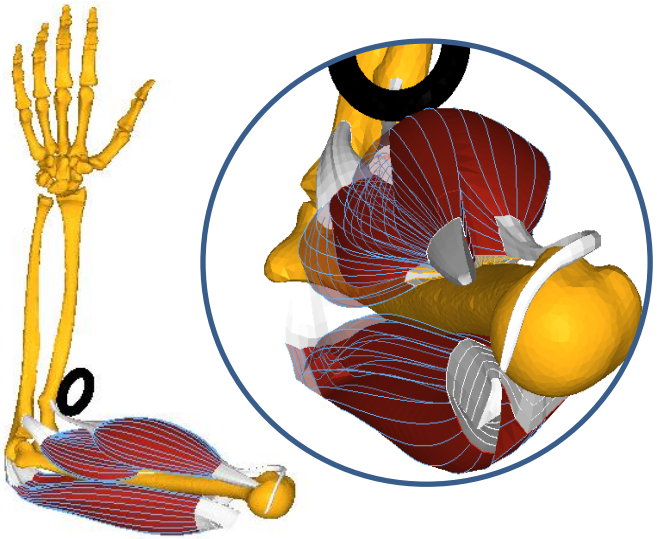
# Integration of Sensory and Motor Loops in a Finite Element Biomechanical Model for Movement Control Application



**D. Salin[1,2], P.J. Arnoux[1], K. Kayvantash[2], M. Behr[1]**

[1]LBA, IFSTTAR, Aix-Marseille Université, Marseille, France

[2]CADLM, Massy, France



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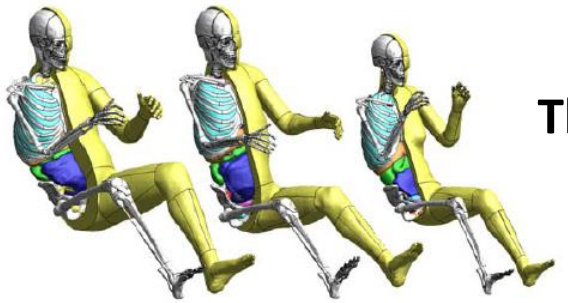
# Context

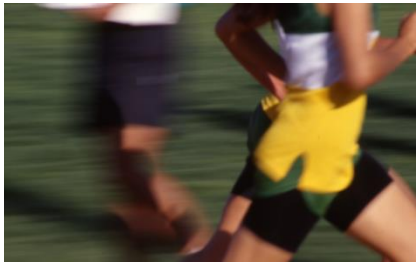
- Various FE models:

**Humos**

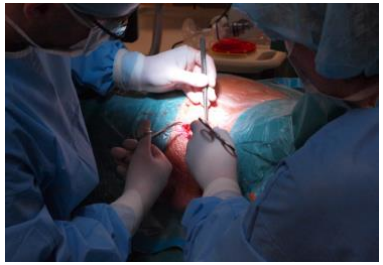


**Thums**

- For various applications:



**Sport**



**Medicine**

**Automotive safety**



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# Context

- Shared needs:
  - Muscle bracing
  - Reactivity to boudary conditions changes

➔ Jointly study biomechanics and movement control

- Proposed solution:

➔ Integrate sensory and motor loops in a FE biomechanical model

# Problematic

How to integrate sensory and motor loops in a FE biomechanical model?

How to control movement?

What are the steps?

**1st step: Create a biomechanical model that incorporate motor skills**

(muscle force generation, movements)

**2nd step: Modeling of the peripheral nervous system:**

Integration of sensors in the biomechanical model and modeling of associated reflexes.

Realization of test of reflexes

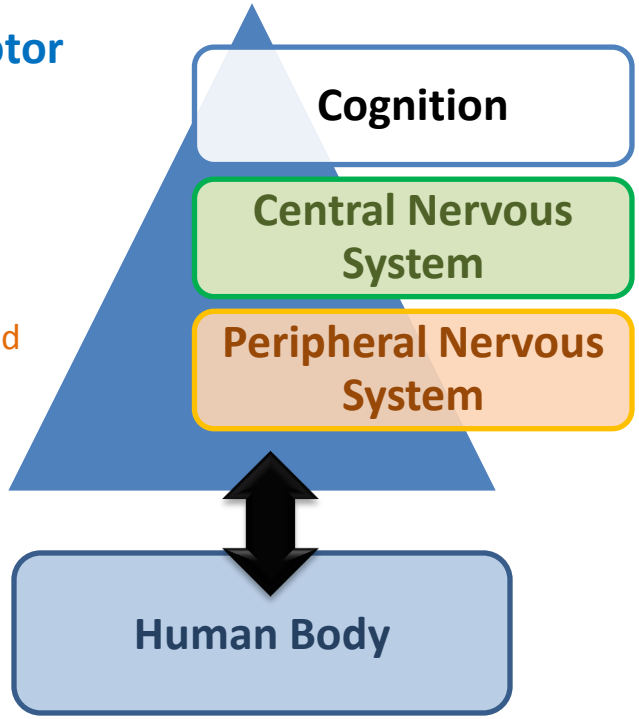
Model validation

**3rd step: Modeling of the central nervous system:**

Learning proprioception and the dynamics of the movement

Optimal control of the movement

Sensitivity analysis of movement parameters



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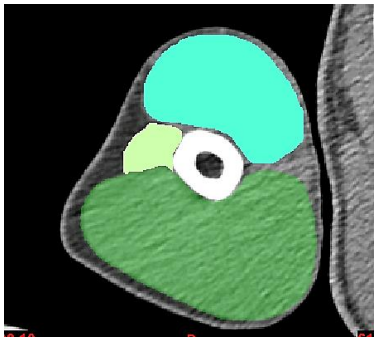
# 1st step : Biomechanical model

