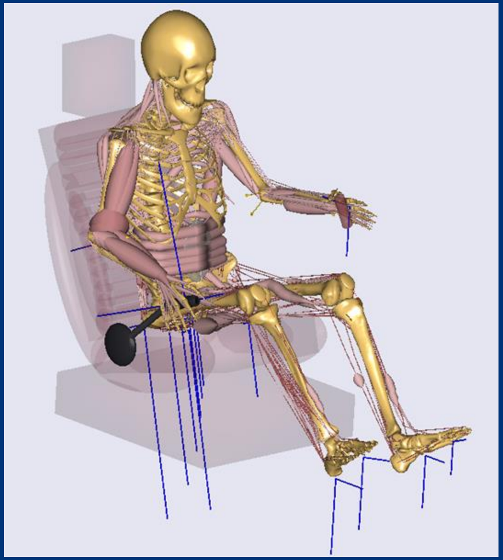
APPLICATION OF MOTION ANALYSES AND DIGITAL HUMAN MODELING FOR THE ERGONOMIC EVALUATION OF HANDBRAKES IN PASSENGER VEHICLES

A. Upmann[°], J. R. Rausch[°], K. Heinrich[*+],
I. Fischbein[°], G.-P. Brüggemann[*]



[°]Ford-Werke GmbH, Cologne, Germany
[*]German Sport University Cologne, Institute of Biomechanics and Orthopaedics, Germany
[+]University of Applied Sciences Koblenz, Department of Mathematics and Technology, Remagen, Germany

Go Further

INTRODUCTION

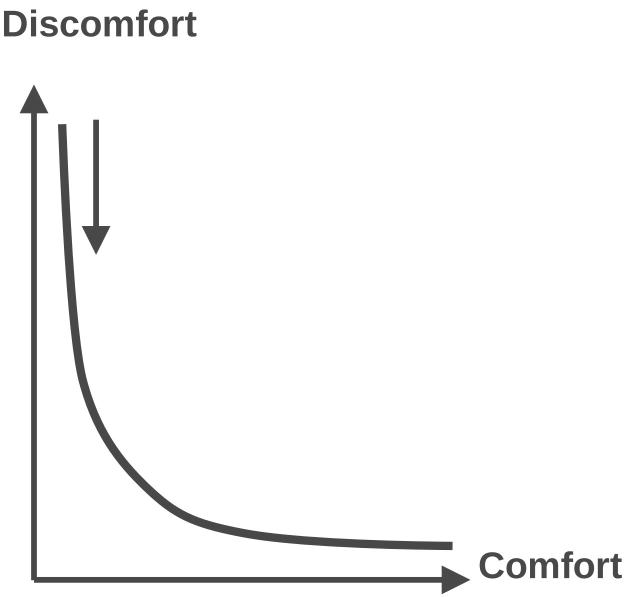
Discomfort and Comfort

"How to measure the discomfort perceived by a subject, knowing that it is subjective […] ?" (Wang, 2009)

"How to define discomfort criteria based on biomechanical parameters, such as joint angles, joint forces, work, energy, muscle efforts, ..." (Wang, 2009)

Discomfort:

- Pain and strain
- Biomechanical and physiological aspects
- Fatigue
- Restlessness
- Climate
- Vibrations
- Quality (sound)



Comfort:

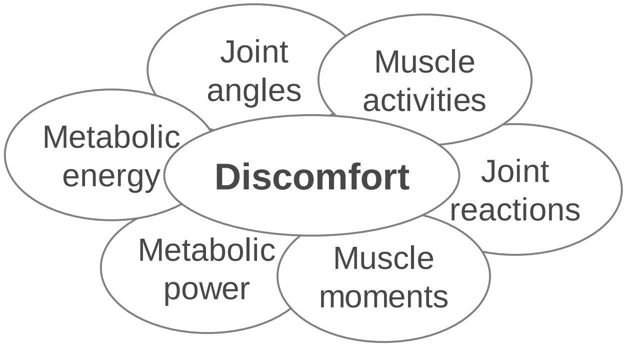
- Design
- Delight and surprise
- Relaxation, relief and refreshment
- Well being
- Fun to drive

Zhang et al. (1996)

INTRODUCTION

Ergonomics is crucial for car design

- Comfort is a major selling argument (Hartung 2006)
- Car manufacturers aim for ergonomic vehicles with minimized discomfort and maximized comfort



