POLITECNICO DI TORINO

PhD in Mechanical Engineering
33° Cycle

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Modeling the Physical Human-Exoskeleton Interface

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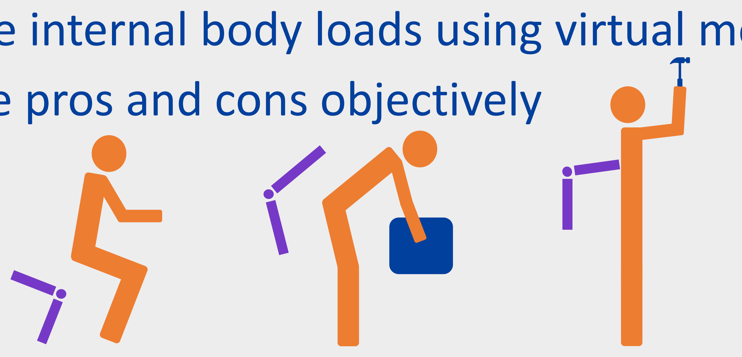
Industrial Partners:
FCA – CRF

Background

Biomechanical analysis of exoskeletons through musculoskeletal modeling

- Estimate internal body loads using virtual models
- Evaluate pros and cons objectively



Modeling forces at Human-Exoskeleton Interface

- Exoskeletons work by transferring loads
- Correct simulation of interface forces is critical

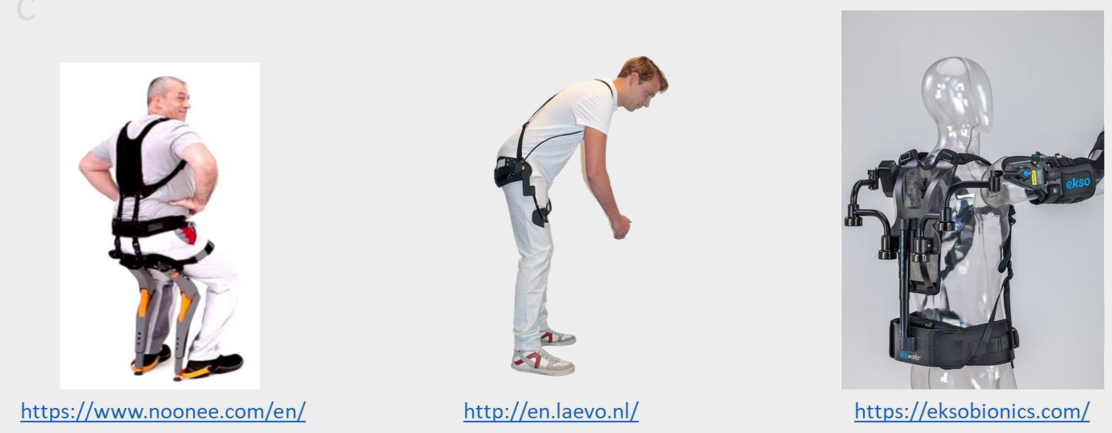
The Problem

Conventional approach – Kinematic joints between human and exoskeleton

- Kinematic constraints during motion
- Limitless interaction forces in constraints

