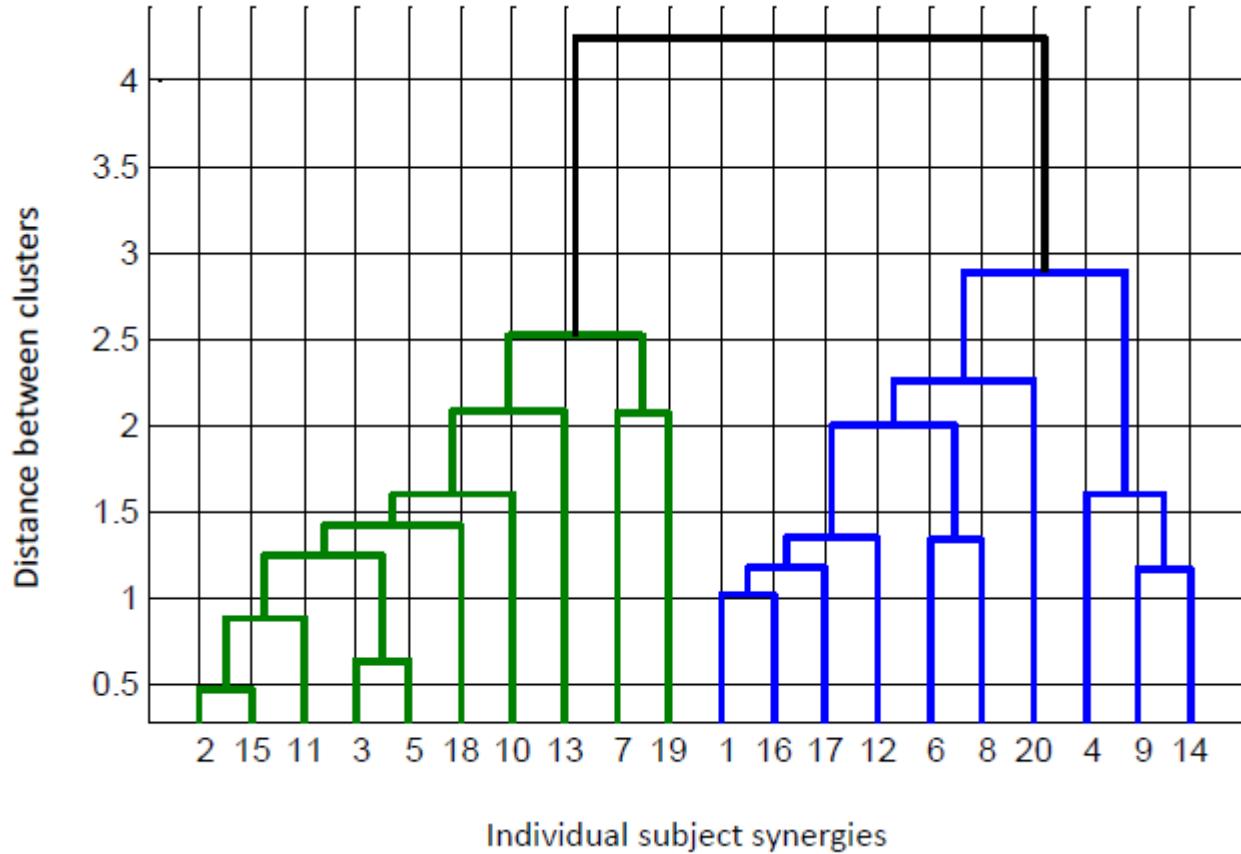
$$s(i) = \frac{b(i) - a(i)}{\max(a(i), b(i))}$$

$a(i)$ Average dissimilarity between element i and its cluster c
 $b(i)$ Average dissimilarity between element i and the « neighbouring cluster » c'



→ The number of « well separated clusters » is equal to the number of identified synergies accross subjects

