Subtask 3.2.2 Muscle models, kinematic controllers and muscle control systems for HBMs

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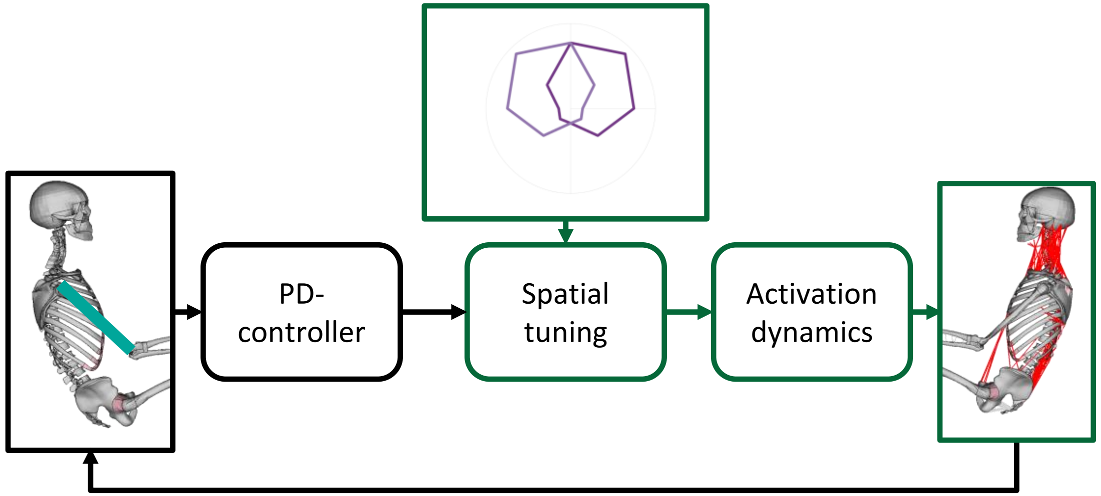
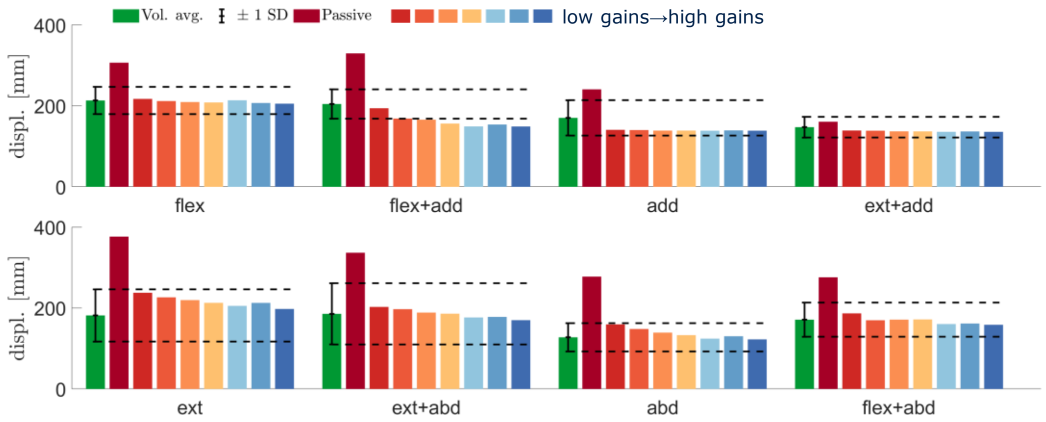
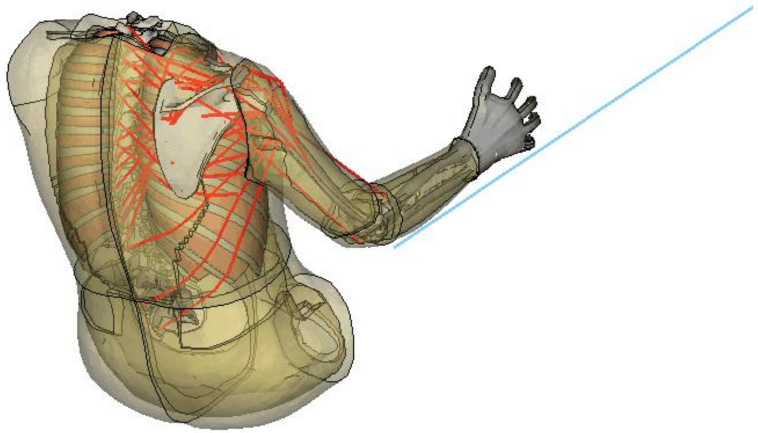
OSCCAR has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 768947.

