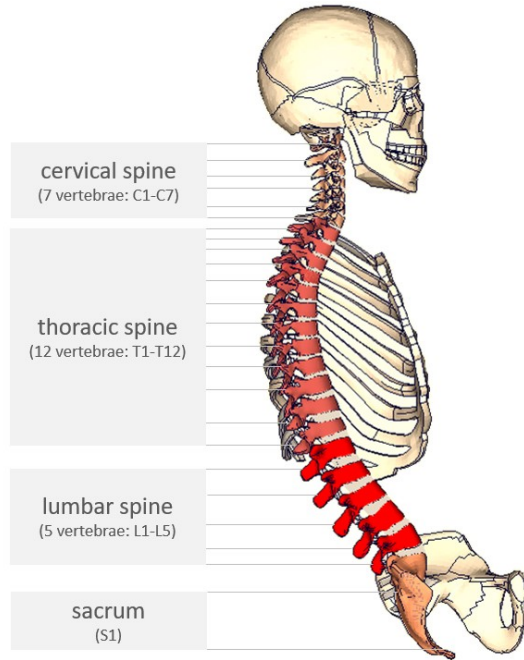# Spinal Curvature Measurements to Position Human Body Models in Occupant Safety Applications

Daniel Hintze, Kai Ikels, Özgür Cebeci
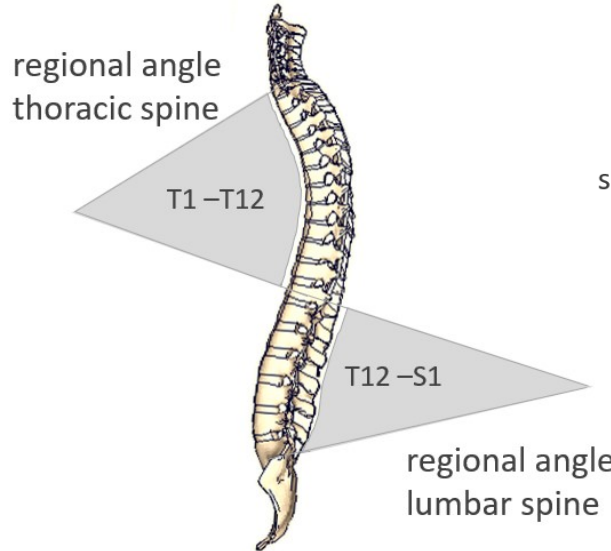
IAT - Ingenieurgesellschaft für Automobiltechnik mbH

8th International Symposium:
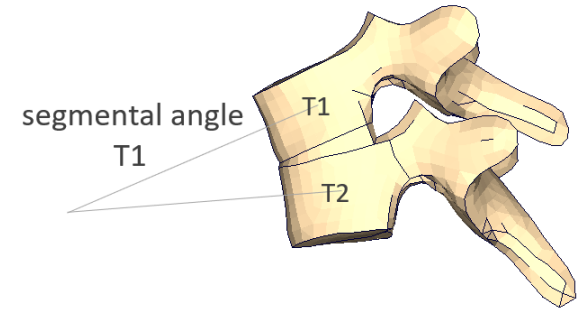Human Modeling and Simulation in Automotive Engineering
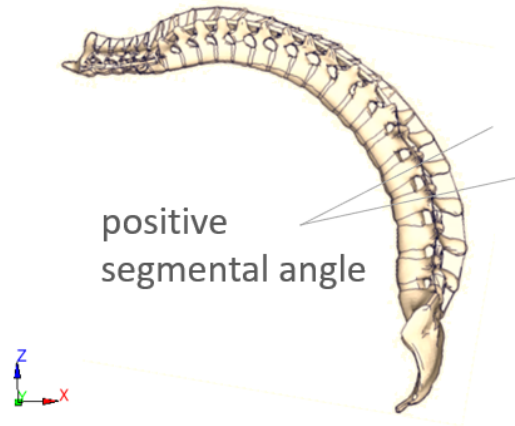**November 19 - 20, 2020**

structure and naming of spinal sections

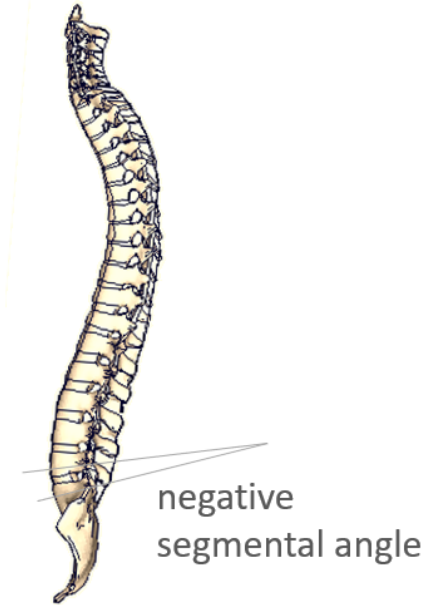convention of regional and segmental angles (sagittal plane)

positive
segmental angle

negative
segmental angle

kyphotic lumbar curvature
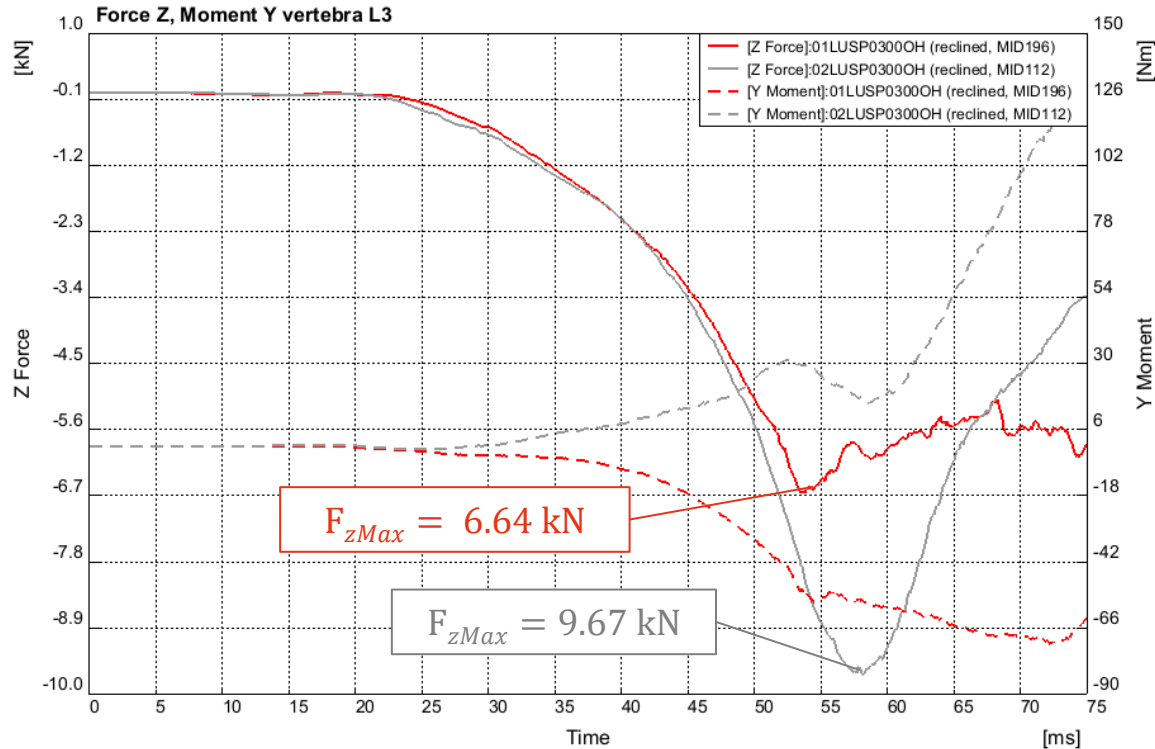
lordotic lumbar curvature