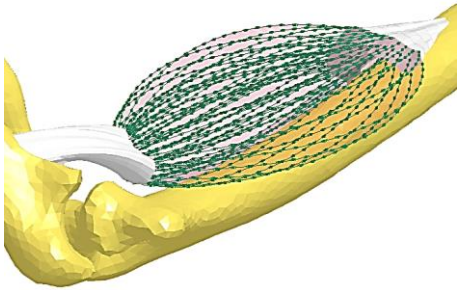
**Scanner**

**Segmentation**

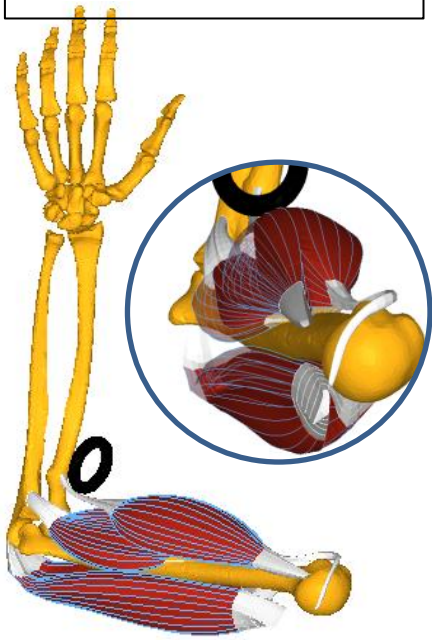


**Bones Meshing**

**Muscles meching**



**Implementation of data in the model**





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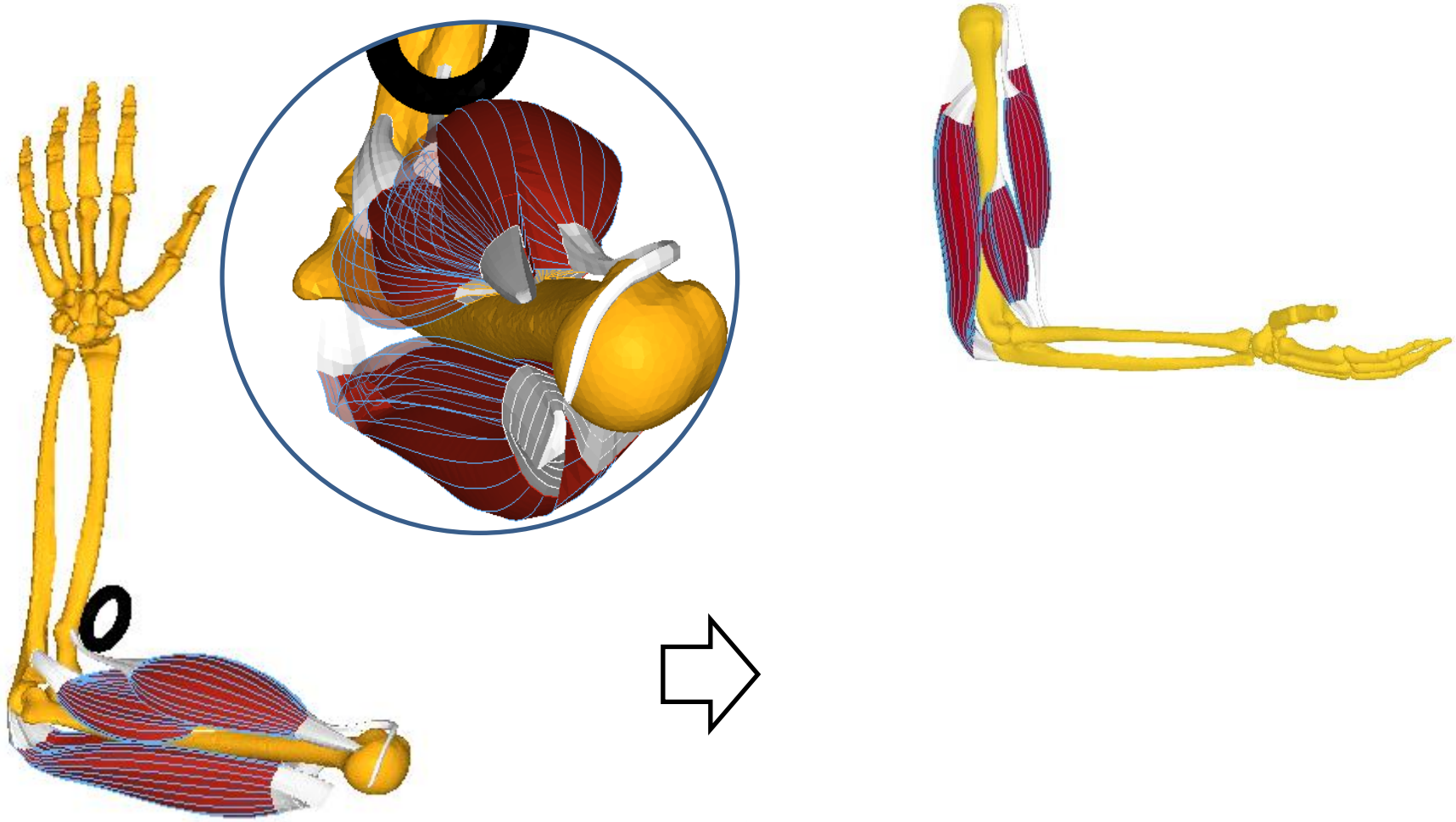
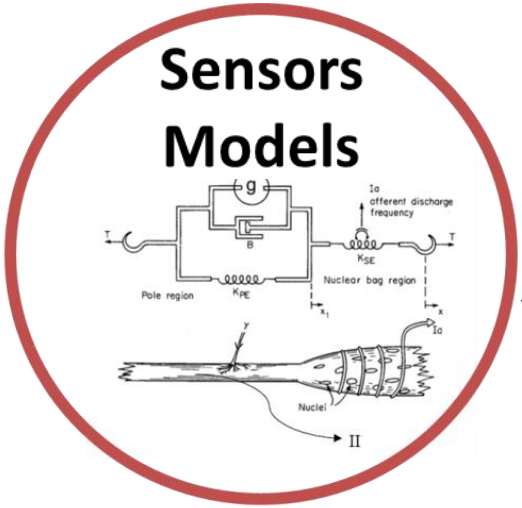
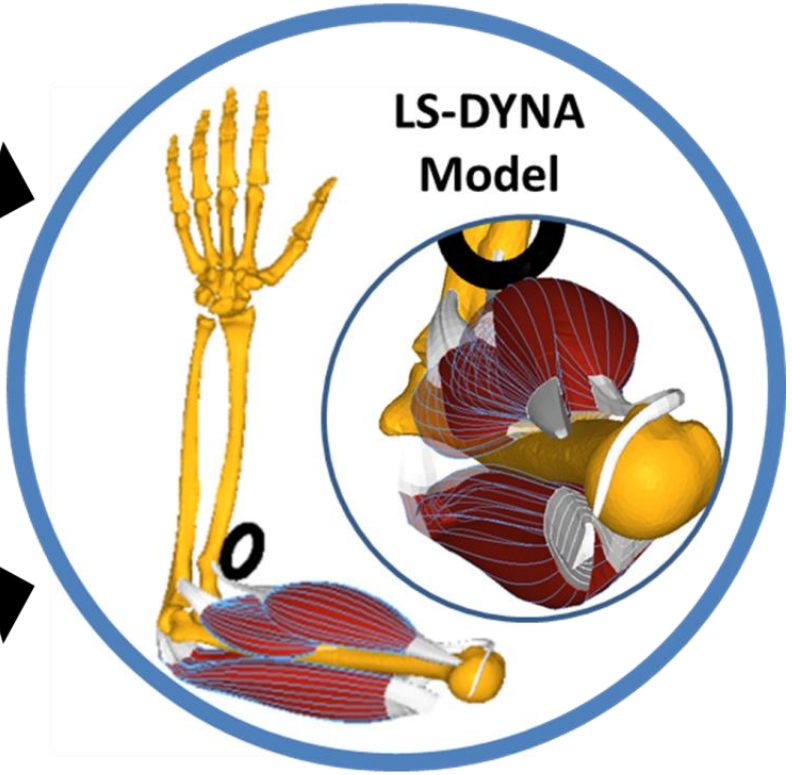
# 1st step : Biomechanical model