Development of a Shoulder Muscle Feedback Controller for Human Body Models

- Implementation of feedback controller in a shoulder of the SAFER AHBM.
  - Angular position feedback for humerus movement, spatial tuning from 'weight drop experiments'.
  - Muscle length feedback for scapula movement.
- Verification of model kinematics using 'weight drop experiments'.
  - Successfully captured peak elbow displacements.



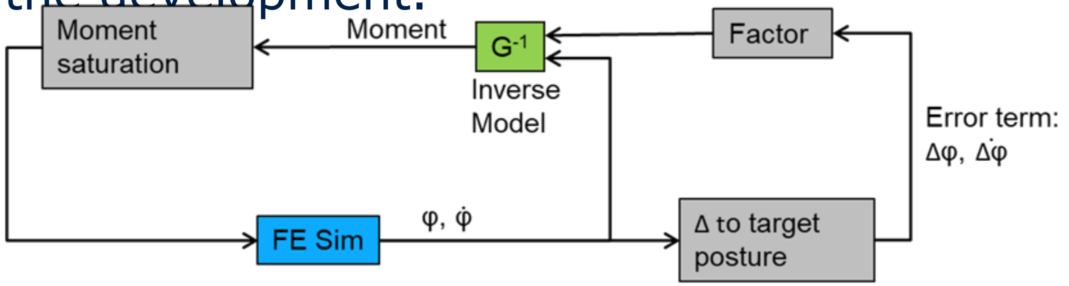


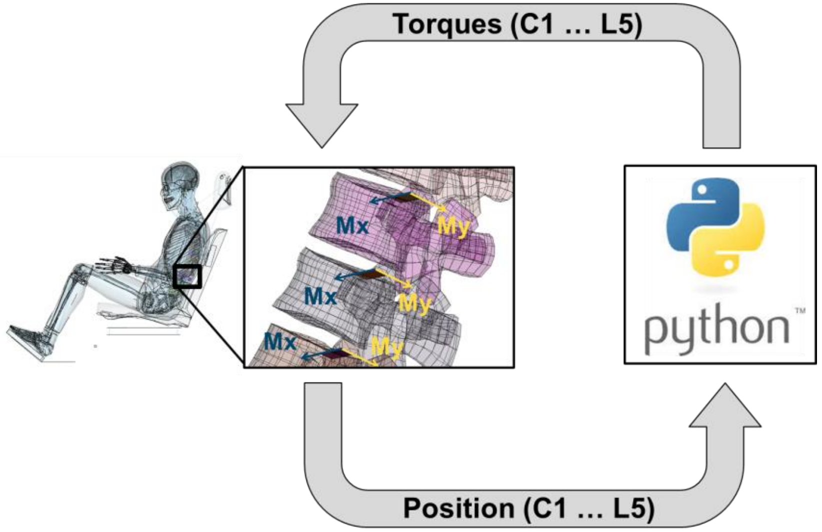


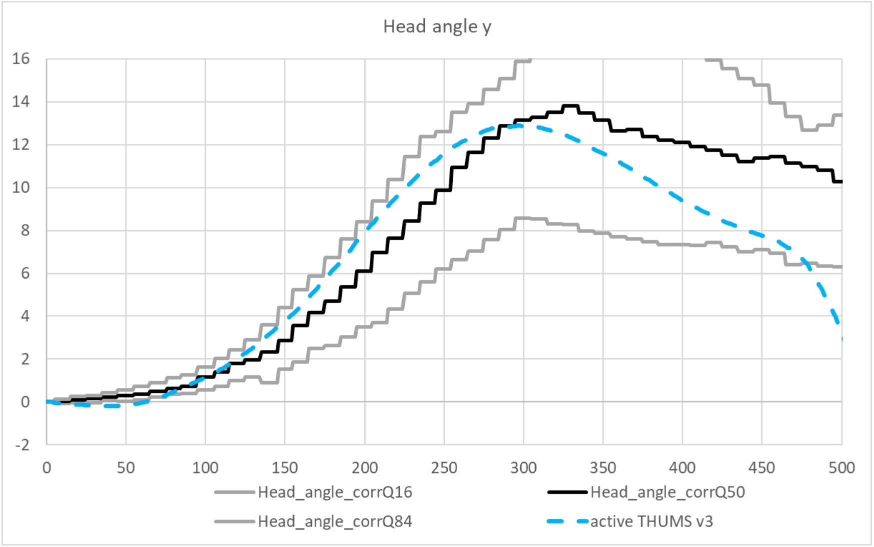
FiceEtAl2021, LarssonEtAl202X

VIF Torque Controller

- Working Principle
  - HBM Model position is controlled by torques in the spine (on each vertebra).
  - An external invertible surrogate model calculates the torques for each vertebra.
  - Combined OM4IS pulse (Breaking/Steering) is used for the development.