- Motivation

- Comparison of Spinal Positioning (PIPER) & Spinal Measuring Positioning Process (IAT)

- Individual spinal curvature measurement

  - *Measurement method*

  - *Reproducibility of measurement and positioning process*

- Evaluation of measured spinal curvatures

  - *Influence of seat modifications*

  - *Influence of anthropometric characteristics*

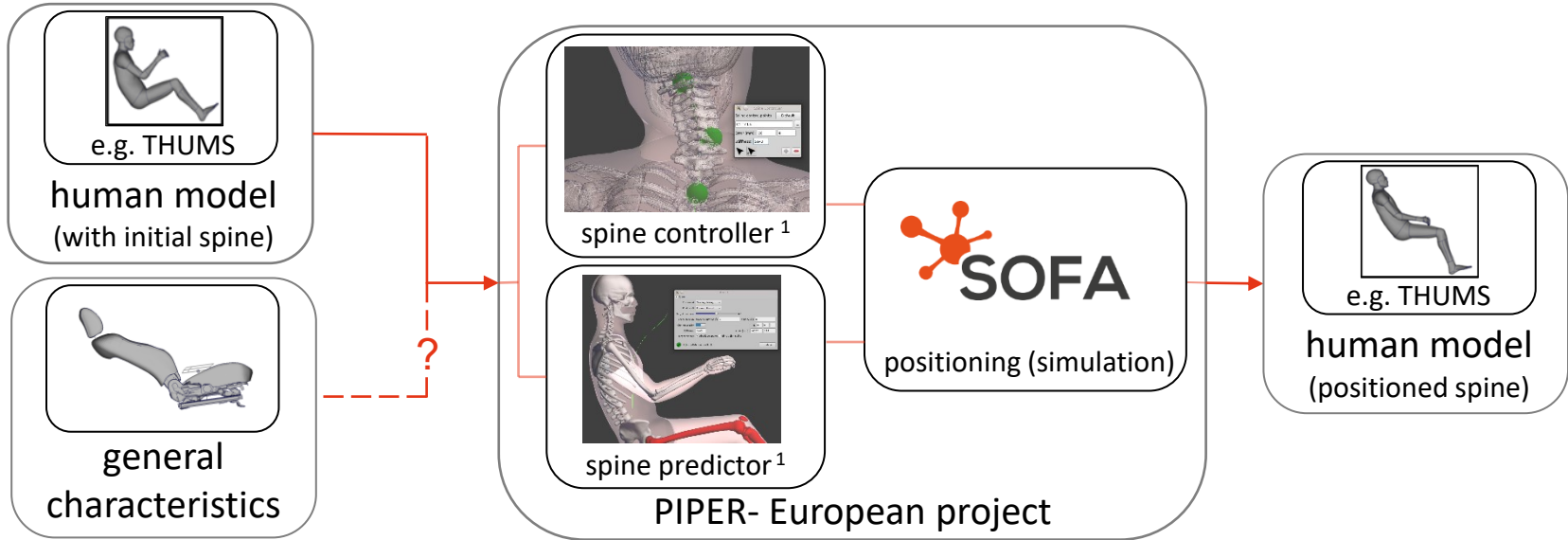- Conclusion and outlook

HUMAN MODELING AND SIMULATION IN AUTOMOTIVE ENGINEERING
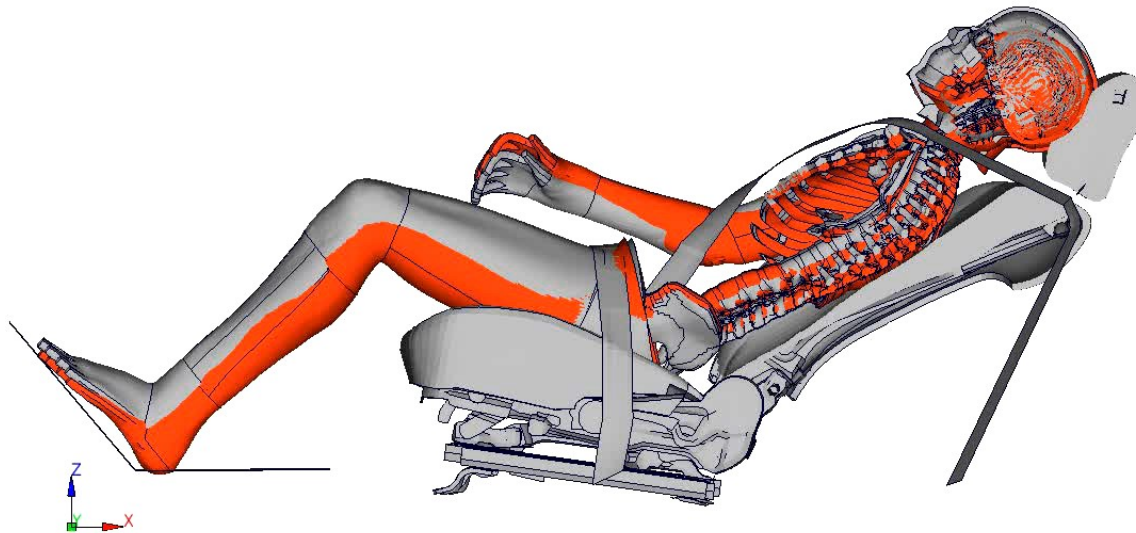
- spine curvatures taken from real persons with similar anthropometry