Factors influencing discomfort

Evaluation of car ergonomics & discomfort

- Discomfort in cars is often assessed by studies in which subjective and objective measurements are taken (Ulherr & Bengler, 2014)
    - ➢Many factors are contributing that cannot be measured
    - ➢Difficult to get objective and reproducible data
    - ➢Resource intensive
    - ➢Requires prototypes, so conducted late in the product development process

➔**Virtual assessments are essential for cost and time reasons and for a holistic evaluation** (Ulherr & Bengler, 2014)

INTRODUCTION

The handbrake is

- (Still!) an essential vehicle control element
- Typically located in the center console where numerous trade-offs are required between components and attributes

Handbrake in Ford Focus RS*

Automotive discomfort research has focused on

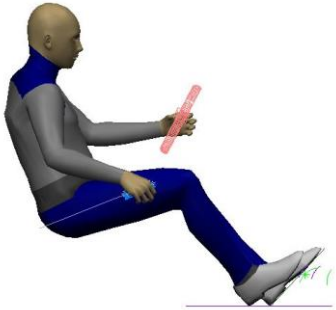
- Sitting / seat discomfort (De Looze et al., 2003)
- Joint angles for driving posture (Kyung & Nussbaum, 2009; Schmidt et. al., 2014)
- Pedal operation (Wang, Le Breton-Gadegbeku & Bouzon, 2004)
- Ingress and egress (Dufour & Wang, 2005)
- Reach (Jung & Choe, 1996; Wang & Trasbot, 2011)

*www.facts.ford.com, Motor Show Brüssel 2016, picture downloaded 12.10.2016

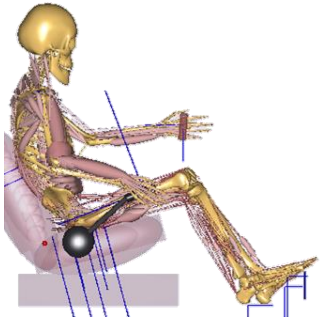
OBJECTIVES

Objective

- Develop a virtual procedure to simulate handbrake application and predict discomfort through using DHMs and mathematical modeling
    - Procedure needs to be reliable and user-friendly
    - DHMs to be commonly used by automotive manufacturers
- Identify factors influencing the perception of discomfort and their effect on discomfort for handbrake application
- Identify handbrake application movement strategies and simulate these



RAMSIS*



AMS (AnyBody Modeling System)*

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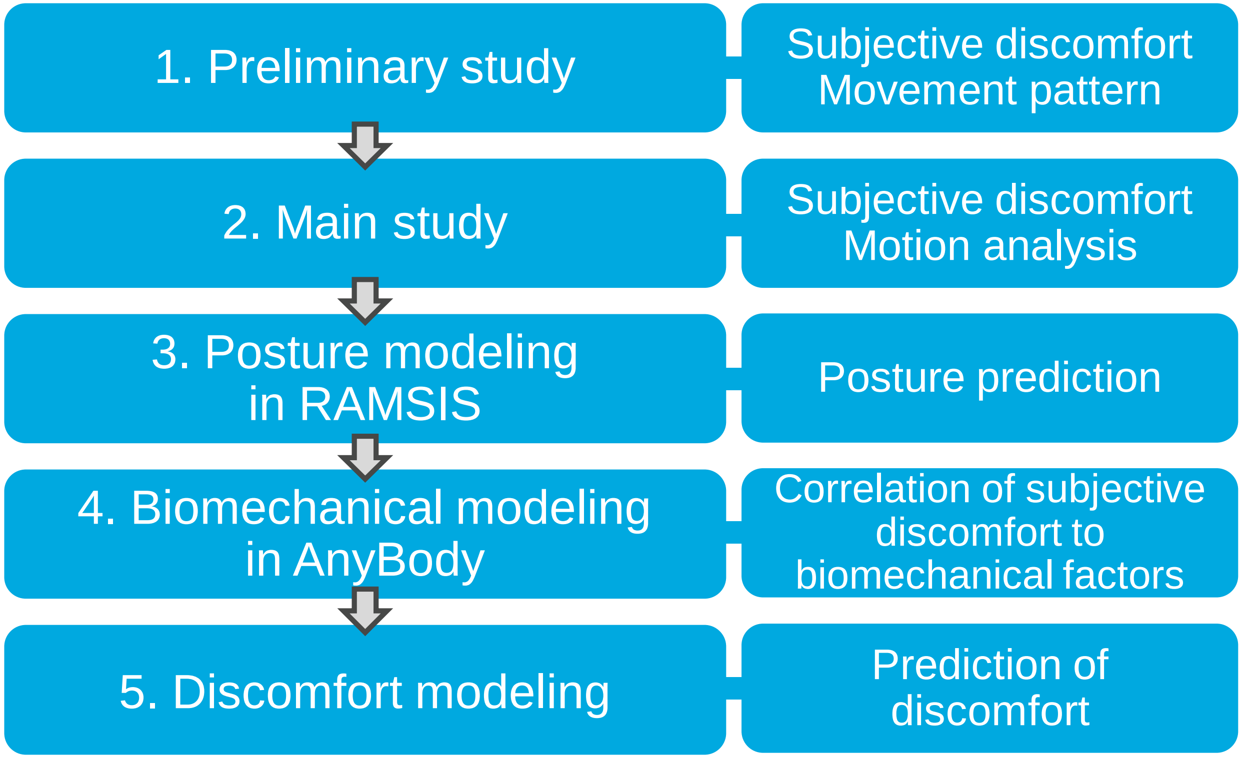
*Human Solutions GmbH, Kaiserslautern, Germany
**AnyBody Technology A/S, Aalborg, Denmark