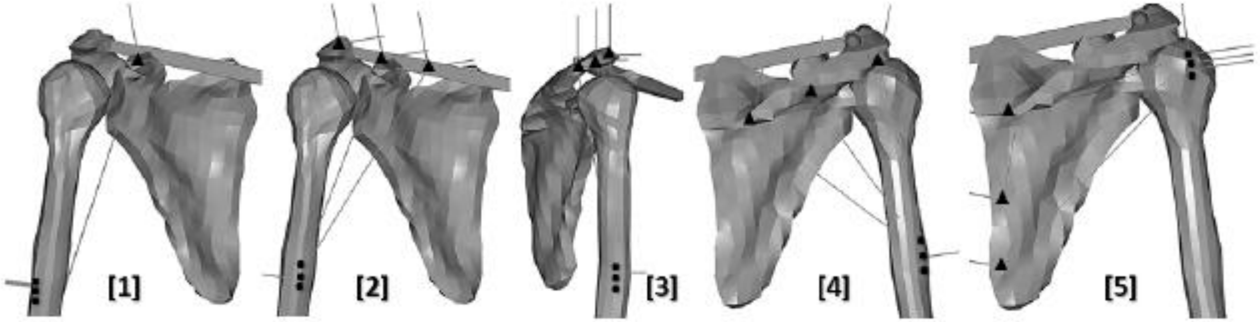


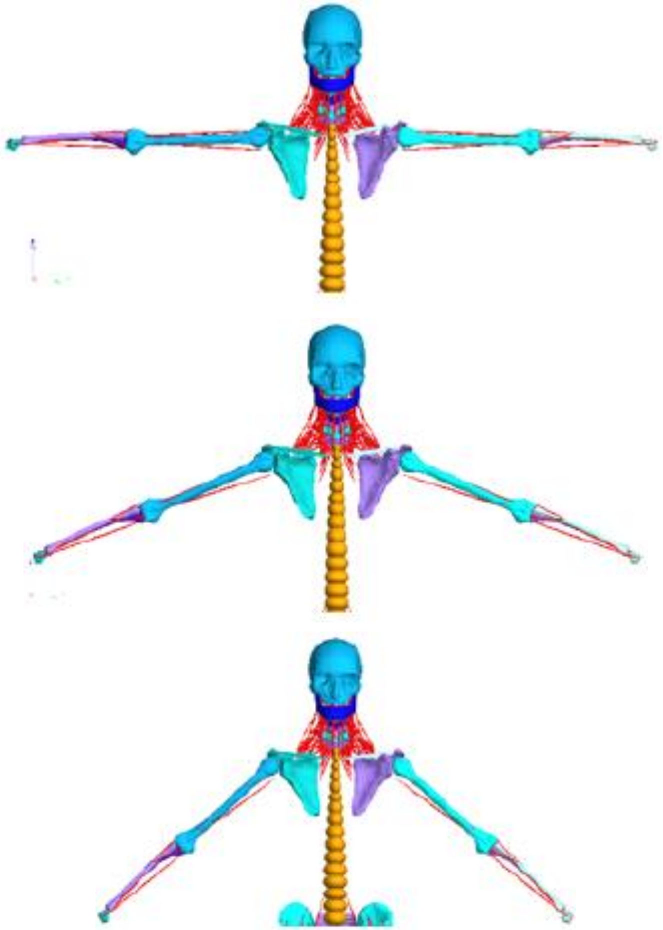


- Results
  - Applicable Active HBM kinematics
  - Method transferable to other HBMs