- substantial kinematic differences in lumbar spine

Force Z, Moment Y vertebra L3

$F_{zMax} = 6.64$ kN

$F_{zMax} = 9.67$ kN
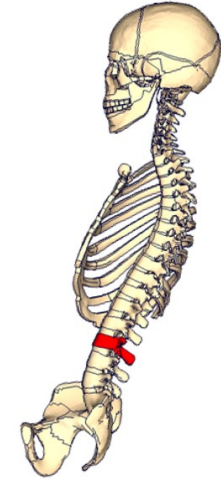
- Example:
  load differences (L3)
  for real spinal
  curvature

- e.g. THUMS
  human model
  (with initial spine)

- **general characteristics**

- spine controller [1]
- spine predictor [1]

SOFA
positioning (simulation)

PIPER- European project

- e.g. THUMS
  human model
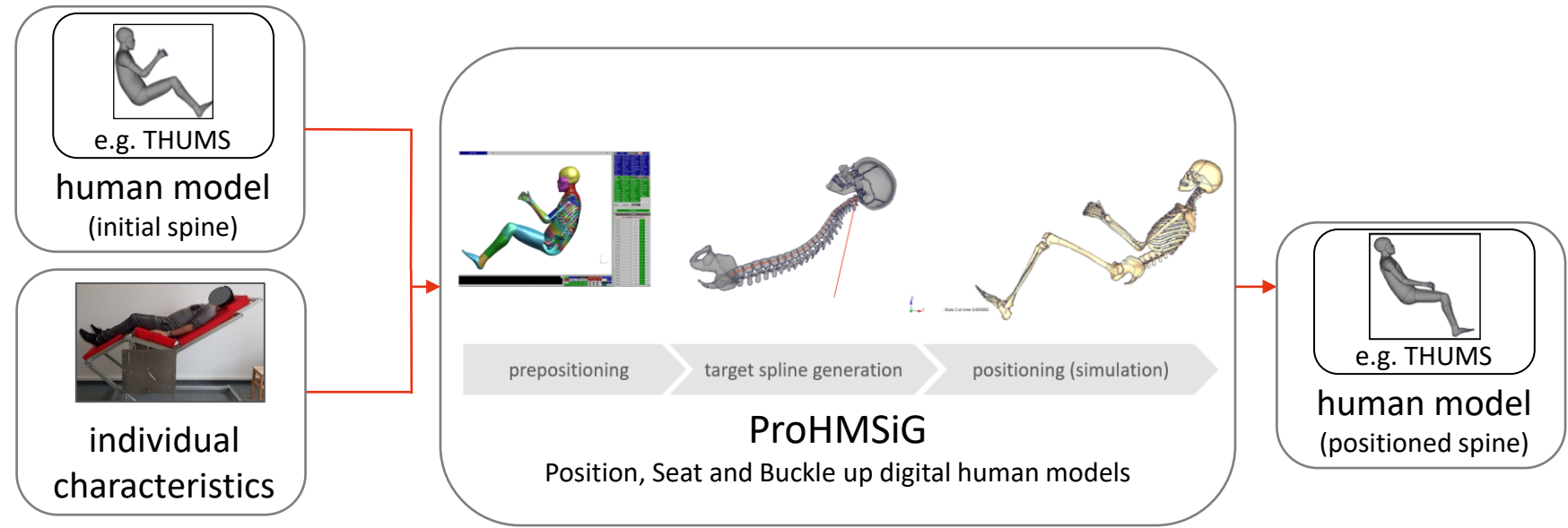 (positioned spine)

✓ proven methods to position spine of digital human model

✓ solver independent and rapid simulative positioning

○ individual anthropometric and car seat characteristics not considered

[1] – information and pictures taken from PIPER Project
Source: http://piper.gforge.inria.fr/doc/modulePhysPosiInter.
html#secPhysPosiInterSpine

HUMAN MODELING AND SIMULATION IN AUTOMOTIVE ENGINEERING

e.g. THUMS

human model
(initial spine)

**individual
characteristics**

prepositioning → target spline generation → positioning (simulation)

ProHMSiG
Position, Seat and Buckle up digital human models

e.g. THUMS

human model
(positioned spine)

✓ enhanced spine positioning process by means of kinematic and segmental angles
✓ spinal measurement to consider individual characteristics

○ measuring method to detect spinal curvature is required

8

IAT   carhs.
Empowering Engineers

ADVANTAGE
- ✓ highest precision to illustrate vertebral position and segmental angles
- ✓ measurement of total spinal range (C1 and S1)
- ✓ non-contact method

DISADVANTAGE
- – radiation exposure
- – to scan total spine huge radiography devices needed

NO USAGE IN STUDY
- – desired method when measure spinal curvature
- – not usable due to radiation exposure

Source: https://radiopaedia.org/cases/trauma-ct-of-the-thoracic-and-lumbar-spine-without-injury?lang=gb.

ADVANTAGE

- ✓ radiation-free measurement method
- ✓ precision comparable to radiography analysis
- ✓ output: segmental angles and spinal length

DISADVANTAGE

- – measurement only between C7 and S1
- – no valid information about sacrum and pelvis angle
- – requires measurement seat