STUDY DESIGN

A multistep study was planned and completed



1. Preliminary study

Subjective discomfort
Movement pattern

2. Main study

Subjective discomfort
Motion analysis

3. Posture modeling
in RAMSIS

Posture prediction

4. Biomechanical modeling
in AnyBody

Correlation of subjective
discomfort to
biomechanical factors

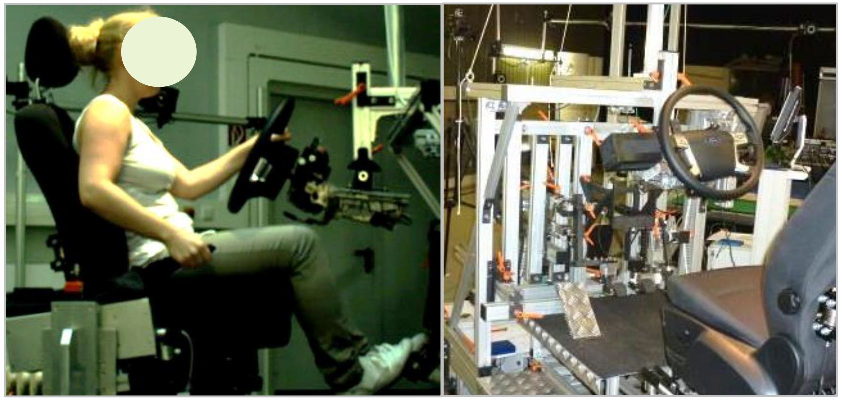
5. Discomfort modeling

Prediction of
discomfort

PRELIMINARY STUDY

Overview

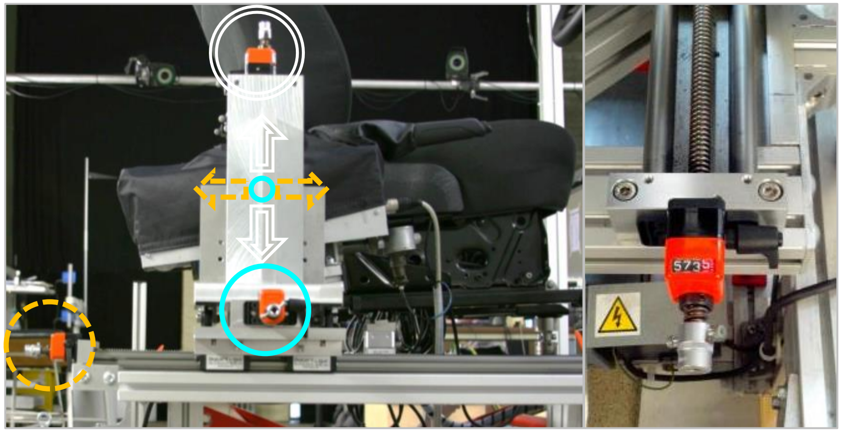
- 117 subjects
- Test drive in passenger vehicle
- Evaluation of 7 handbrake locations (1 repeated) in test rig, random order
- Video recording
- Anthropometric measurements