Improvements in Limb Control of Simcenter AHM

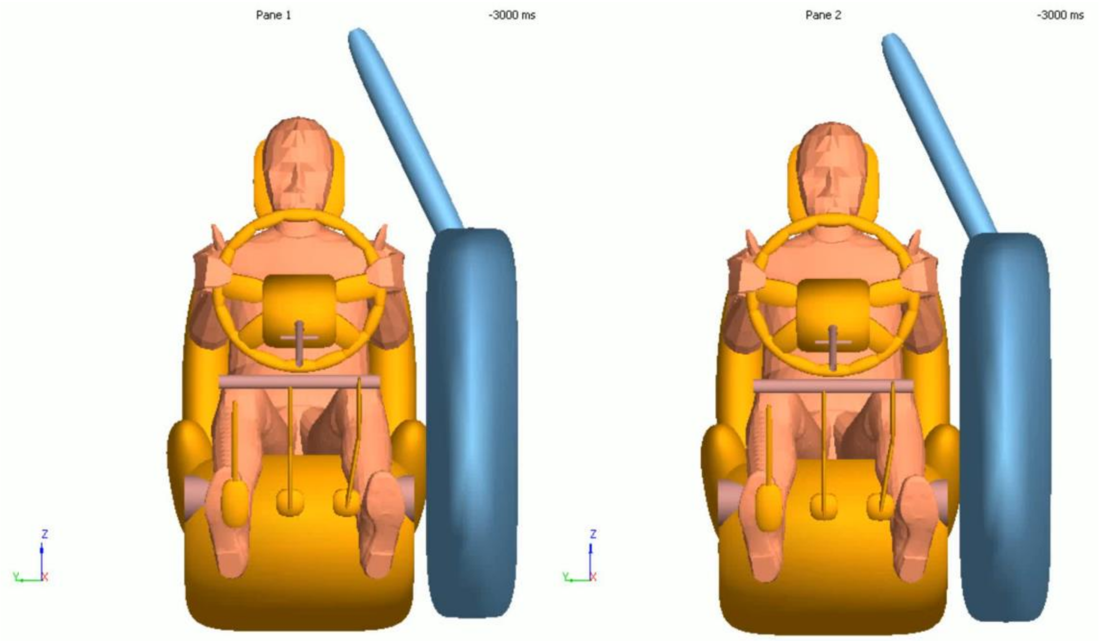
- Glenohumeral joint motion important for arm bracing during pre-crash manoeuvring and emergency braking.
- Issues identified with multibody implementation of shoulder.
- Cardan restraint-based modelling of stabilising tissues.
  - Improved numerical stability of shoulder.
  - Improved symmetry and biofidelity of response.
- Load functions modified and smoothed.





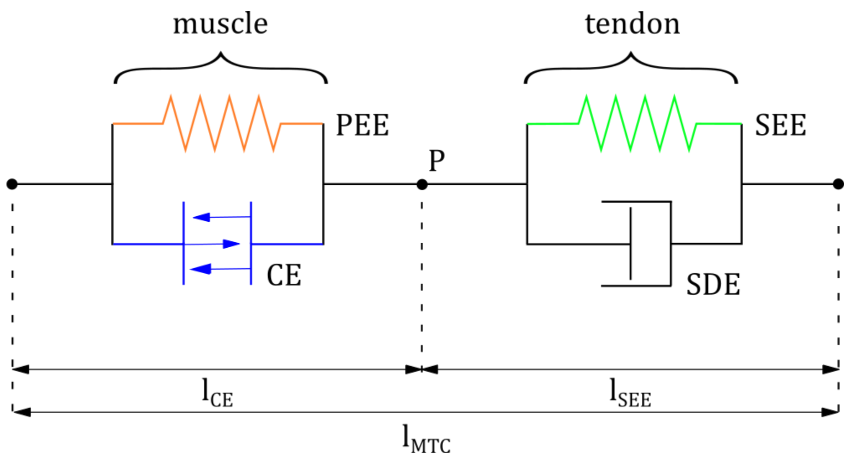
Improvements in Limb Control of Simcenter AHM

- In some AV loadcases modelled in OSCCAR, the lower leg pulls out and up.
- Adductor muscle groups causing excessive medial (instead of lateral) rotation.
- Gluteus medius posterior recruitment identified as inappropriate for seated HBM.
- Hip restraints modified for numerical stability and realistic range of motion under medial rotation.
- Updated model tested:
  - ☐ Stable in OSCCAR application.
  - ☐ Stable in AHM validation database.
  - ☐ Stable under robustness test.