USAGE IN STUDY

- ✓ radiation-free alternative to radiography

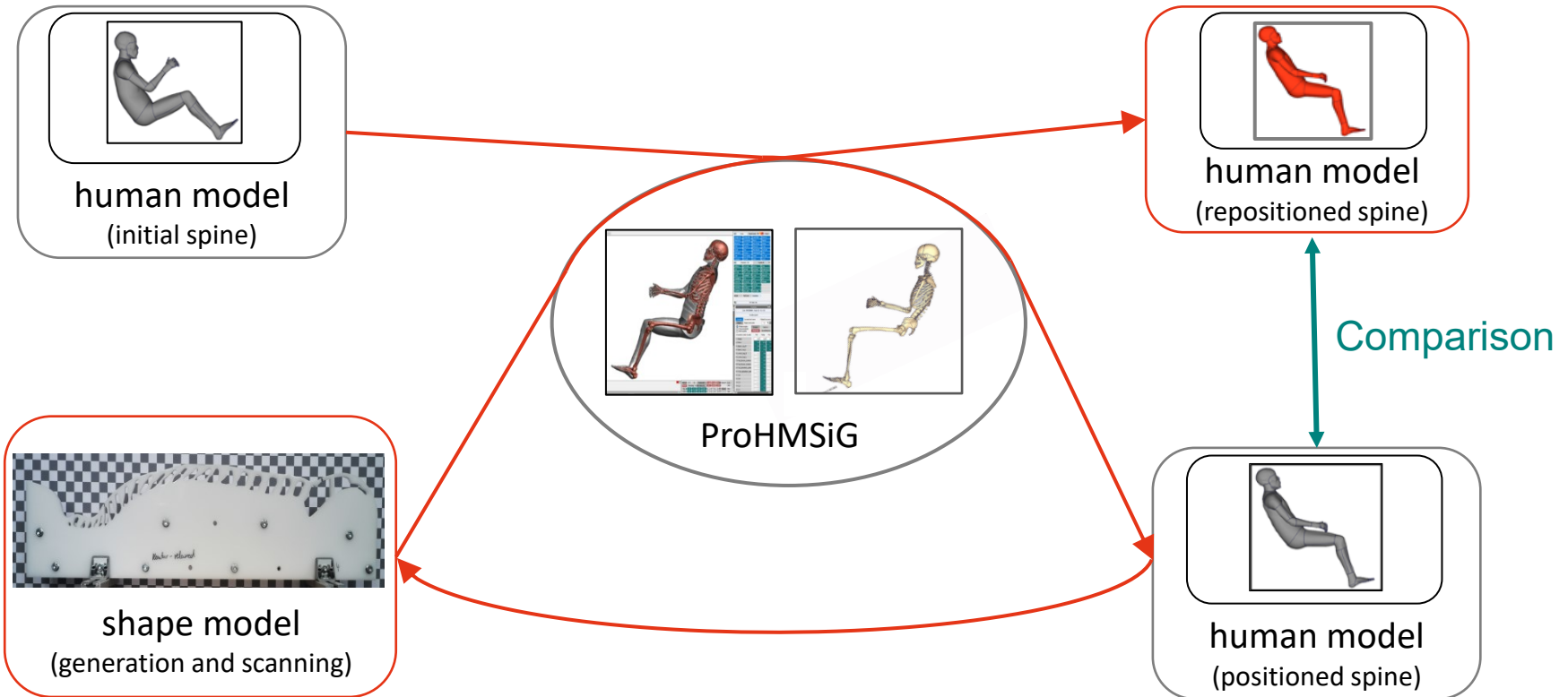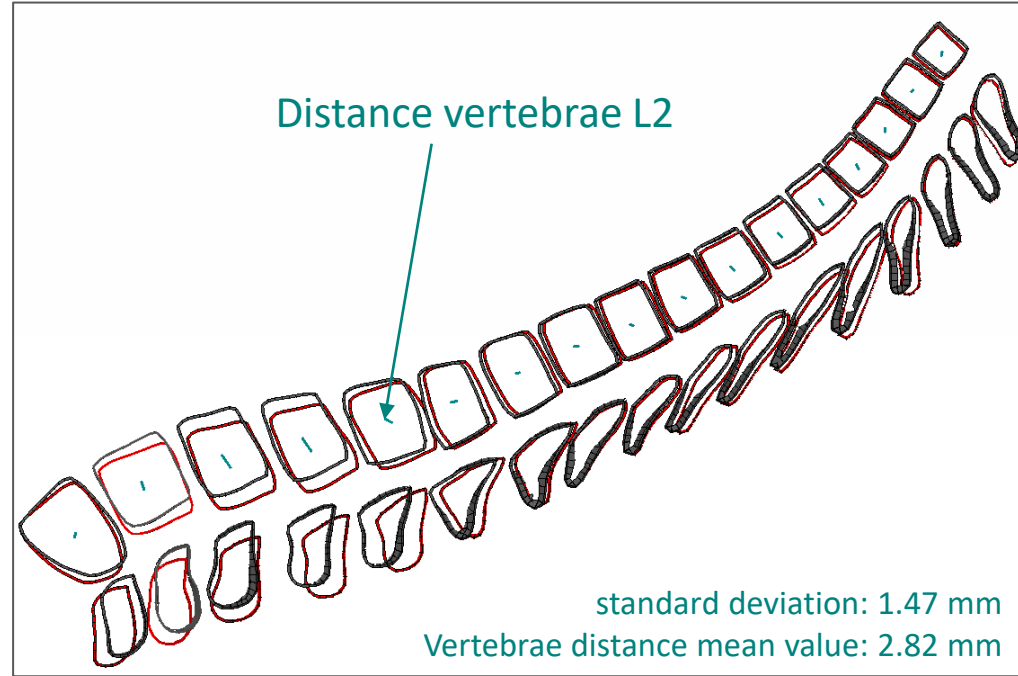Source: IDIAG AG, „IDIAG M360," IDIAG AG, 2019. [Online]
Available: https://www.idiag.ch/idiag-m360/

HUMAN MODELING AND SIMULATION IN AUTOMOTIVE ENGINEERING

- free adjustable in any desired seating position

- variable cushion shape and stiffness

human model
(initial spine)

human model
(repositioned spine)

ProHMSiG

Comparison

shape model
(generation and scanning)

human model
(positioned spine)

Distance vertebrae L2

standard deviation: 1.47 mm
Vertebrae distance mean value: 2.82 mm

✓ positioned and repositioned THUMS spinal curvature by using "IAT-position-process"

THUMS (positioned spine)

THUMS (repositioned spine)

13
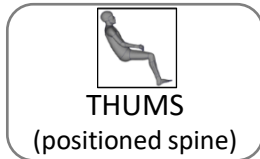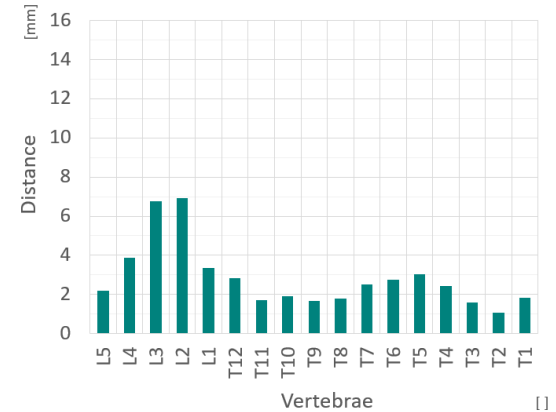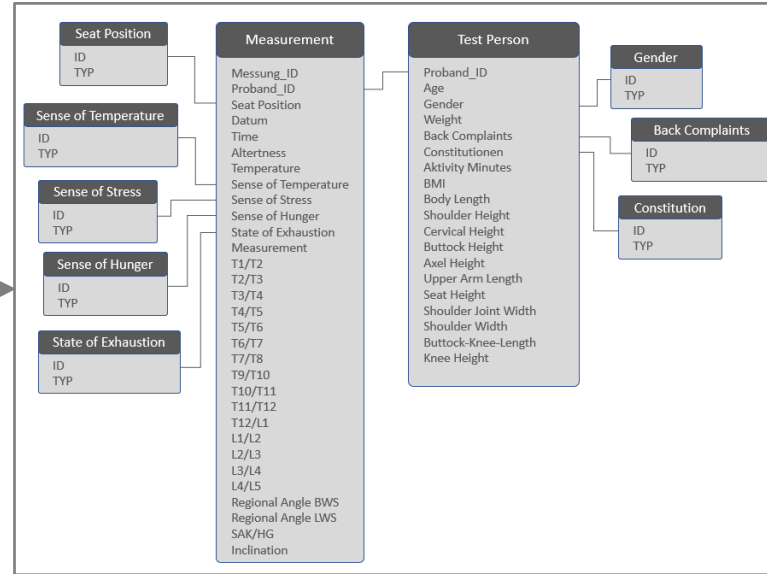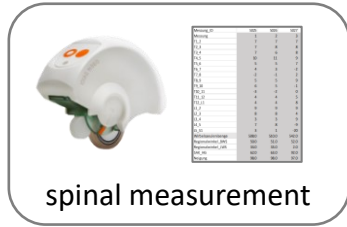
- all spinal measurements are structured and archived in a database system