# 2nd step: the peripheral nervous system

# a. modelling of the peripheral nervous system



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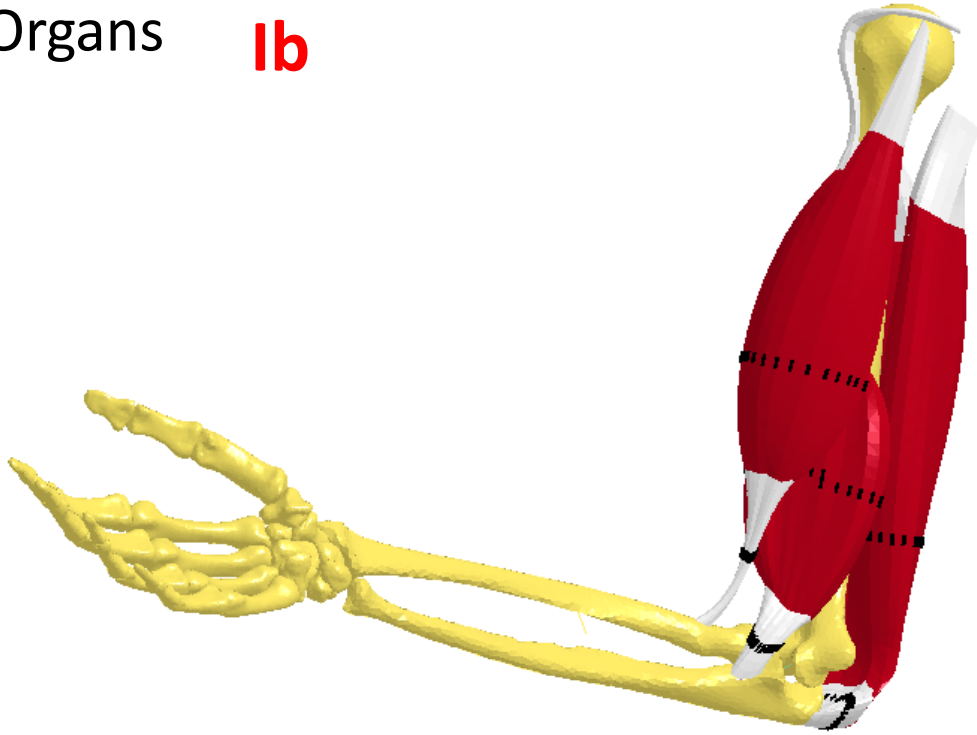
# a. modelling of the peripheral nervous system

2 types of sensors:

- Muscle spindles **Ia** **II**
- Golgi Tendon Organs **Ib**





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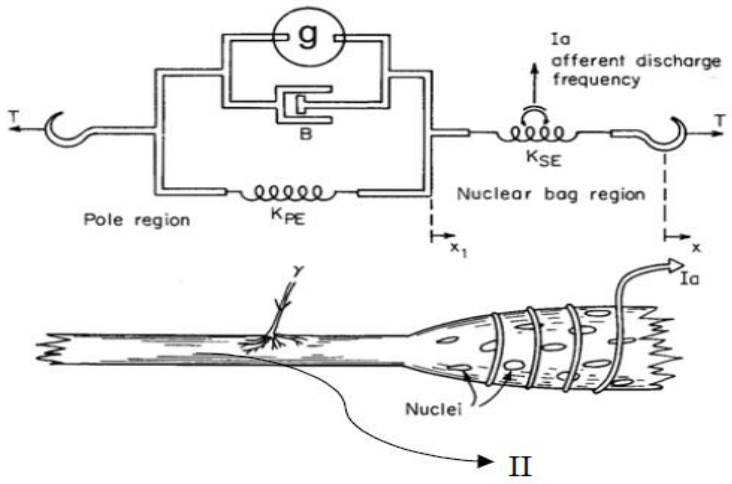
# a. modelling of the peripheral nervous system

## Models of sensors:

- Muscle spindles:

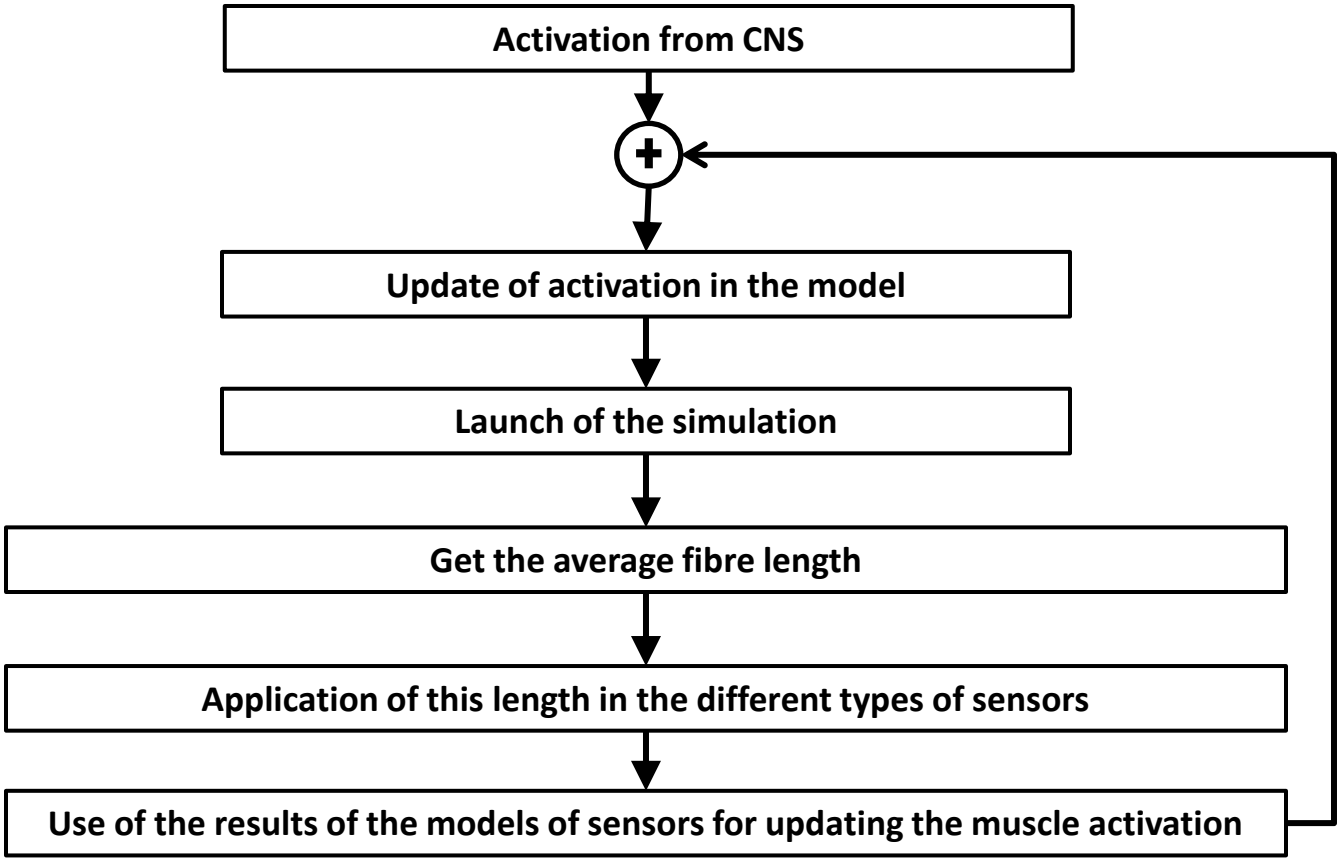
  *McMahon Model (1984)*



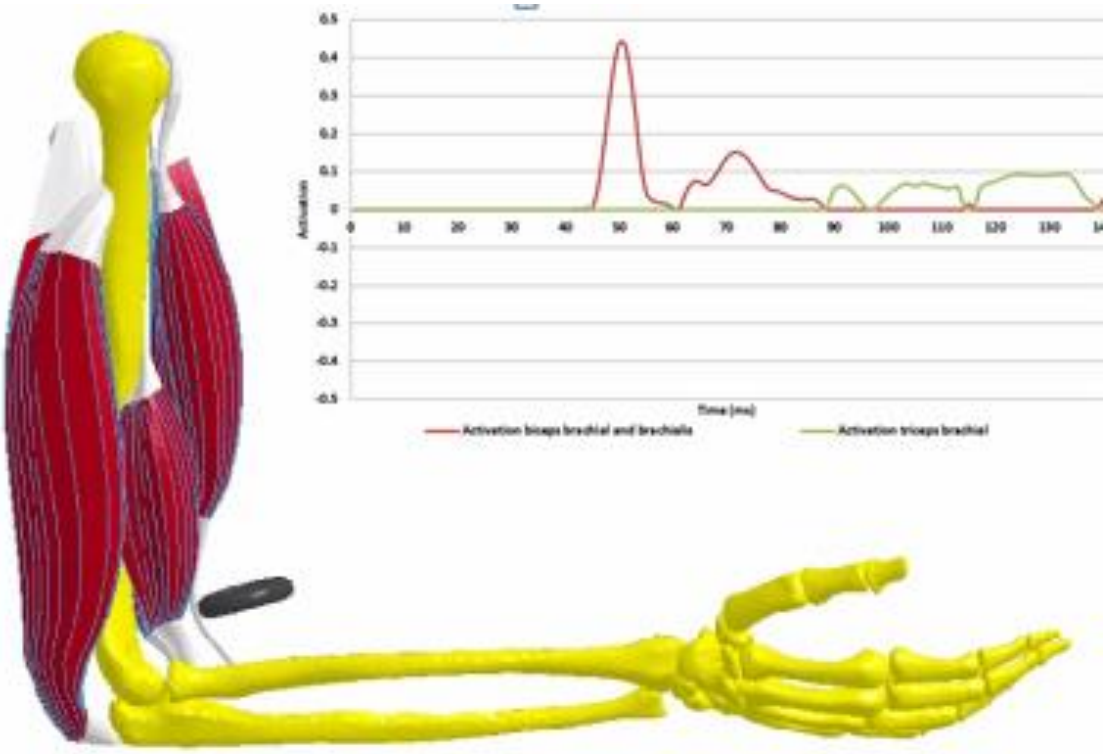

- Golgi Tendon Organs:

  $Ib = \Delta\text{fibre length} * \text{tendon section}$ *(Because tendon are elastics)*

# a. modelling of the peripheral nervous system



# a. modelling of the peripheral nervous system



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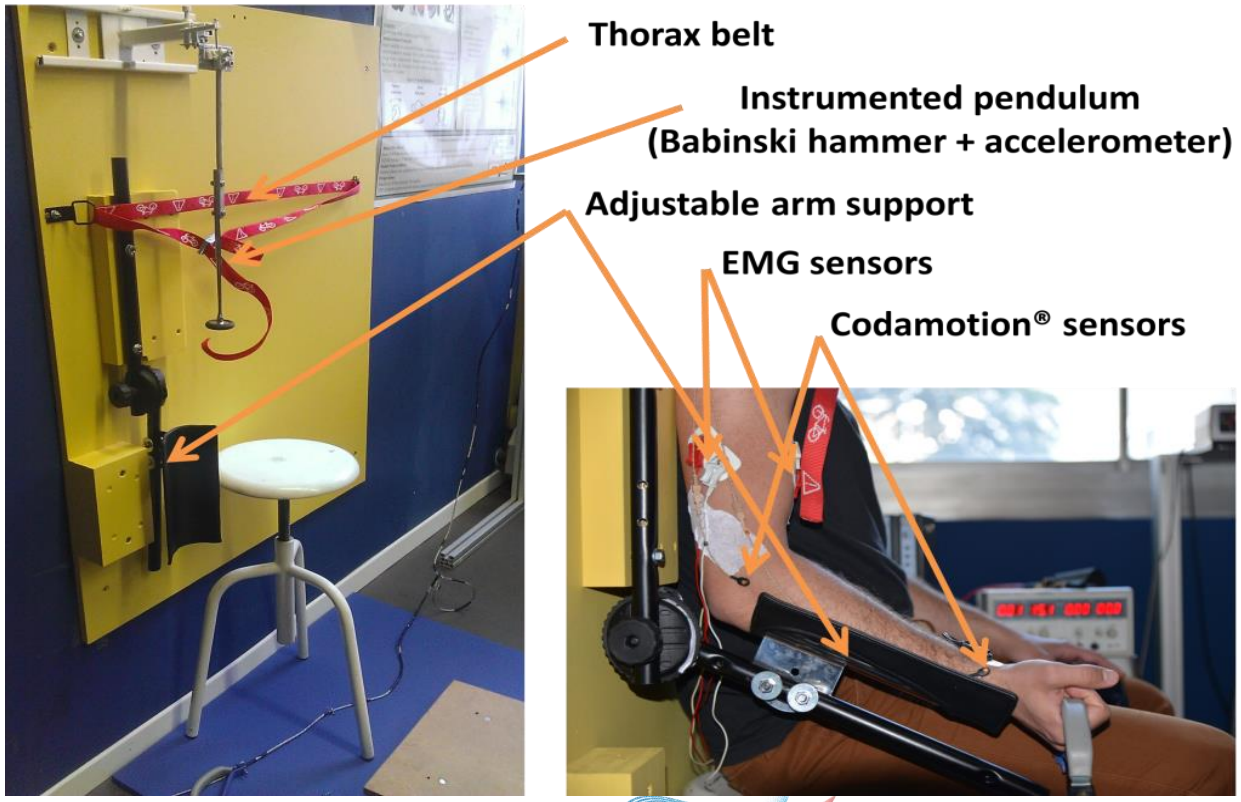
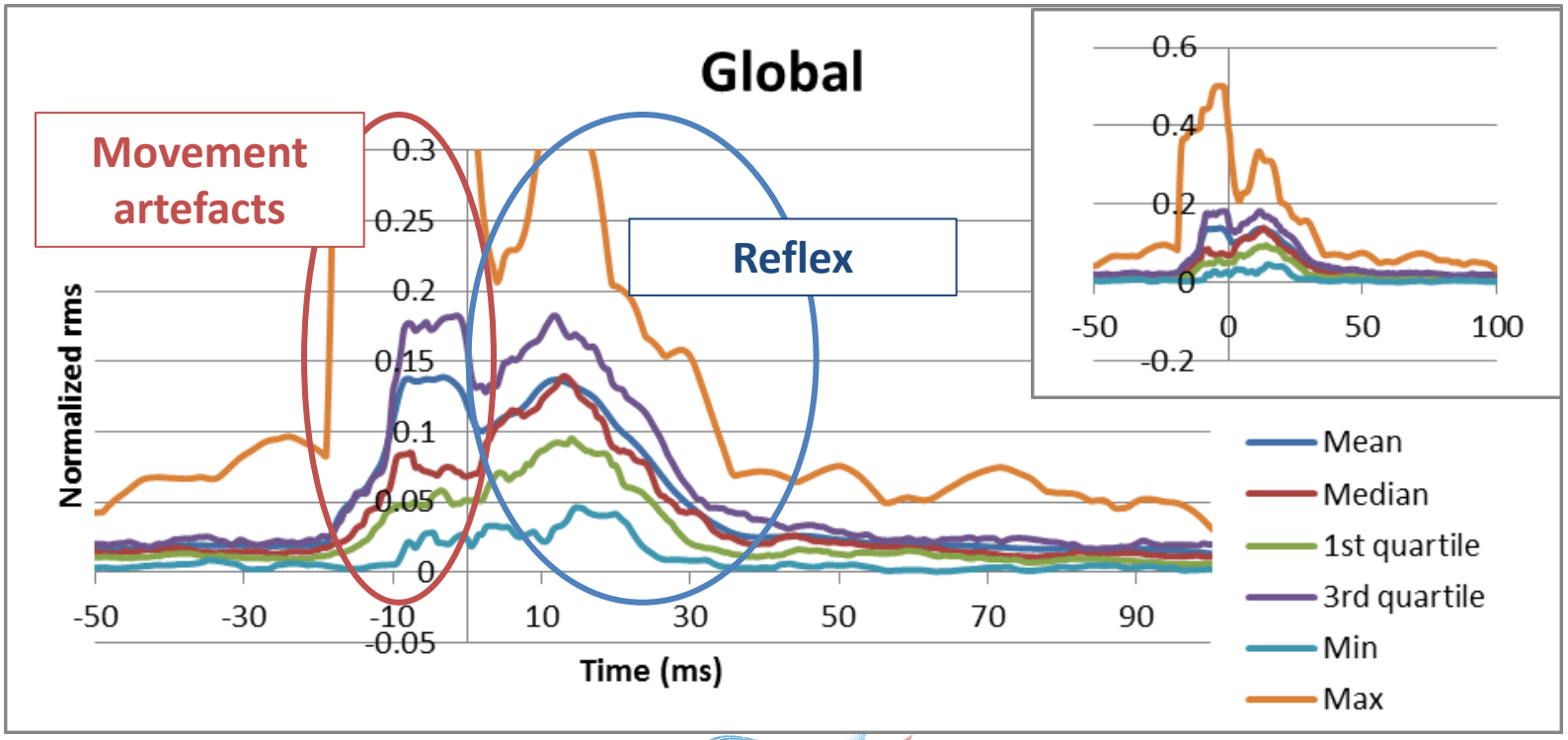
# b. Experiments