Reality

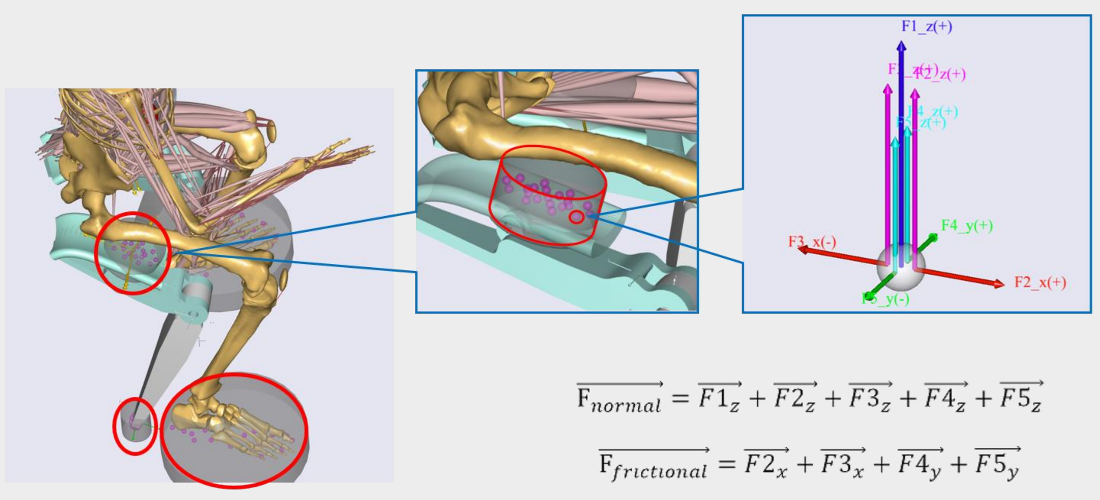
Contact through straps, cuffs or molded surfaces



- Friction at the interface
- Limited forces – pain/comfort considerations

Interface Model

Validated conditional contact model (Fluit 2014, Skals 2017)



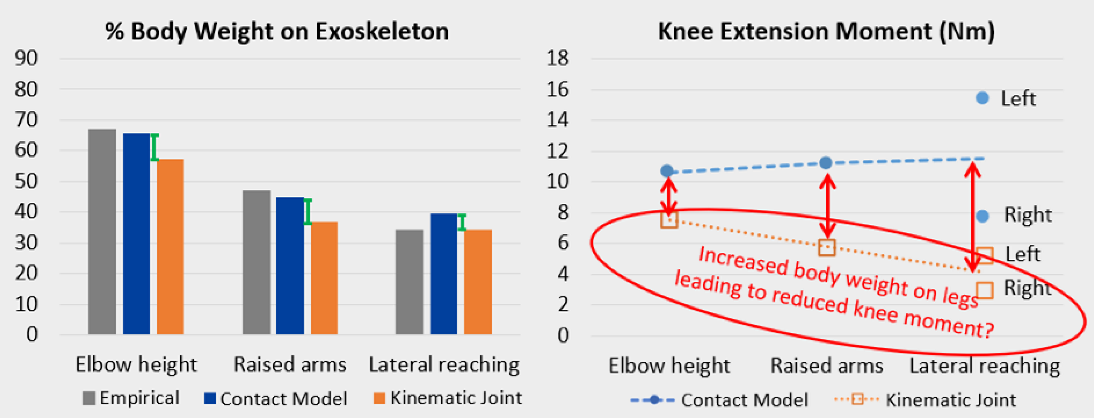
$$\overrightarrow{F_{normal}} = \overrightarrow{F1_z} + \overrightarrow{F2_z} + \overrightarrow{F3_z} + \overrightarrow{F4_z} + \overrightarrow{F5_z}$$

$$\overrightarrow{F_{frictional}} = \overrightarrow{F2_x} + \overrightarrow{F3_x} + \overrightarrow{F4_y} + \overrightarrow{F5_y}$$

- 5 force actuators: 1 (normal) + 4 (coplanar)
- Modeling friction at the interface: **F = µ.N**