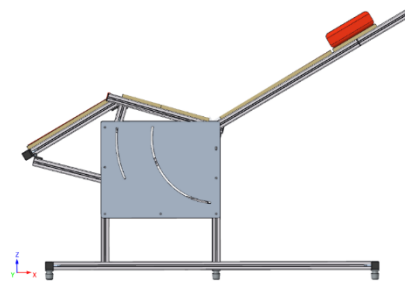- including & combining anthropometric measurements

- seat adjustments (backrest 60° to vertical, seat pan 17° to horizontal, lower leg support about -30° to horizonal)
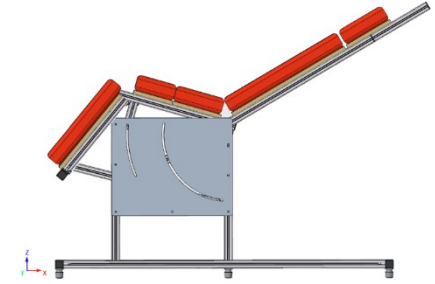- identical test person in entire study
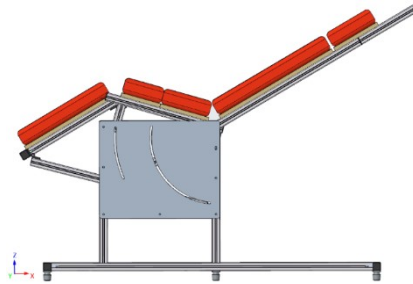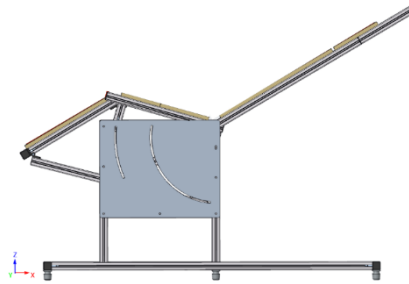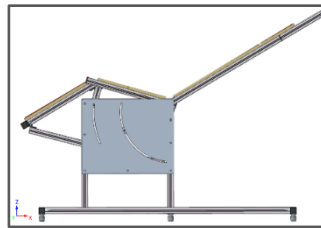

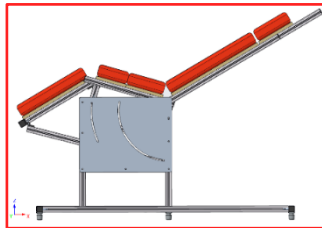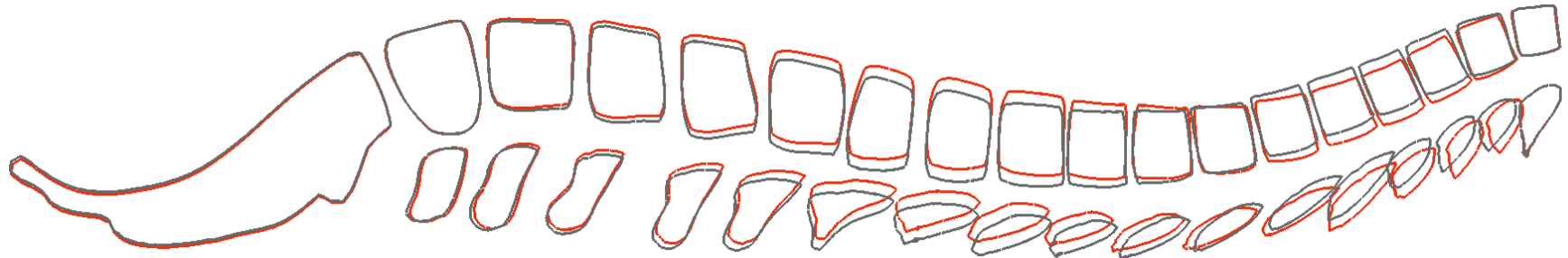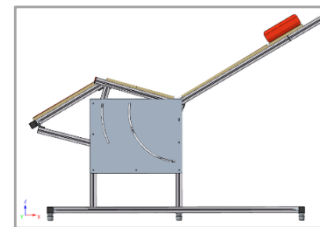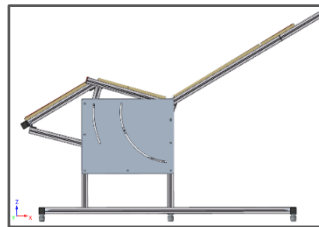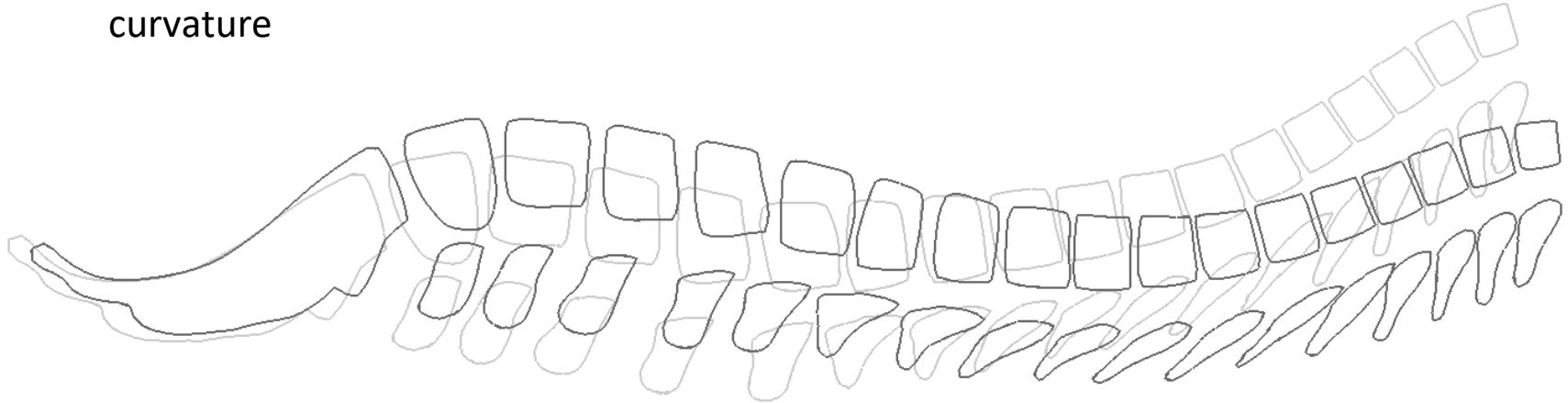"full cushion"   "without cushion"   "headrest only cushion"   "low inclination lower leg support"