Tests of characterization of the deep tendon stretch reflex of the biceps brachial:



# b. Experiments

Measures EMG of biceps brachii are exploited after filtering, average RMS and normalization.



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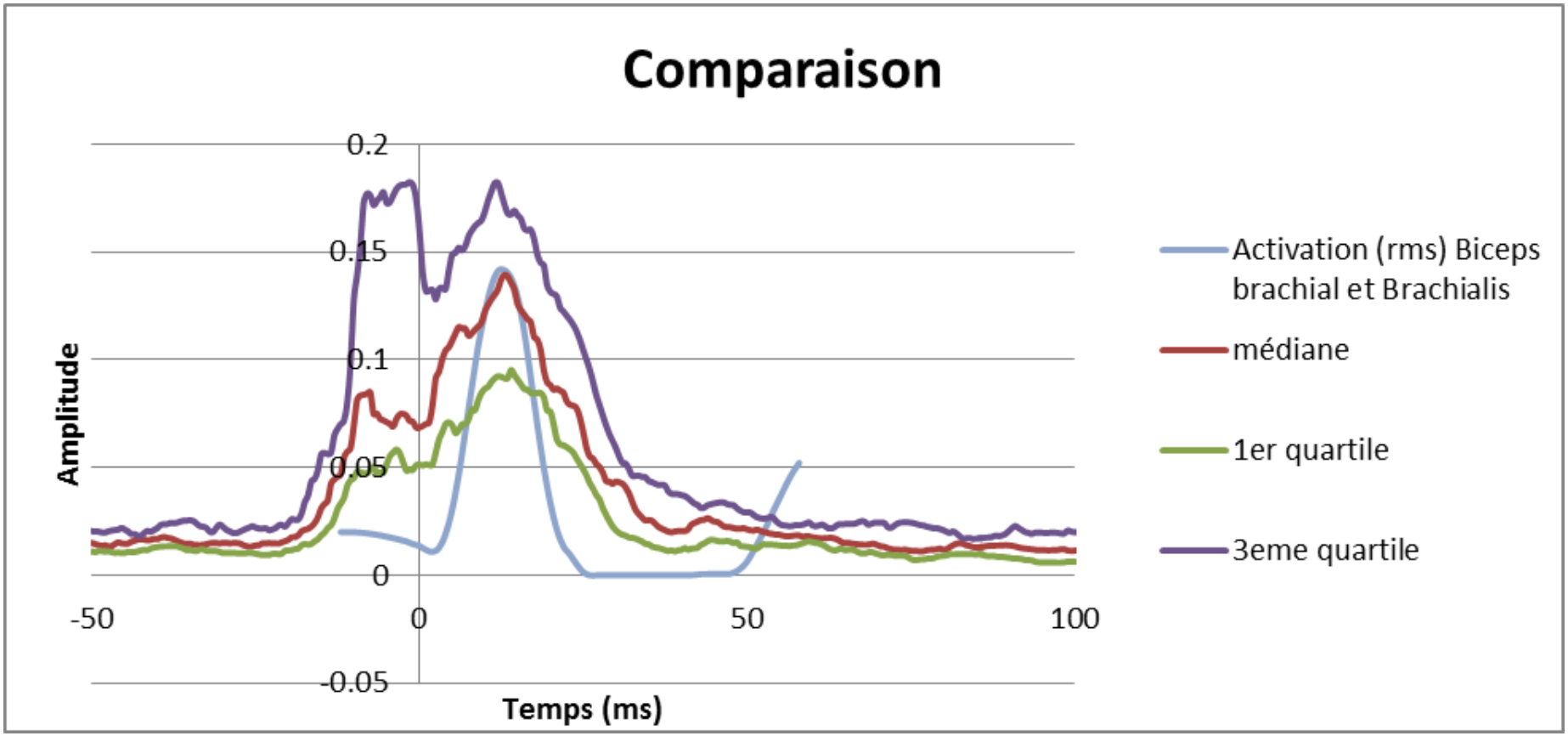
# b. Model validation



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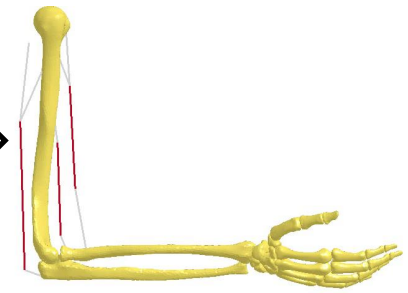
# 3rd step: modelling of the central nervous system