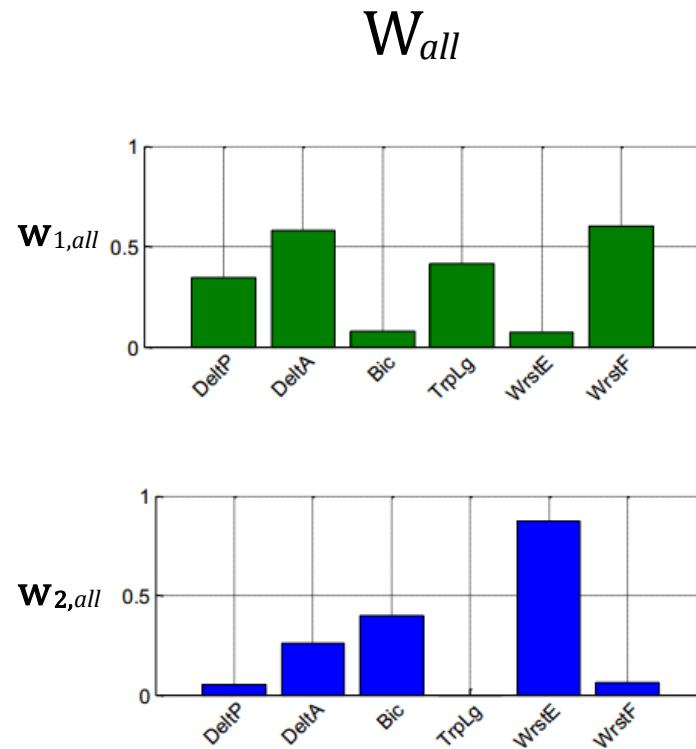
Resulting synergies (W)



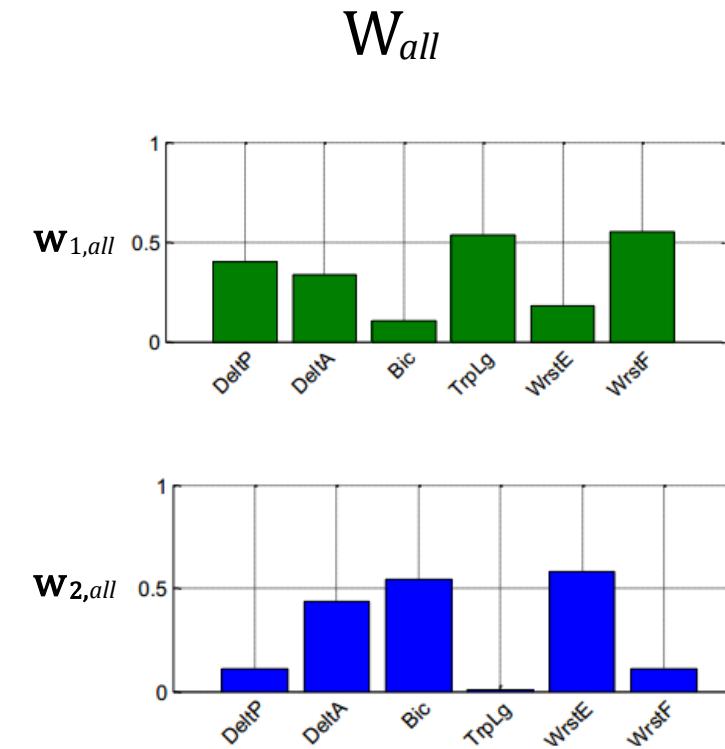
Hierarchical clustering gives similar trend

Resulting synergies (W)