Initial results with planar seat – Year 1

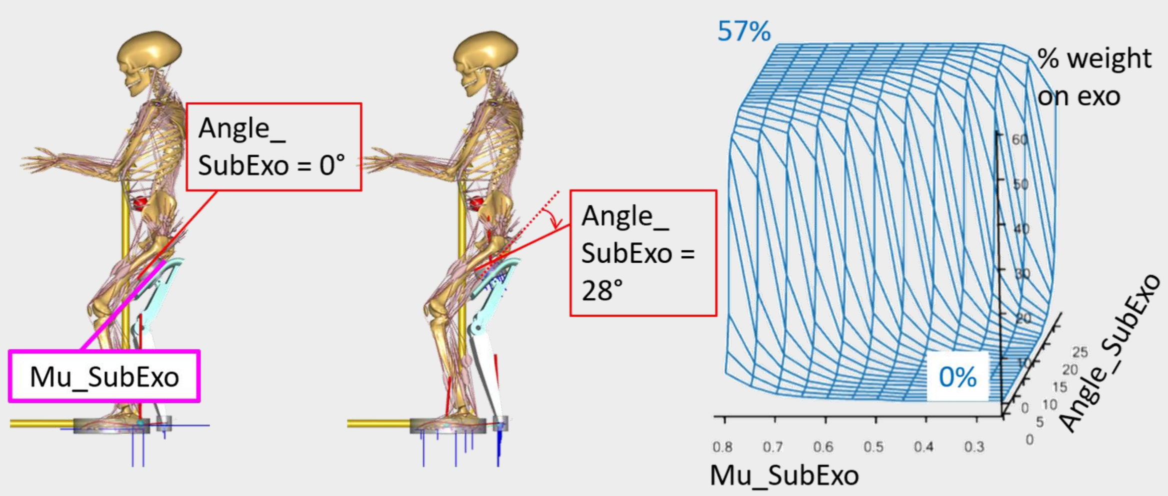
Contact model vs kinematic joint model



- Weight distribution: Similar trends
- Knee extension moment: Different trends.

Kinematic rigid joint provides unrealistic results.

Parametric studies – Coefficient of friction



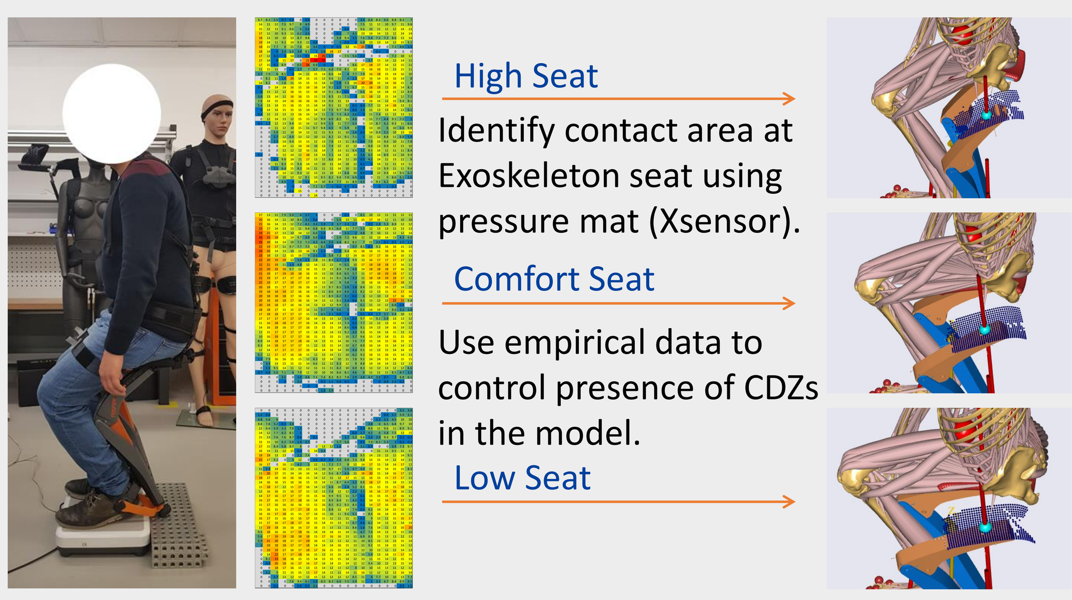
- Exoskeleton efficiency depends on coefficient of friction and angle of contact at the human-exoskeleton interface

Advancement – Year 2

Simulation of curved seat surface

Simulation of planar seat:
-Location of support?
-Angle of contact?