**Learning**

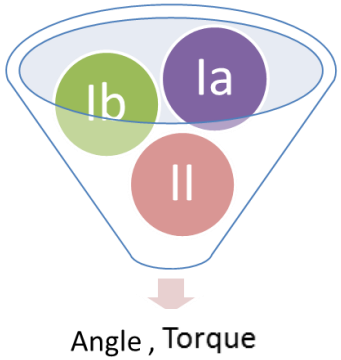
**Random:**
**Activation(t)**
**Torque (t)**



**Database**

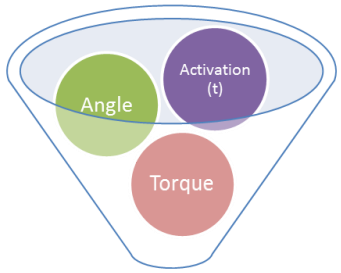
Activation(t)
Torque (t)
Angle(t)
Ia(t),Ib(t), II(t)

**Proprioceptive model**




Angle , Torque

**Dynamic model**




Angle(t)



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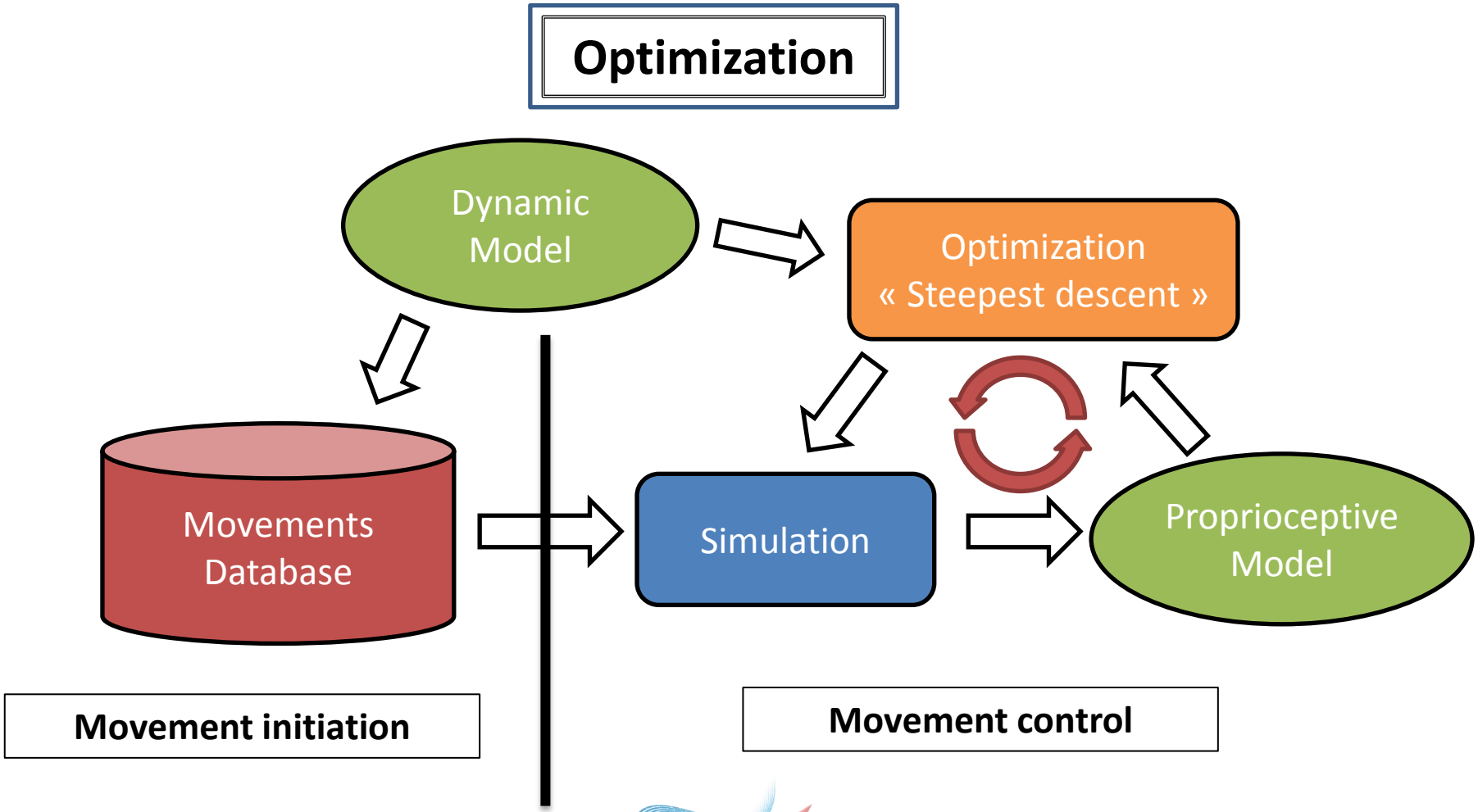
# 3rd stage: modelling of the central nervous system



# 3rd step: modelling of the central nervous system

- Cost function:

Energy

Smoothness

$$J = \alpha_{energy} \cdot \sum_{0}^{k} \sum_{t}^{t_{fin}} a_i(t) + \alpha_{jerk} \cdot \sum_{0}^{k} \sum_{t}^{t_{fin}} \dot{a}_i(t) + \alpha_{obj_temp} \cdot \sum_{t}^{t_{fin}} (\Theta(t) - obj)^2 \cdot \left(1 - \frac{1}{1 + \beta_{temp} * t}\right)$$