Handbrake application in test rig

Results

- Influence of handbrake location on discomfort
- Different movement patterns
- Reproducible discomfort ratings



Handbrake adjustment unit

MAIN STUDY

Methods

- 40 subjects from pre-study included based on defined criteria
- Same test rig, extended range of handbrake locations
- Evaluation of 7 handbrake locations, mid repeated, random order
- Modified rating scale: CP50 (Heller, 1985; Shen & Parsons, 1997)
  Question: “How do you rate the application of the handbrake?”
- Motion analysis with Vicon Nexus system

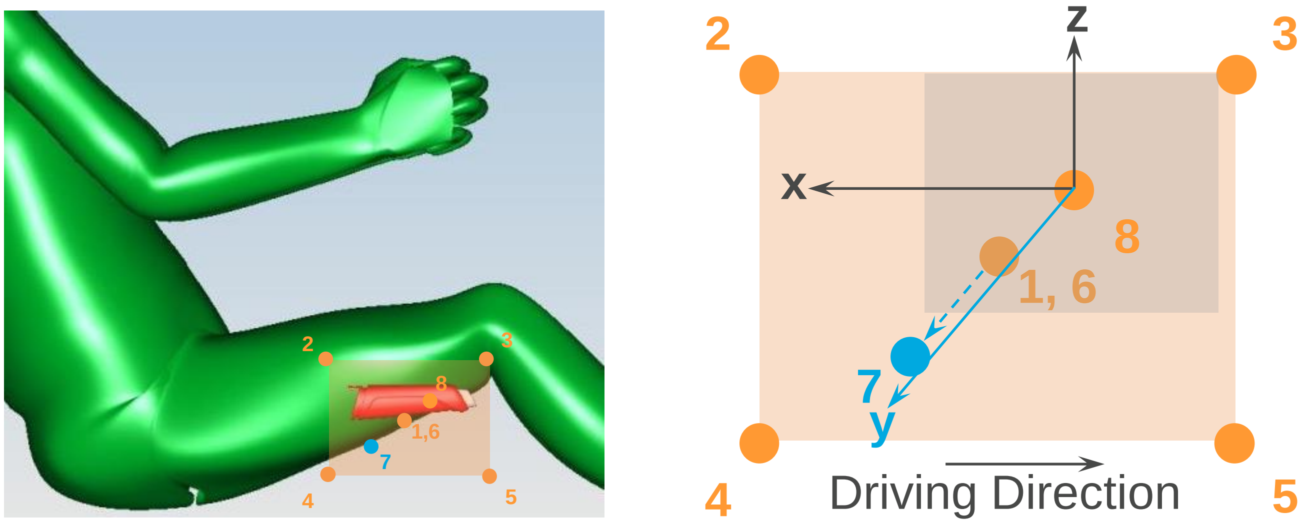
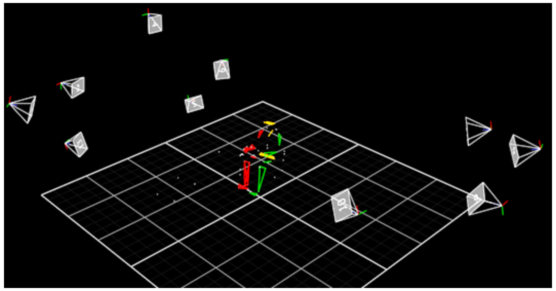