- "full cushion" ↔ "without cushion" → minor difference in spinal curvature

- "without cushion" ↔ "headrest only cushion" → major difference along full spinal curvature

- "full cushion" ↔ "modified inclination lower leg support"→ noteworthy difference of spinal curvature especially in lumbar spine
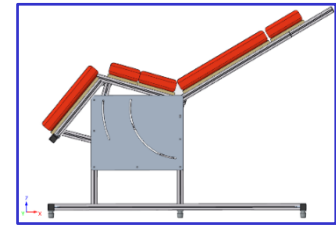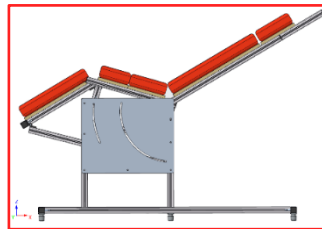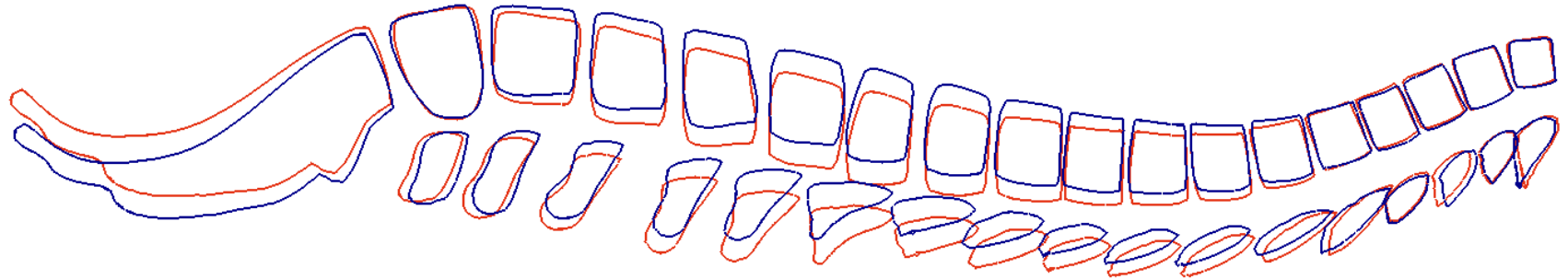
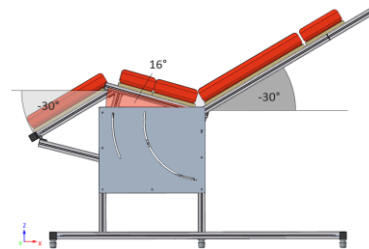- three different seat adjustments (upright, relaxed, horizontal)
- 25 test persons (21 male and 4 female)
- measurement of spinal curvature and anthropometric characteristics and landmarks[1]
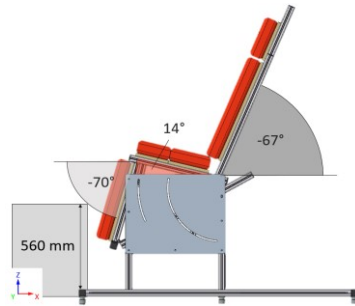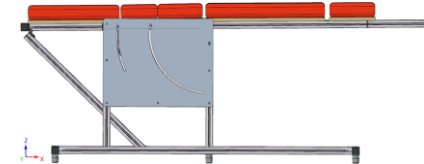
"upright"   "relaxed"   "horizontal"

[1] – landmark measure methods taken from literature (also used in PIPER Project)
Source: ANTHROPOMETRIC SURVEY OF U.S. ARMY PERSONNEL: METHODS AND SUMMARY STATISTICS, Yellow Springs, OHIO USA: U.S. Army Natick Soldier Research, Development and Engineering Center Natick, 2014.

HUMAN MODELING AND SIMULATION IN AUTOMOTIVE ENGINEERING

$|r_{max}| = 0.51$

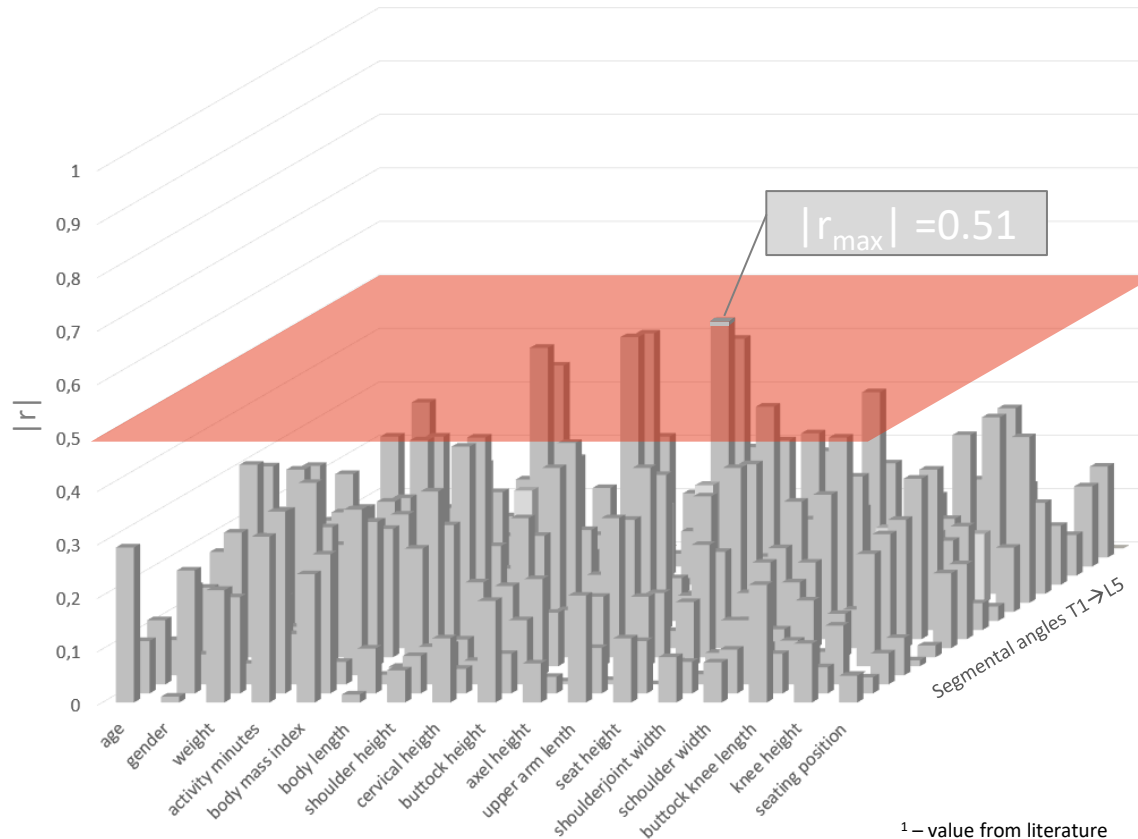- low correlation between anthropometry & segmental angle