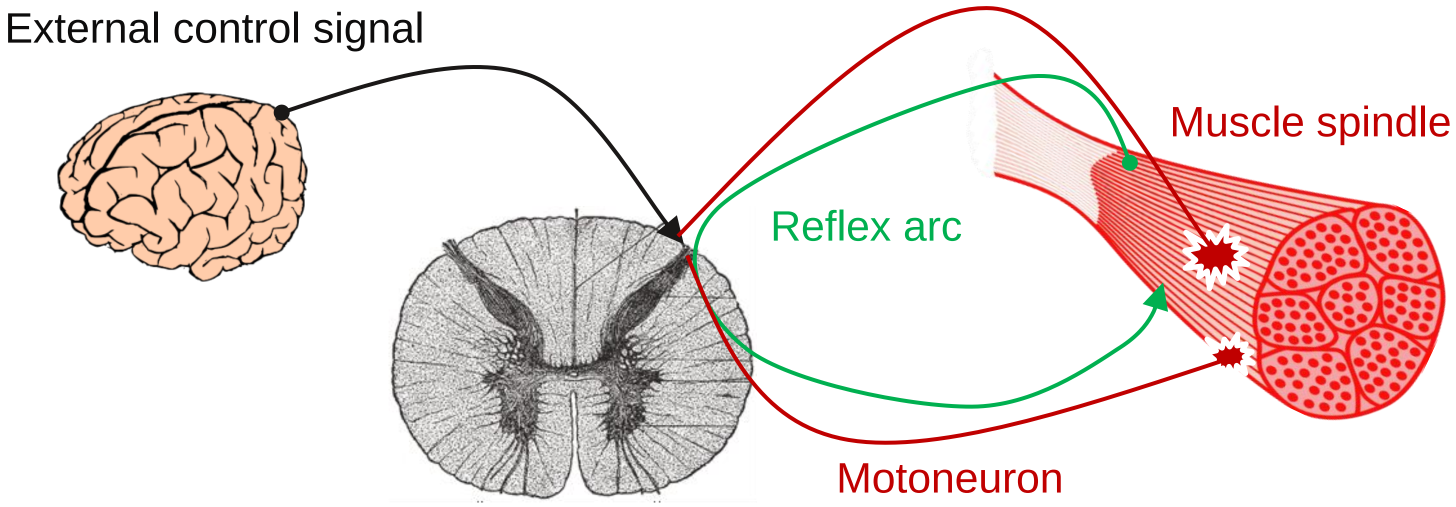


Implementation and Validation of the Extended Hill-type Muscle Model (EHTM)

- EHTM was made available in LS-DYNA and VPS software during OSCCAR.
  - More physiological material behaviour due to the direct inclusion of the muscle and tendon characteristics and integrated muscle activation dynamics.
  - Option to add signals from an external controller.
- EHTM advantages in LS-DYNA:
  - Significant AHBMs simulations speed-up in LS-DYNA on account of integrated muscle controller.
  - Possibility for further features and functions extension through open-source code availability.



Schematic elements structure of EHTM



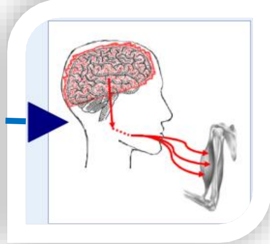
KleinbachEtAl2017, MartynenkoEtAl2018, MartynenkoEtAl202X

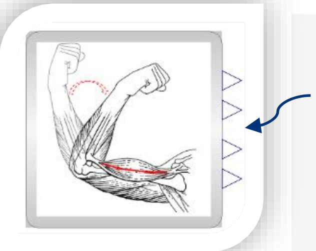
Implementation and Validation of the Extended Hill-type Muscle Model (EHTM)

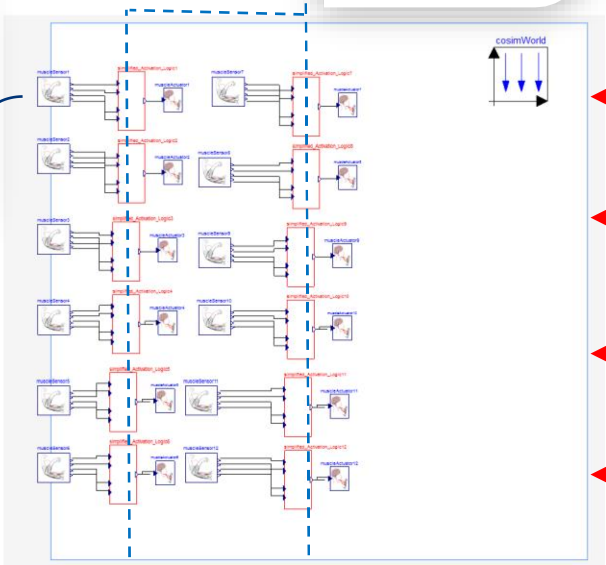
- EHTM advantages in VPS:
  - ☐ A combined muscle-tendon unit modelling
  - ☐ Muscle control by coupling between VPS and SimulationX
    - ○ defined through Visual-System
  - ☐ Available from VPS 2020.0 release