Illustration of investigated handbrake locations

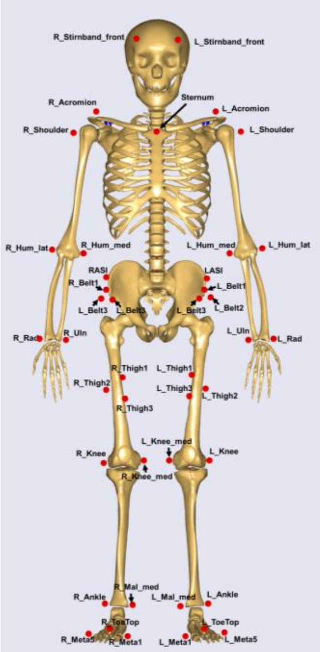
MAIN STUDY

Motion analysis

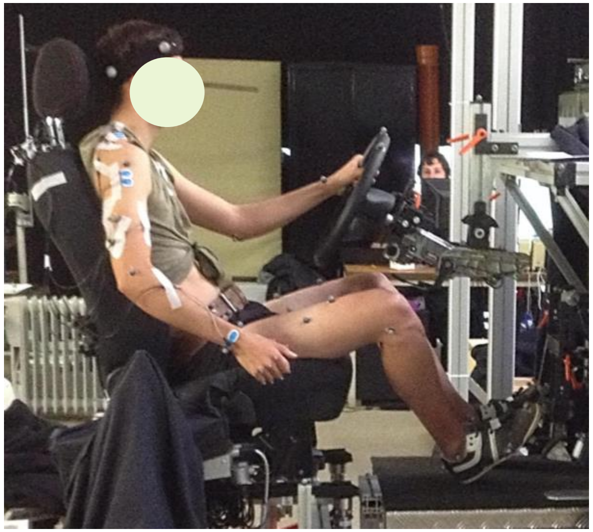
- 10 Vicon Nexus infrared cameras
- Handbrake equipped with force and angle sensors
- Recreation of motion in AMS**
- Key frames: start and end of handbrake application
- Joint angles of torso and right shoulder, clavicle, elbow and wrist joint



Arrangement of Vicon cameras*



Front view of marker set up**



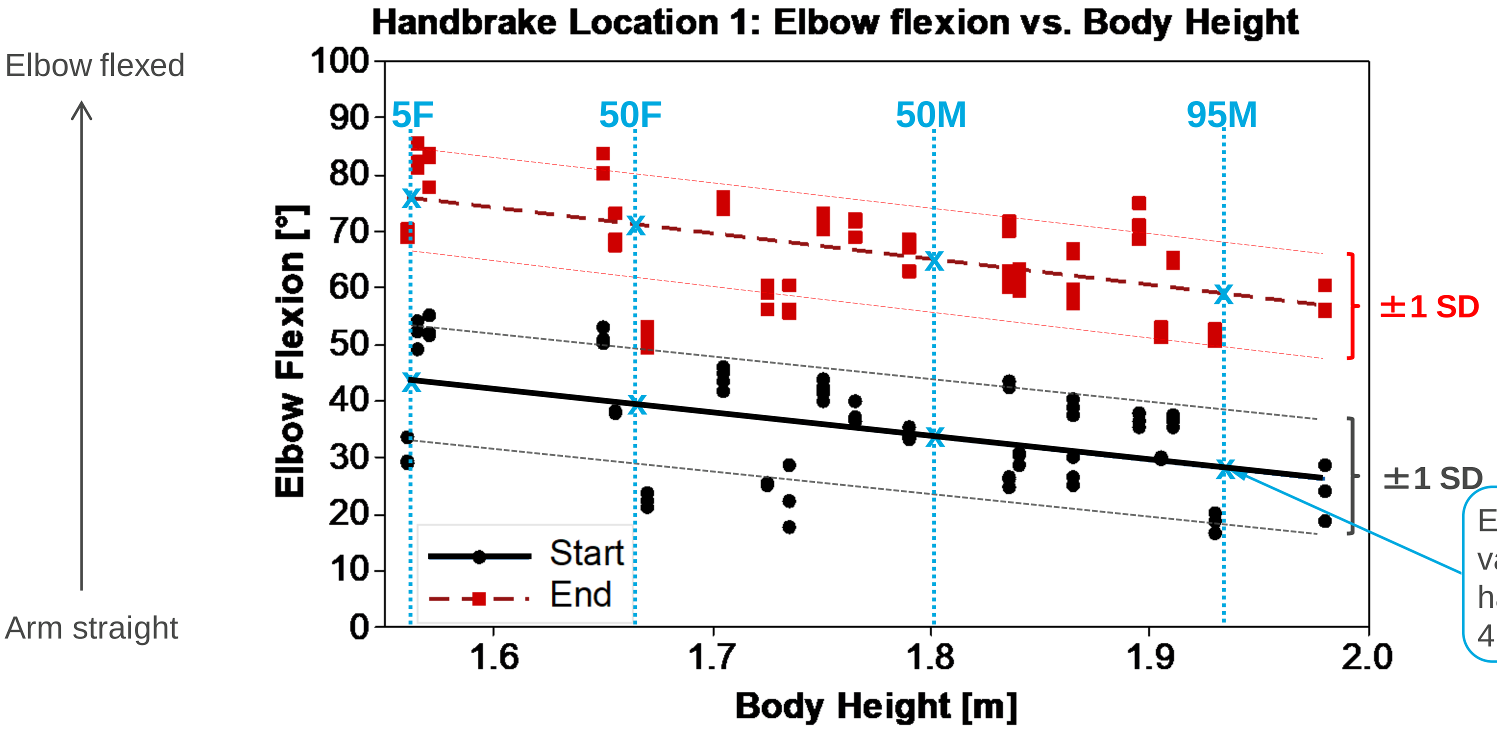
Subject equipped with reflective markers