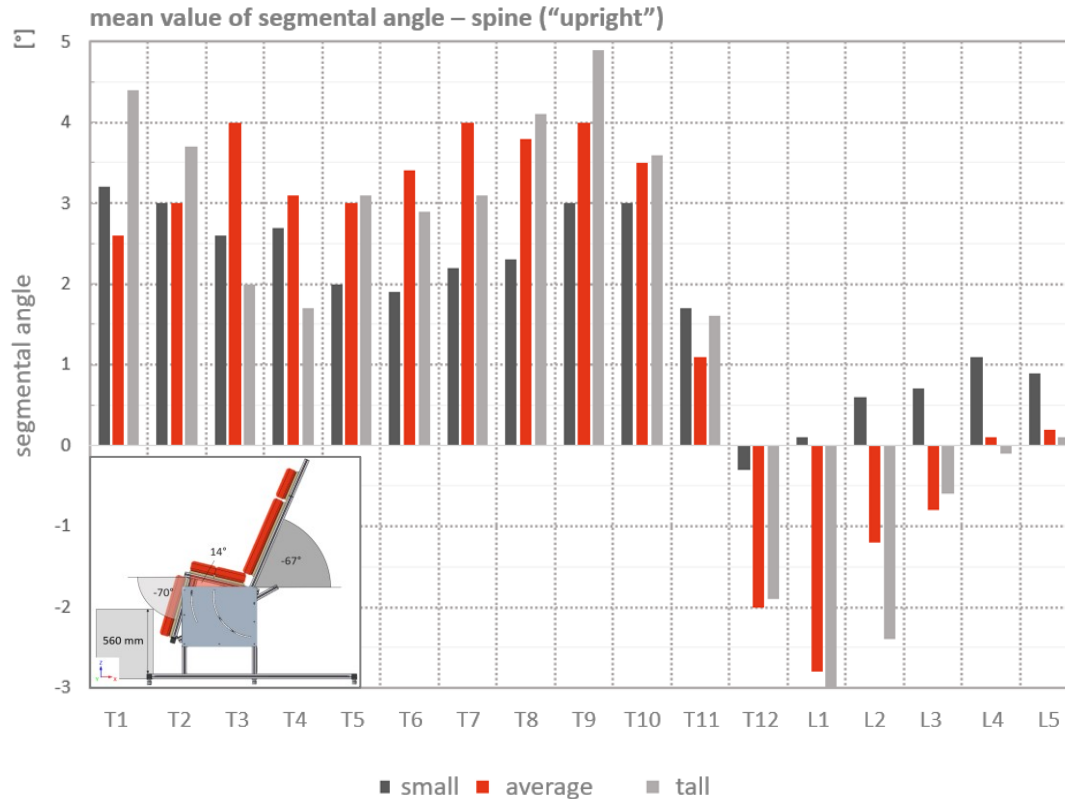→no spinal curvature prediction by anthropometry

$|r| \geq 0.5$
high correlation[1]

[1] – value from literature
Source: Jacob Cohen: "*A power primer*",
Psychological Bulletin, Volume 112, 1992

mean value of segmental angle – spine ("upright")

- kyphotic curvature of lumbar spine seen in group "small"

- other groups show lordotic lumbar curvature

Distribution of body length of test person

mean value of segmental angle – spine ("relaxed")
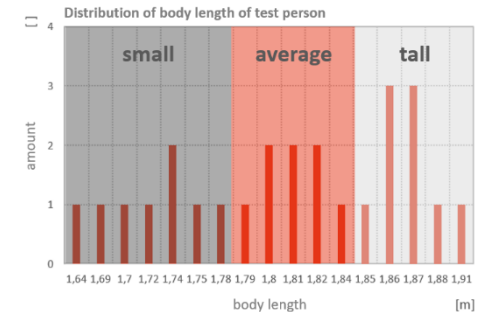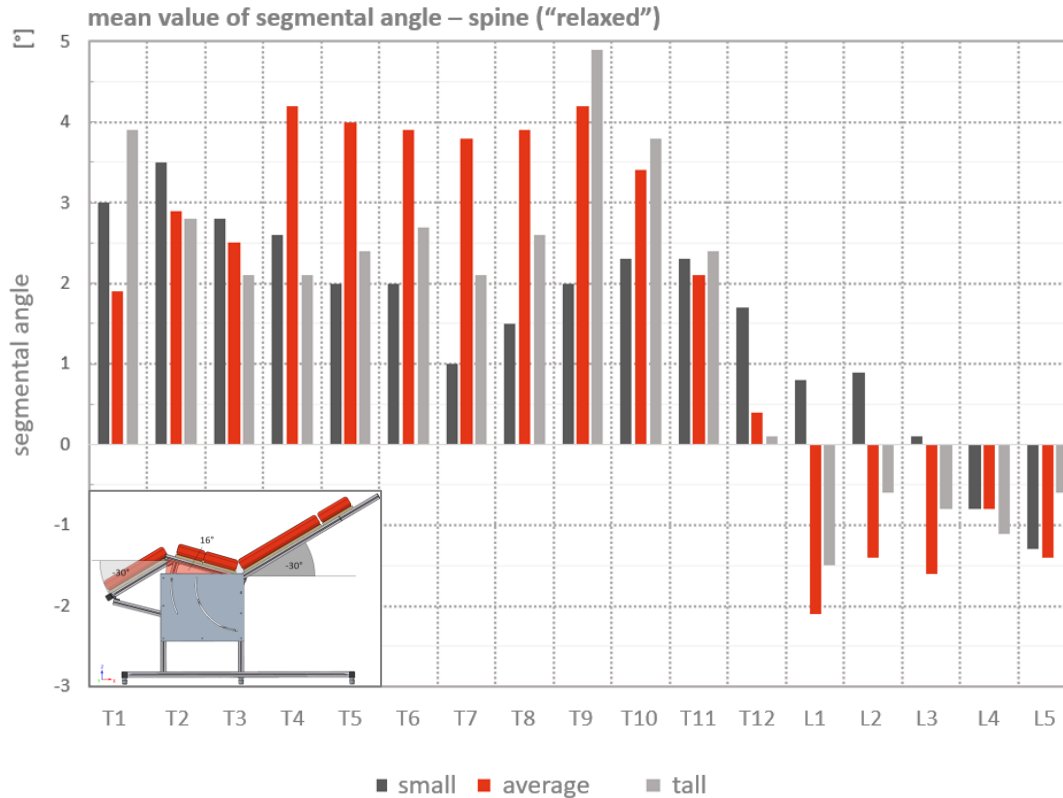
- less thoracic angle variability in comparison to lumbar spine due to rip cage