Controllers (*SI units*)

Coupling period







Components	Value
cosimWorld	
tStart (s)	0.0
tStep (s)	1.0E-4
tEnd (s)	0.5
vpsModel	C:/Users/mcm/ESIProjects/OSCCAR...
vpsVersion (-)	VPS_2019
fileLogging...	true
solverType ...	SimulationX
muscleActuat...	
vpsLoad (-)	101 =>NACT_101 (FASCI /)
simplified_A...	
L_opt (-)	0.283
tSample (s)	1.0E-6
muscleActuat...	
vpsLoad (-)	102 =>NACT_102 (FASCI /)
simplified_A...	
L_opt (-)	0.303
tSample (s)	1.0E-6
muscleActuat...	
vpsLoad (-)	103 =>NACT_103 (FASCI /)
simplified_A...	
L_opt (-)	0.156
tSample (s)	1.0E-6
muscleActuat...	
vpsLoad (-)	104 =>NACT_104 (FASCI /)
simplified_A...	
L_opt (-)	0.119
tSample (s)	1.0E-6
muscleActuat...	
vpsLoad (-)	105 =>NACT_105 (FASCI /)
simplified_A...	
L_opt (-)	0.248
tSample (s)	1.0E-6
muscleActuat...	
vpsLoad (-)	106 =>NACT_106 (FASCI /)
simplified_A...	
L_opt (-)	0.135
tSample (s)	1.0E-6
muscleActuat...	

Muscle 1

Muscle 2

Muscle 3

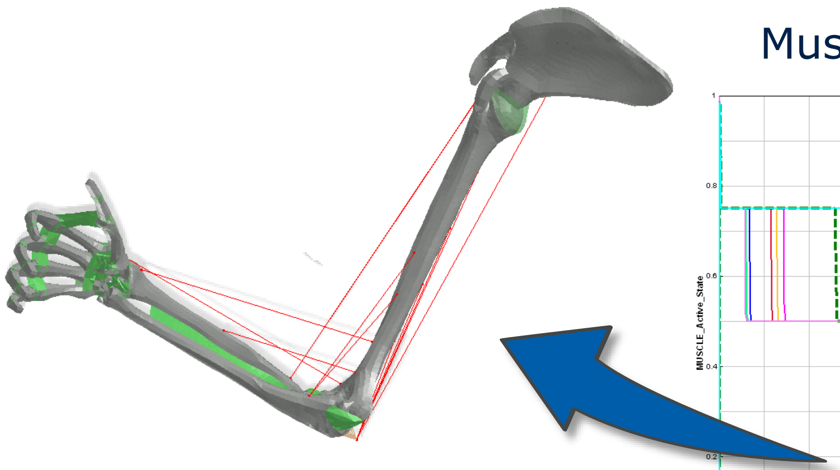
Muscle 4

Muscle 5

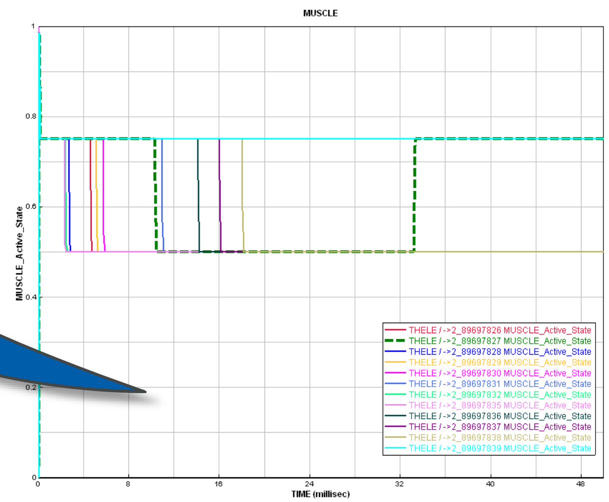
Muscle 6

Management of muscles activation level

based on their length variation



Muscle activation level



Implementation and Validation of the Extended Hill-type Muscle Model (EHTM)

- Simulations speed-up in LS-DYNA:
  - Up to 10 times for components.
  - Up to 8 times for full AHBM.