Concatenation-based identification

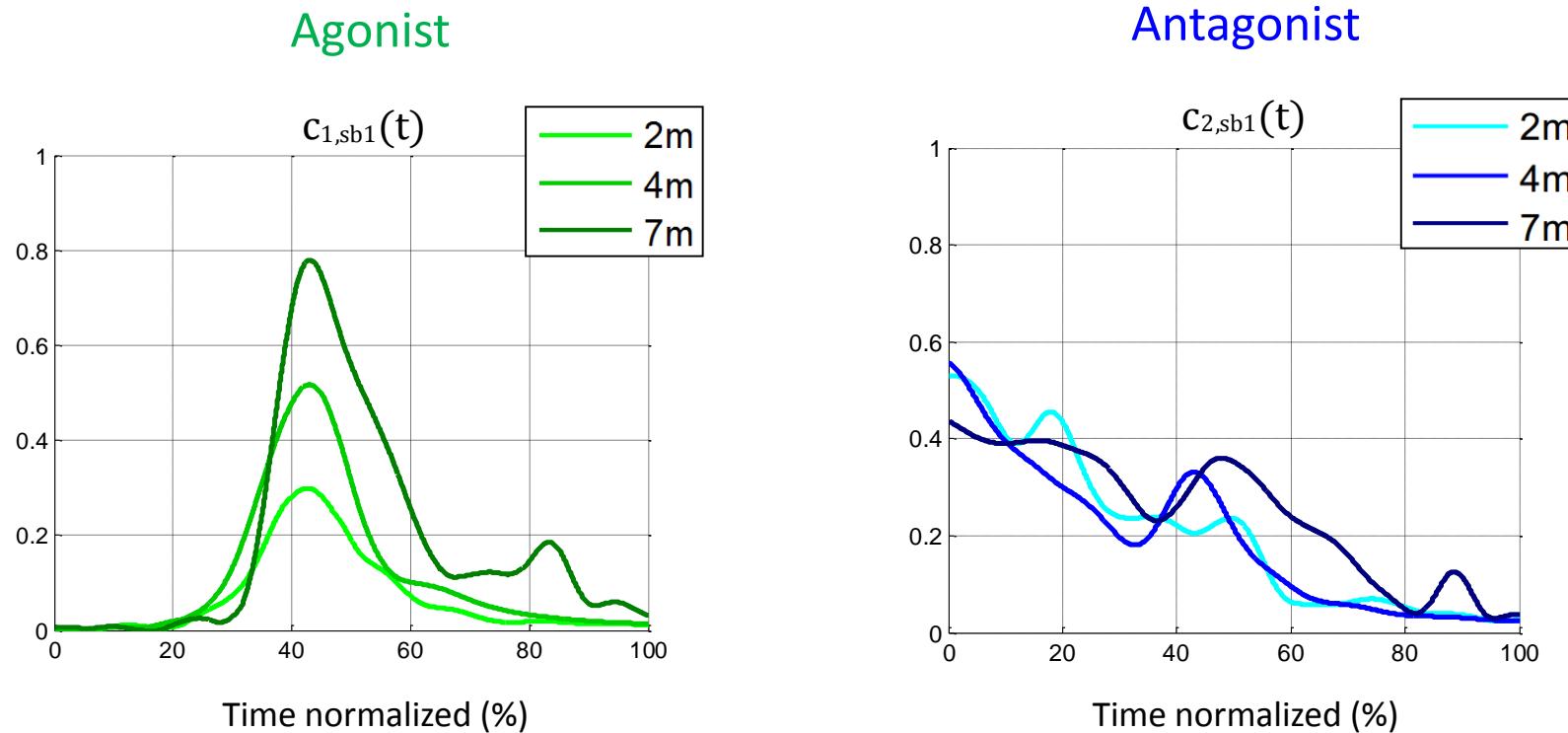


Clustering-based identification



A low-dimensional control strategy exists: 2 synergies for 6 muscles (Set_6)

Resulting combination coefficients (C)



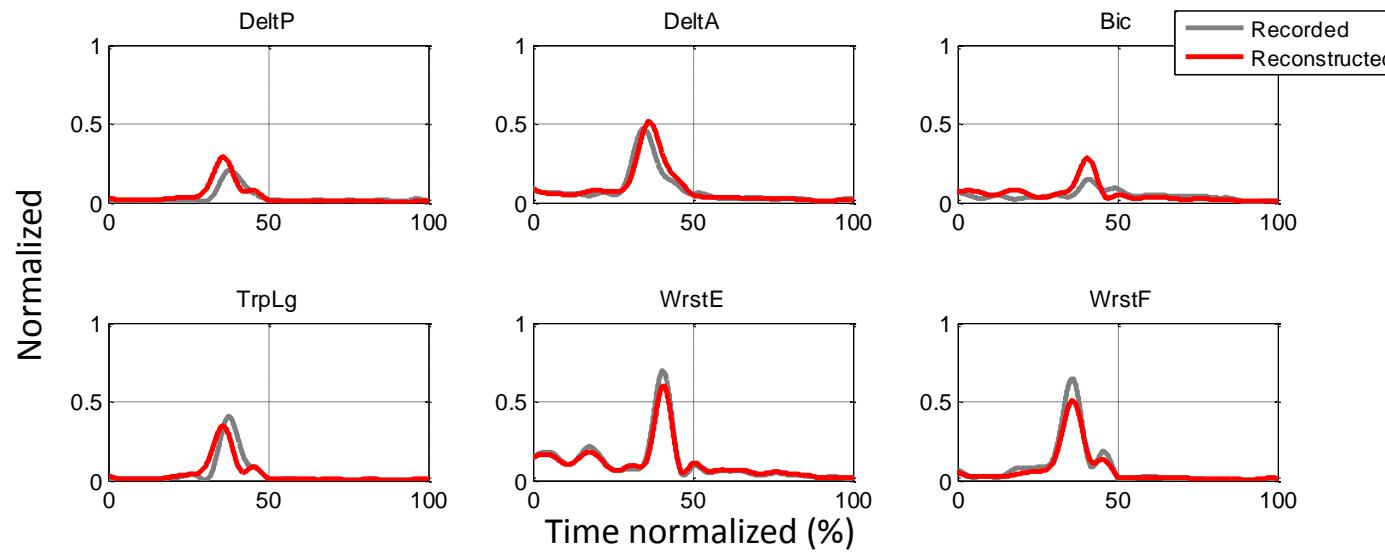
Triggering order: characteristic of activity in the upper limb while throwing