Simulation of seat with curved surface

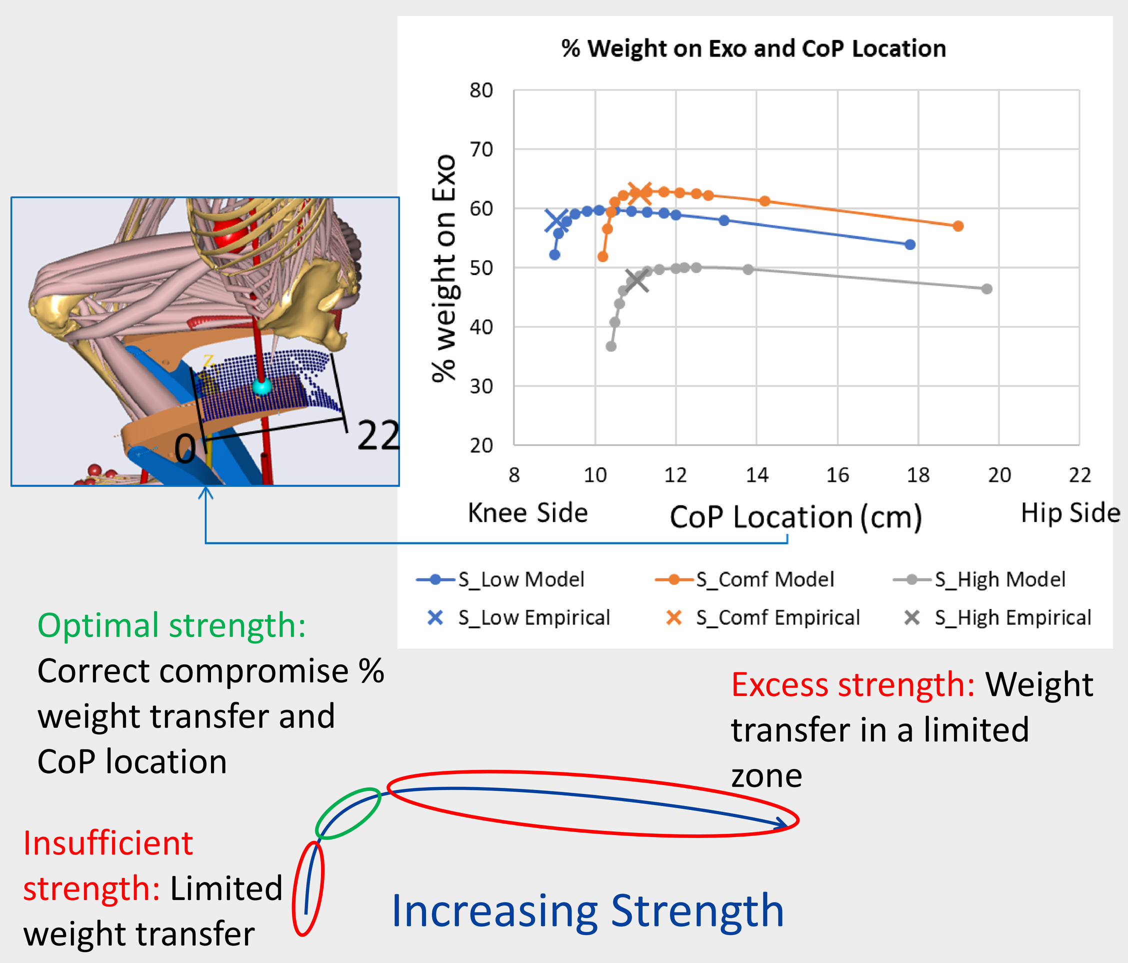


- Multiple contact detection zones (CDZ)
- Each CDZ oriented normal to the seat surface
- Weight distribution & interface pressure in 3 cases