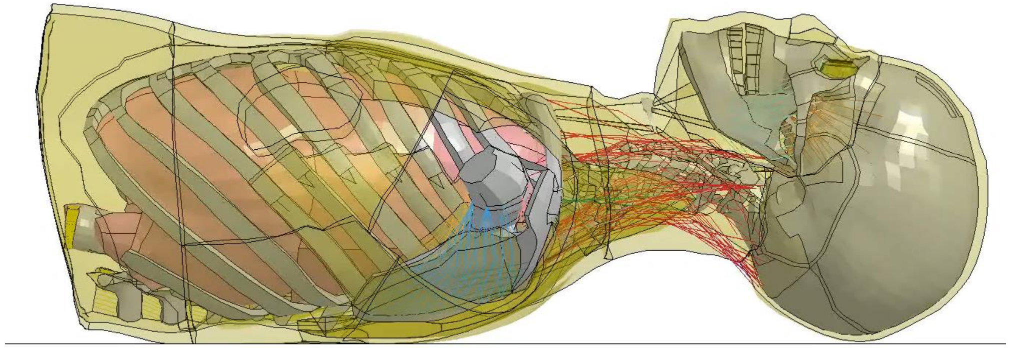
	α, EHTM	α, *MAT_156	λ, EHTM	λ, *MAT_156
Element processing	0,719	6,386	0,724	6,751
Rigid Bodies	1,137	13,771	1,141	14,196
Time step size	2,010	23,521	2,004	23,638
Misc. 1	0,976	10,547	0,961	11,057
Misc. 4	2,797	33,255	2,781	33,965
Problem cycle	45001	517624	45001	549290
Total CPU	9,021	97,897	8,987	100,650

- Implementation in different AHBMs:
  - A-THUMS-D (LS-DYNA, full body).
  - THUMSv5 (LS-DYNA, neck).
  - THUMS TUC-VW AHBM (VPS, neck).
- Evaluated with different experimental data:
  - “Falling Heads”.
  - OM4IS.
  - CHALMERS.

A-THUMS-D

THUMS TUC-VW AHBM

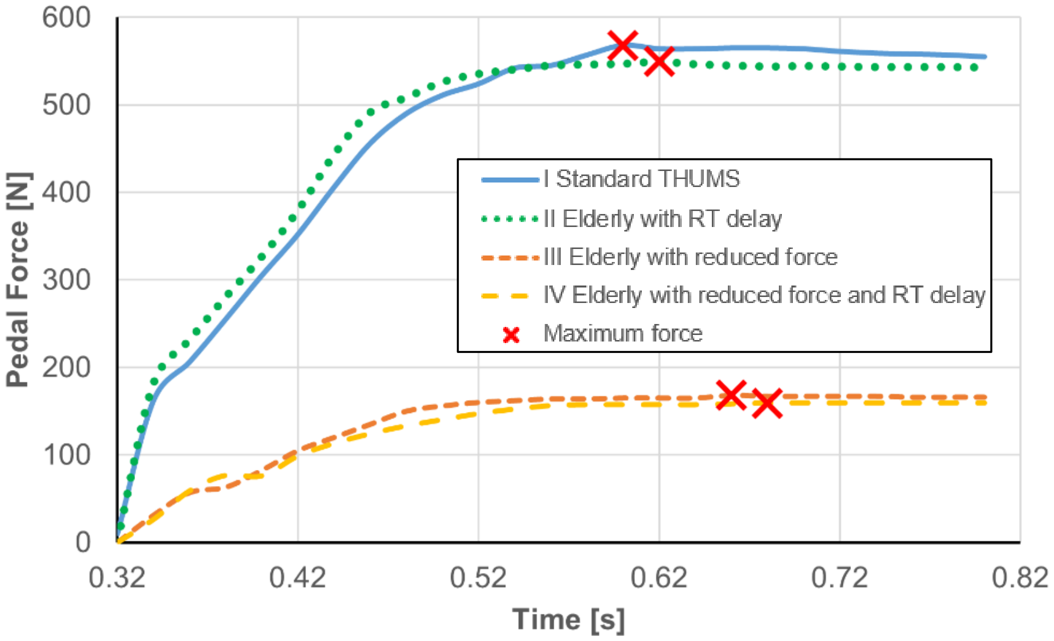
THUMSv5



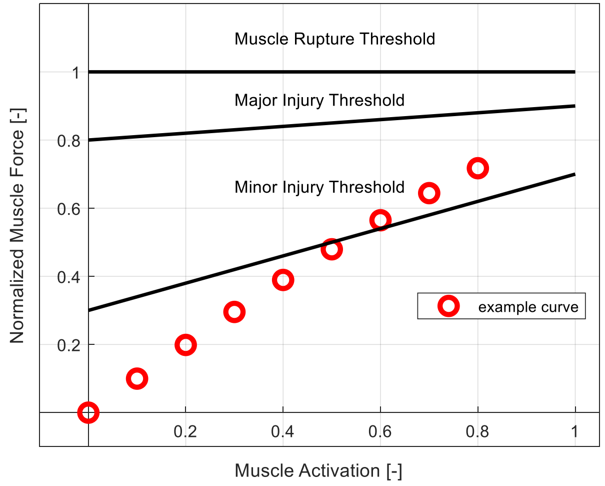
WochnerEtAl2019, MartynenkoEtAl2021, WochnerEtAl202X