Triggering intensity: modulated by the throwing distance

Muscle activation reconstruction

$$W_{all}C_{all} = A_{all}$$

- 10 subjects
- 6 muscles
- 18 throws/subject
- Total: 1080 muscle activations
 $(r^2 = 0.6525)$



Important activation trends are reconstructed with the synergies

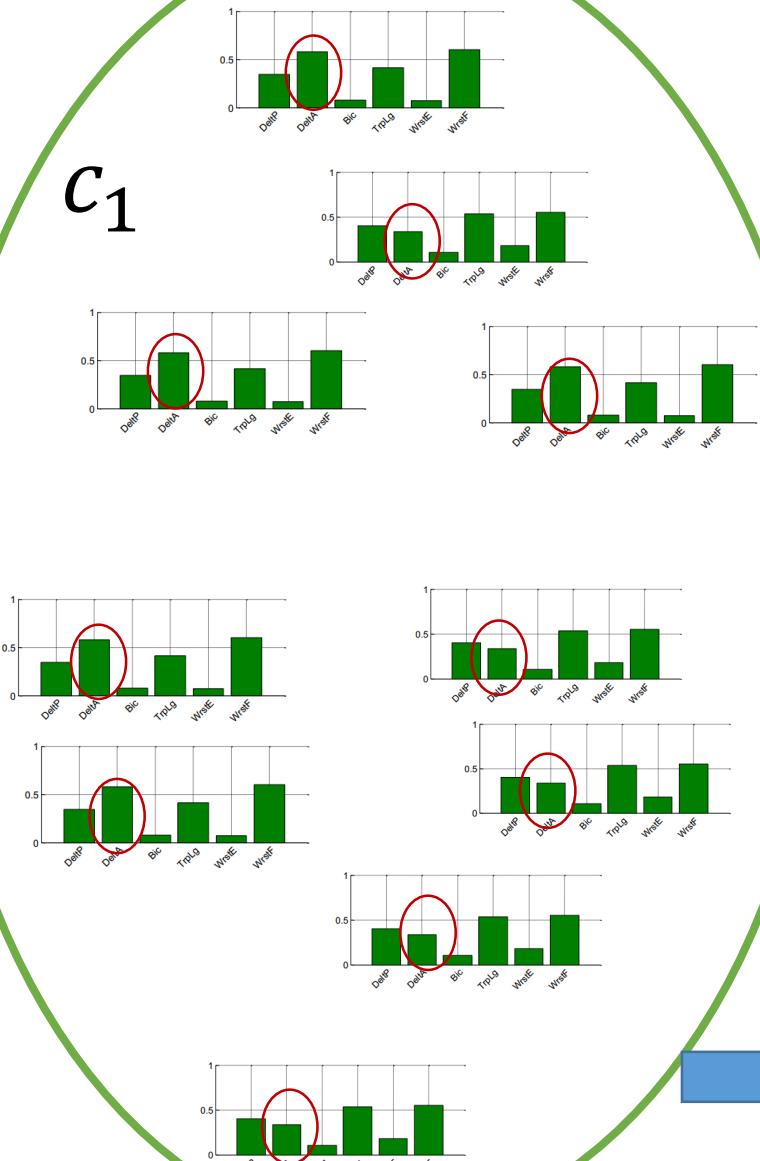
Conclusion and perspectives

Conclusion

- ✓ A representative kinematic and control strategy (synergies) exist during throwing motions.
- ✓ Synergies encode actuation data in a few control variables (2 synergies for 6 muscles).
- ✓ Synergies are modulated by throwing distance, alongside kinematic features.