*Heinrich et al., 2014
**Rausch & Upmann, 2015

MAIN STUDY

Results and conclusion of motion analysis

- Joint angle variation over body height ➔ movement patterns influenced by body height
- Target for prediction: joint angles as suggested by regression line for key percentiles
  - 5th percentile female (5F), 50th percentile female (50F)
  - 50th percentile male (50M), 95th percentile male (95M)



Elbow flexion target value for 95M, handbrake location 4, start

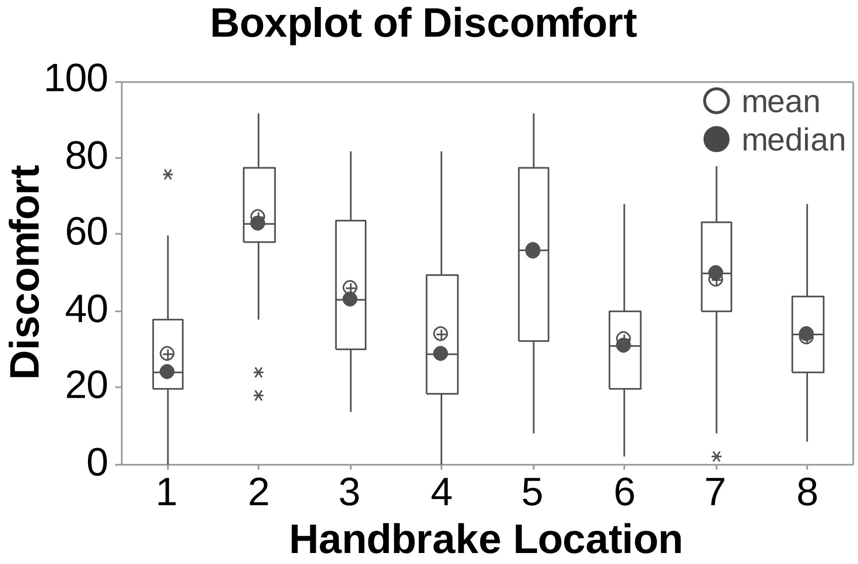
MAIN STUDY

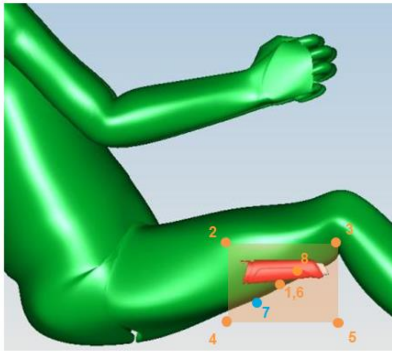
Results and conclusions of subjective evaluation:

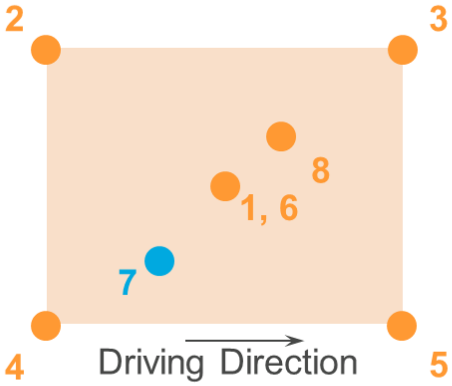
- No significant difference for repeated location (1, 6)*
- Significant differences between several locations*