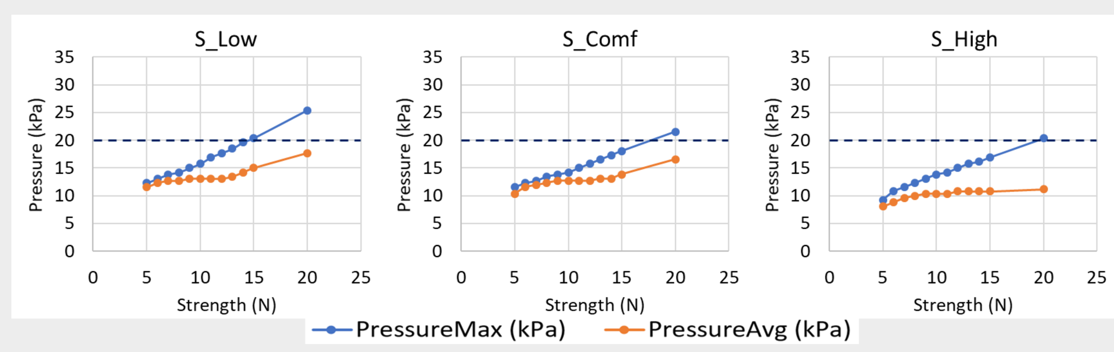
Results

Parametric study – Actuator Strength

% weight on Exo vs CoP Location

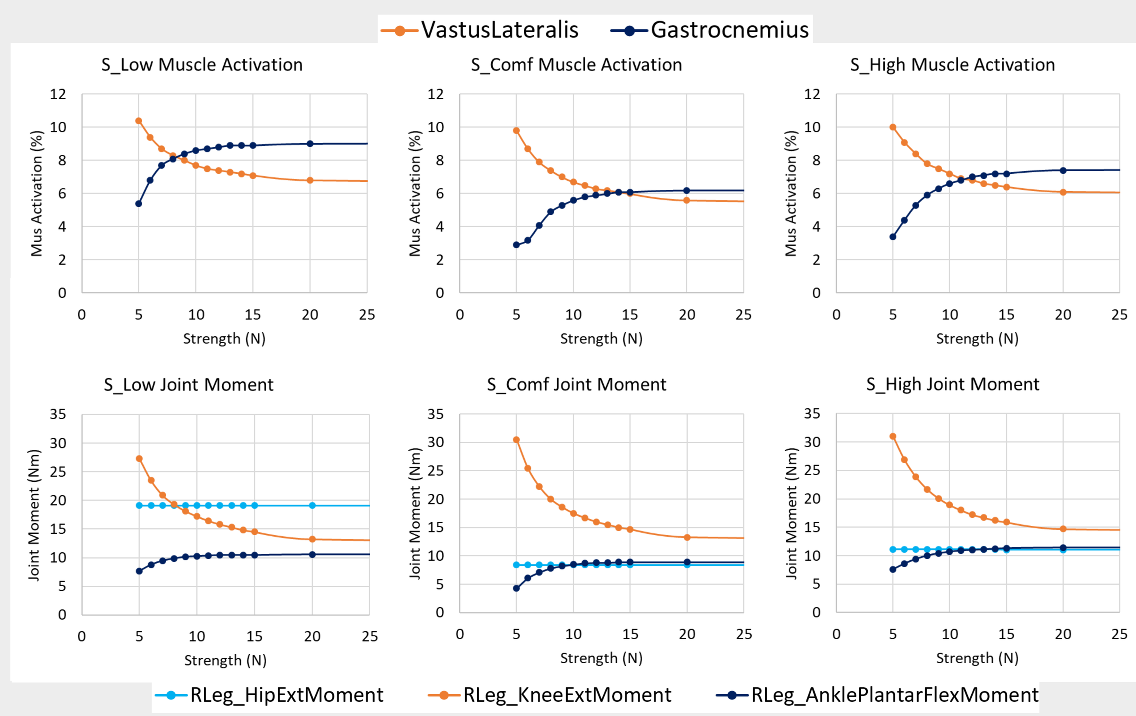


Indications for optimal actuator strength values



- Literature pressure threshold for discomfort: < 20 kPa (buttocks); 3 – 10 kPa (mid thigh). Mergl 2006