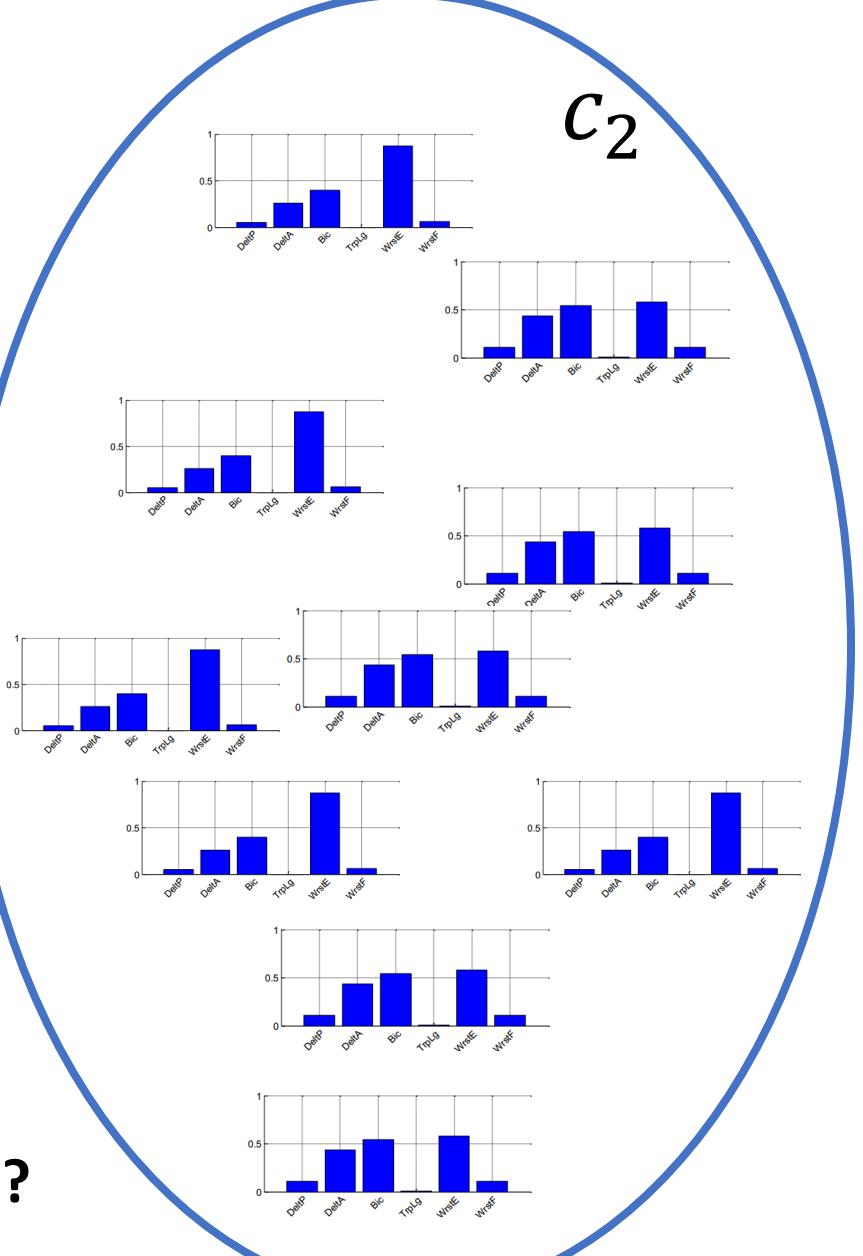
Perspectives

C_1



How each feature
evolves inside a given
cluster ?

C_2



Bi-clustering ?