Accuracy

Speed



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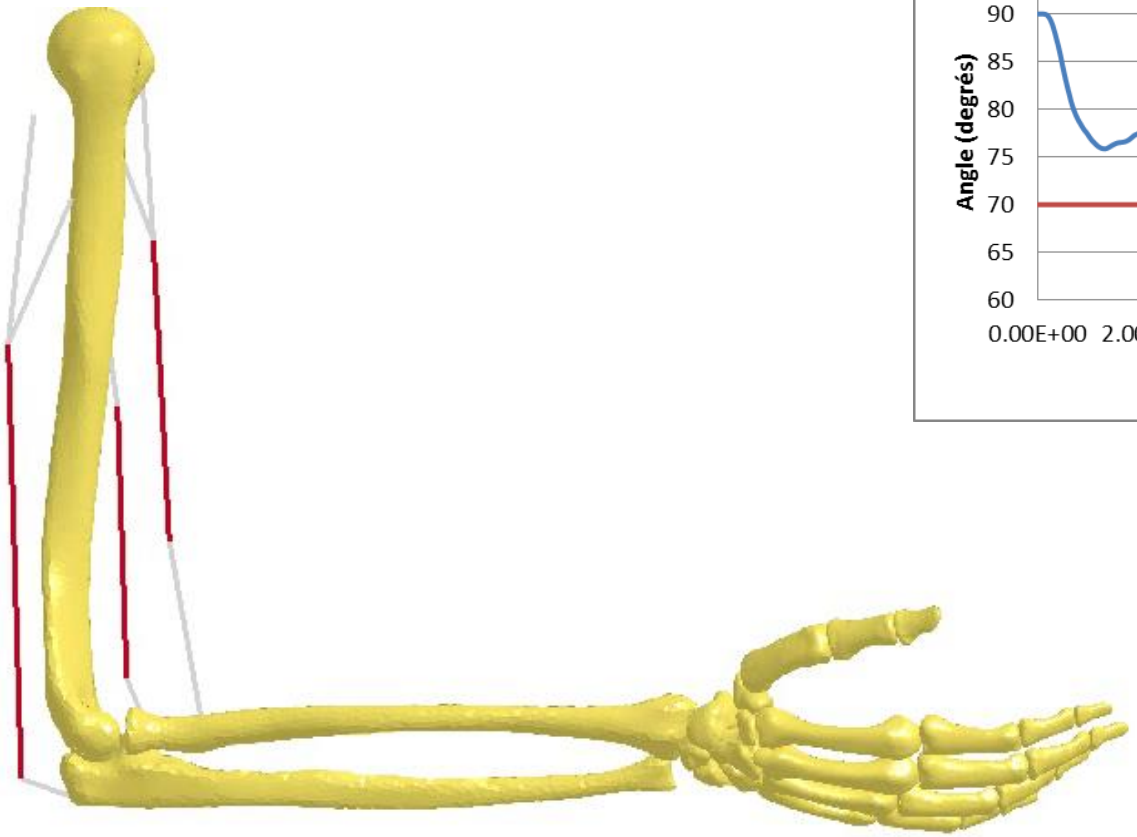
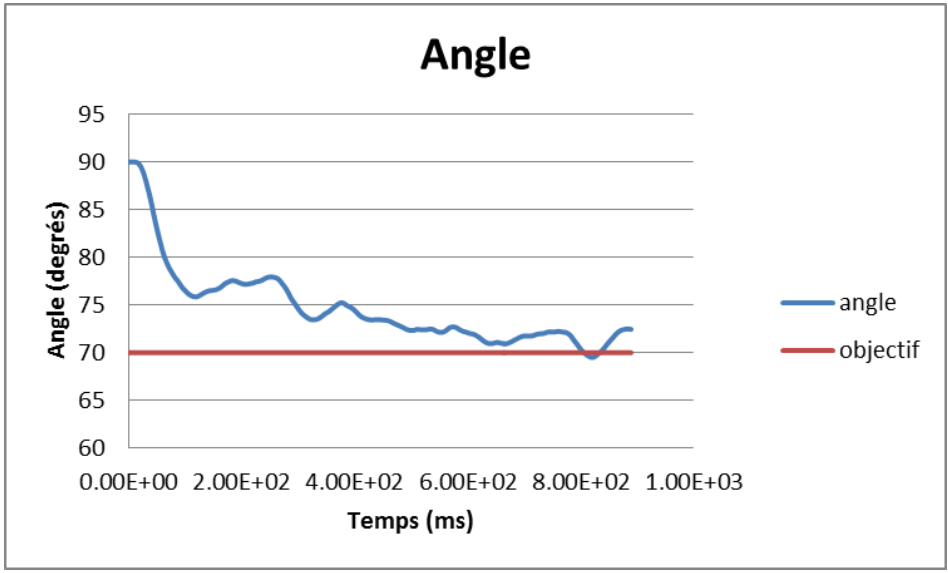
# 3rd step: modelling of the central nervous system





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# 3rd step: modelling of the central nervous system

- Sensitvity analysis:

  + **Positive correlation**
  - **Negative correlation**

  **N/D Not Determined**

Energie Douceur

$$J = \alpha_{energy} \cdot \sum_{0}^{k} \sum_{t}^{t_{fin}} a_i(t) + \alpha_{jerk} \cdot \sum_{0}^{k} \sum_{t}^{t_{fin}} \dot{a}_i(t) + \alpha_{obj_temp} \cdot \sum_{t}^{t_{fin}} (\Theta(t) - obj)^2 \cdot \left(1 - \frac{1}{1 + \beta_{temp} * t}\right)$$

Précision Rapidité

| | $\alpha_{energy}$ | $\alpha_{jerk}$ | $\alpha_{obj_temp}$ | $\beta_{temp}$ |
|---|---|---|---|---|
| **Energy** | - | N/D | + | N/D |
| **Smoothness** | N/D | N/D | N/D | N/D |
| **Accuracy** | N/D | - | + | N/D |
| **Speed** | - | N/D | + | N/D |



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# Conclusion and outlook

- Conclusion :
  - Integration of sensors and reflexes in an active biomechanical model.
  - Validation of the model by the characterization of the stretching of the tendon of the biceps reflex.
  - Use of methods of learning and optimization for the control of the movement.
  - Sensitivity analysis of the movement parameters.
- Outlook :

Implement a software package that integrates tools for the implementation of sensory and motor loops in any type of biomechanical model.



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