- in relaxed position "small" test persons show increased lordotic lumbar curvature

Distribution of body length of test person
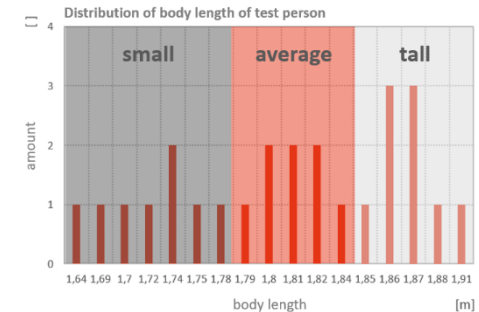
mean value of segmental angle – spine ("horizontal")
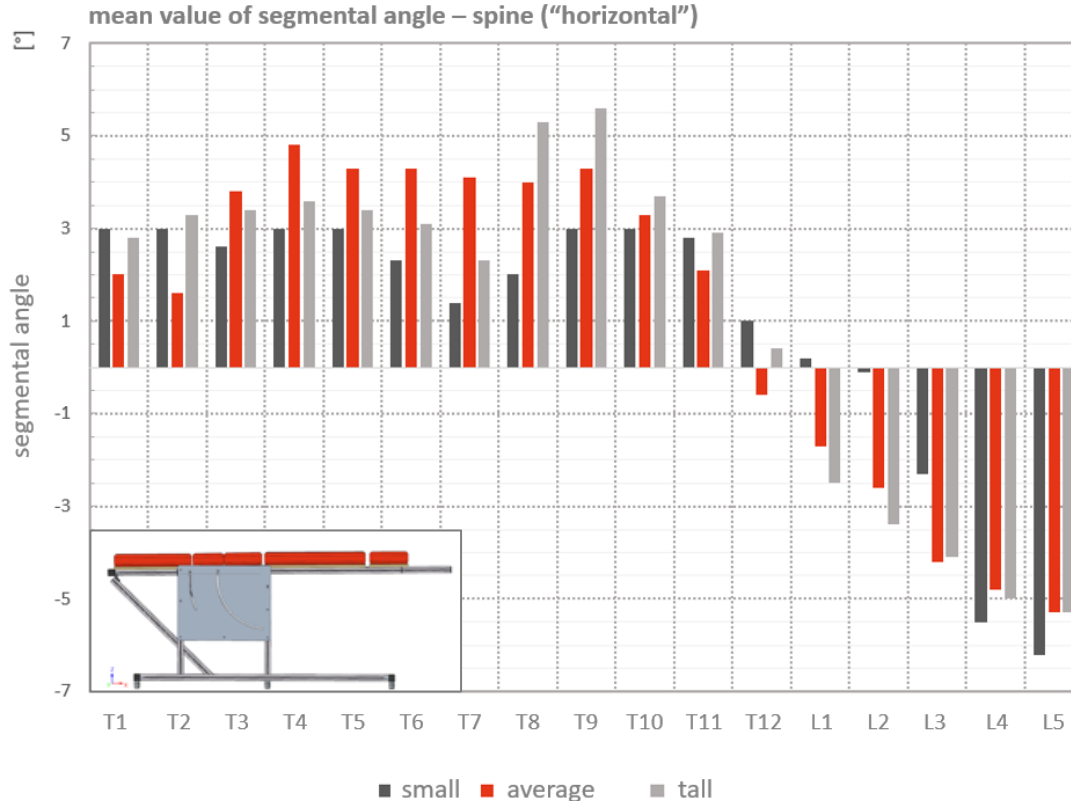
- in horizontal position all groups show a strong lordotic lumbar curvature

- horizontal position shows lowest differences in mean value of segmental angle

Distribution of body length of test person

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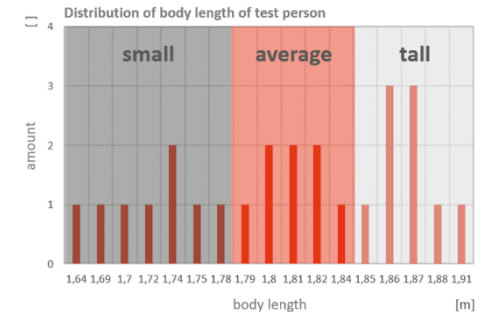
- different initial spinal curvature results specific kinematics and loadings
- lumbar spine loads (axial & flexion) increase with reclined seating positions
- realistic and biofidelic spinal curvature is necessary to get valid spinal loads
- spinal curvature is influenced by individual anthropometric characteristics, but also seat adjustment and seat geometry
- based on available anthropometric data, no valid prediction of the spinal curvature
- "IAT spinal measuring and positioning process"
  - measurement of individual spinal curvature in arbitrary seat and cushion adjustments
  - merge spinal curvatures with anthropometric measurements database to investigate potential correlations
  - positioning process resulting in biofidelic spine curvature

- Complete study with a representative set of test persons
- grouping of test persons based on anthropometric characteristics to investigate potential correlations to spinal curvature
- find method to measure pelvis angle and cervical spinal curvature
- design of experiments to investigate relation between spinal contour and its spinal loads in frontal impact

THANK YOU FOR YOUR ATTENTION
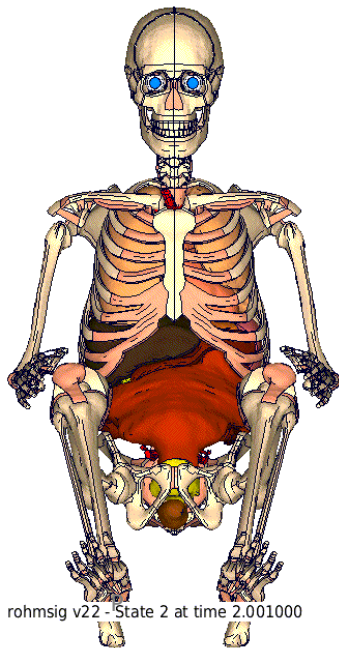
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