Further Applications of the Extended Hill-type Muscle Model in OSCCAR

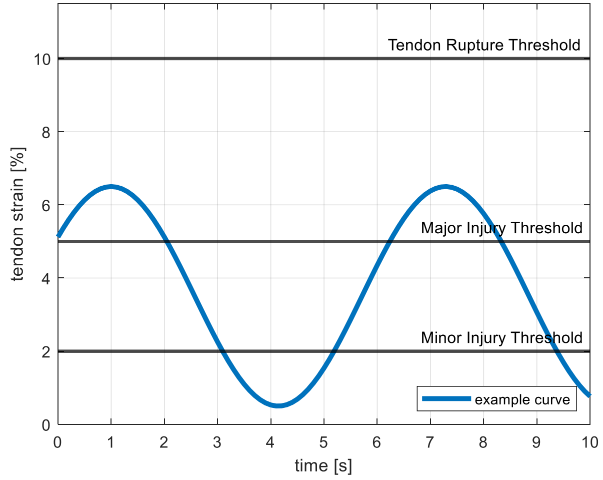
- Representation of the Elderly Population with Active Human Body Models
  - Time history curves for brake pedal force



- MTU Injury Criteria – three injury thresholds:
  - Minor MTU Injury Threshold
  - Major MTU Injury Threshold
  - MTU Rupture Threshold



Muscle Injury Thresholds



Tendon Injury Thresholds

BannikEtAl2021, NölleEtAl2020, NölleEtAl202X

Literature Sources

- **BannikEtAl2021** – Banik et al. (2021), Representation of the Elderly Population with Active Human Body Models. IRCOBI Conference Proceedings, Online, pp. 534-536.
- **FiceEtAl2021 –** Fice et al. (2020), Dynamic Spatial Tuning Patterns of Shoulder Muscles with Volunteers in a Driving Posture. Frontiers in Bioengineering and Biotechnology. Work done outside the OSCCAR Project.
- **KleinbachEtAl2017** – Kleinbach et al. (2017). Implementation and validation of the extended Hill-type muscle model with robust routing capabilities in LS-DYNA for active human body models. BioMedical Engineering OnLine, 16(1). Work done outside the OSCCAR Project.
- **LarssonEtAl202X** – Larsson et al. (202X), Development of a shoulder muscle feedback controller for human body models. Prepared for submission to Annals of Biomedical Engineering.
- **MartynenkoEtAl2018** – Martynenko et al. (2018), Integrated Physiologically Motivated Controller for the Open-Source Extended Hill-type Muscle Model in LS-DYNA. IRCOBI Conference Proceedings, Athens, Greece, pp. 239-241. Work done outside the OSCCAR Project.
- **MartynenkoEtAl2021** – Martynenko et al. (2021), Comparison of the Head-Neck Kinematics of Different Active Human Body Models with Experimental Data. IRCOBI Conference Proceedings, Online, pp. 105-121
- **MartynenkoEtAl202X** – Martynenko et al. (202X), Development and Validation of a Physiologically Motivated Internal Controller for the Open-Source Extended Hill-type Muscle Model in LS-DYNA. Prepared for the submission to the Applied Bionics and Biomechanics Journal.
- **NölleEtAl2020** – Nölle et al. (2020), Defining Injury Criteria for the Muscle-Tendon-Unit. IRCOBI Conference Proceedings, Online, pp. 811-813.
- **NölleEtAl202X** – Nölle et al. (202X), Evaluation of Muscle Strain Injury Severity in Active Human Body Models. Submitted to the Journal of the Mechanical Behavior of Biomedical Materials.
- **WochnerEtAl2019 –** Wochner et al. (2019), Comparison of Controller Strategies for Active Human Body Models with Different Muscle Materials. IRCOBI Conference Proceedings, Florence, Italy.
- **WochnerEtAl202X –** Wochner et al. (202X), 'Falling Heads': investigating reflexive responses to head-neck perturbations. Submitted to the Biomechanics and Modeling in Mechanobiology (BMMB) Journal.
  Based on the experiments done outside the OSCCAR Project.