➔ **Handbrake locations influence discomfort perceptions**

- Variance depending on handbrake location







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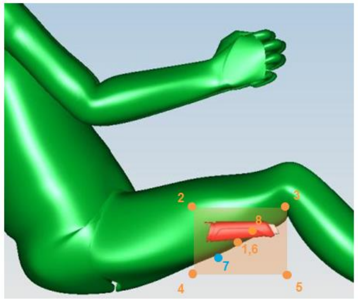
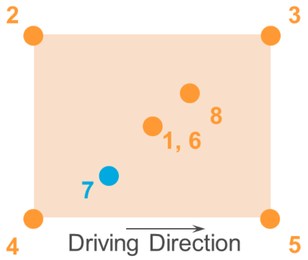
*Pairwise Mann-Whitney tests as data is not normally distributed for locations 1, 3, 7

MAIN STUDY

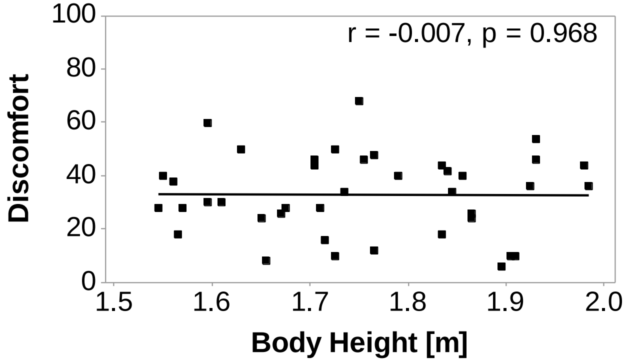
Result and conclusion of subjective evaluation

- Influence of body height on discomfort depends on handbrake location

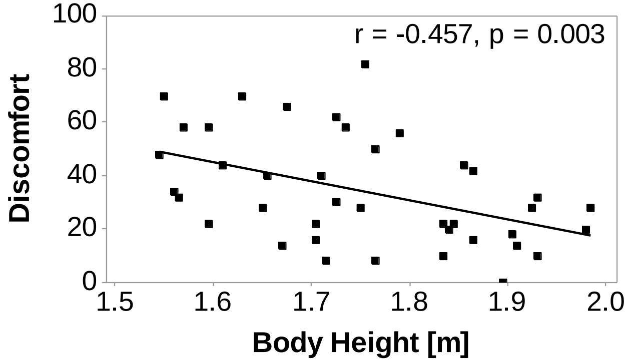




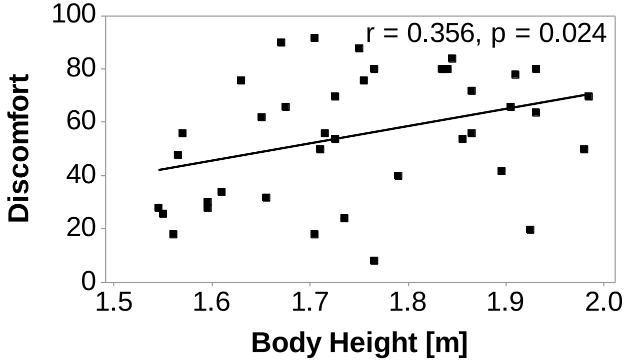
Handbrake Location 8 (mid preliminary study)



Handbrake Location 4 (rear down)



Handbrake Location 5 (fore down)