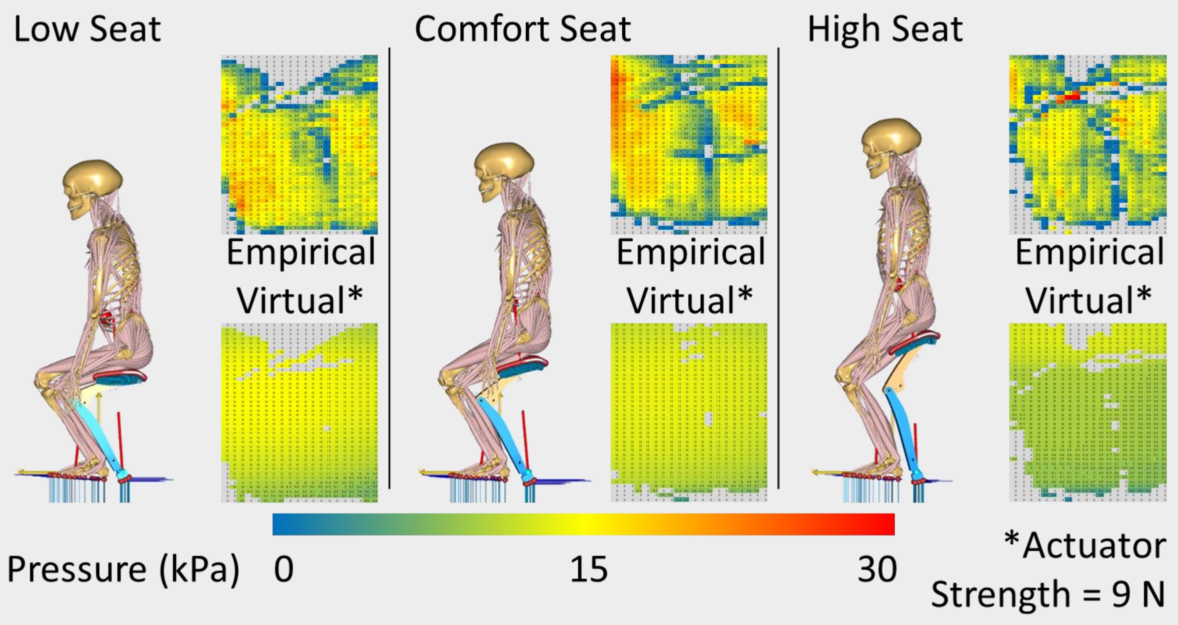
Biomechanical output vs Actuator strength



- Changing the actuator strength can have a significant on the biomechanical outputs

Current Challenges and Future Direction

Distribution of Pressure at the interface



- Contact between rigid bodies – no compression of soft tissue or seat
- Relevant for multibody analysis – amount of force exchanged and Centre of Pressure (CoP)
- Validation of frictional forces – pressure mat does not indicate shear forces
- Discussion with Aalborg University and Leipzig University of Applied Sciences for possible collaboration
- Implementation of interface model on more complex exoskeleton with multiple human-exoskeleton interfaces

Publications:

- **Chander D.S.**, Cavatorta M.P., (Under Review). Modelling friction at the mechanical interface between the human and the exoskeleton, International Journal of Human Factors Modelling and Simulation.
- Spada, S., Ghibaudo, L., Carnazzo, C., Di Pardo, M., **Chander, D.S.**, Gastaldi, L. and Cavatorta, M.P., 2018. Physical and virtual assessment of a passive exoskeleton. In the Proceedings of the Congress of the International Ergonomics Association (pp. 247-257). Springer, Cham.
- **Chander D.S.**, Cavatorta M.P., 2018. Multi-directional one-handed strength assessments using AnyBody Modeling Systems, Applied Ergonomics 67, 225–236.
- **Chander D.S.**, Cavatorta M.P., 2017. An observational method for Postural Ergonomic Risk Assessment (PERA), International Journal of Industrial Ergonomics 57, 32–41.