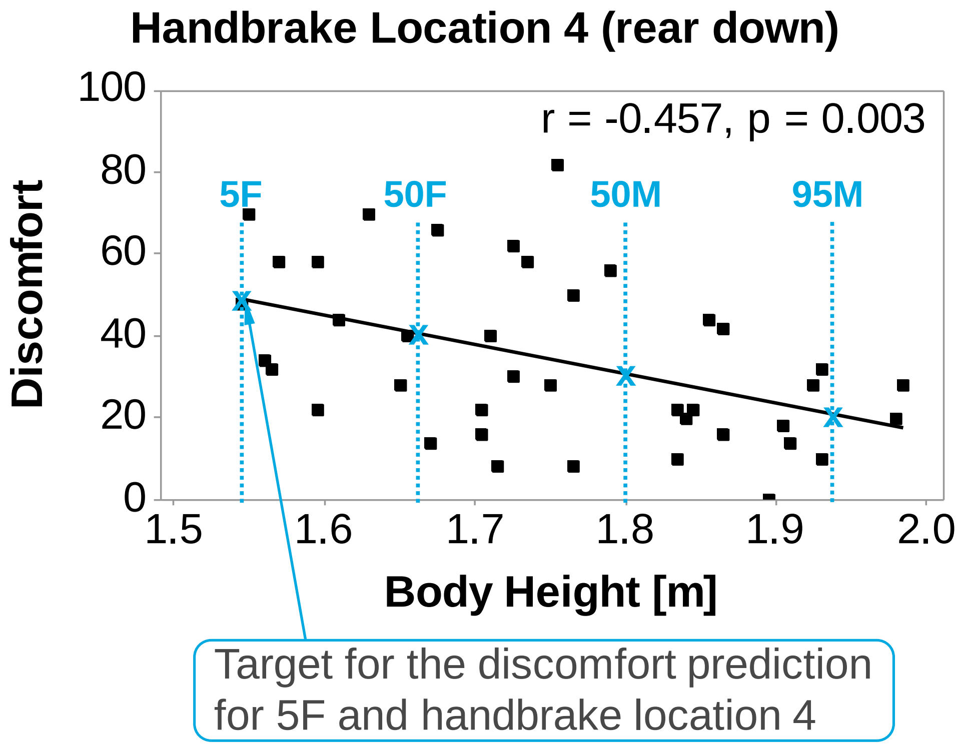


Go Further

MAIN STUDY

Results and conclusions for subjective evaluation

- Targets for the discomfort prediction:
  discomfort values as suggested by regression line for key body height percentiles
  - 5th percentile female (5F), 50th percentile female (50F)
  - 50th percentile male (50M), 95th percentile male (95M)



Target for the discomfort prediction for 5F and handbrake location 4

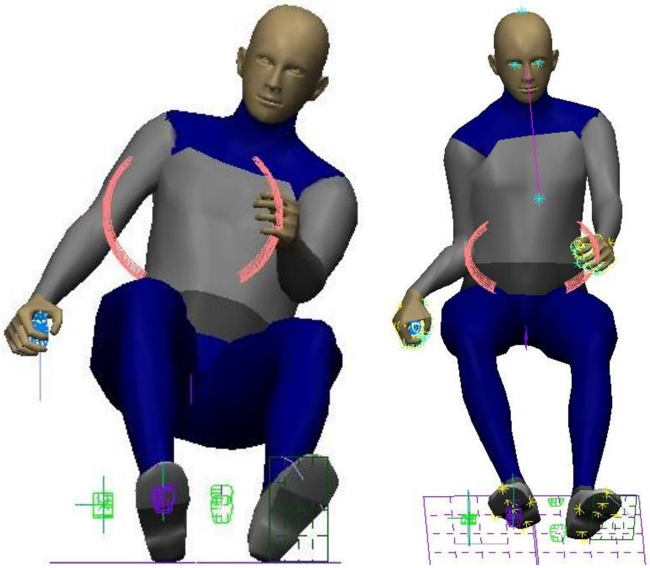
POSTURE MODELING

RAMSIS

- RAMSIS is a digital 3D human model
- Anthropometric and posture models
- Utilized by most global automotive manufacturers

Posture prediction for handbrake application (Raiber, 2015)

- Car driver posture prediction model ➔ unrealistic postures



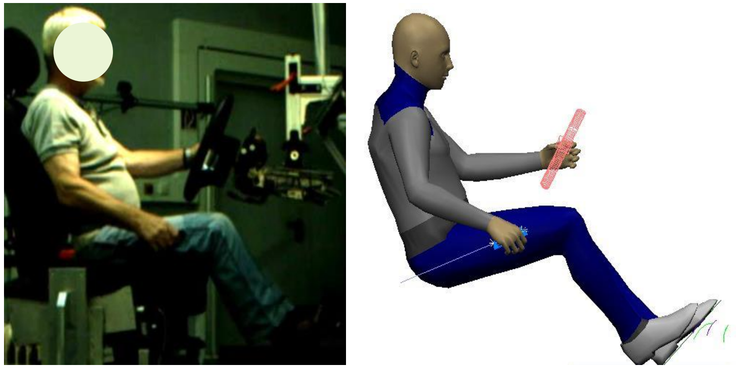
Go Further

POSTURE MODELING

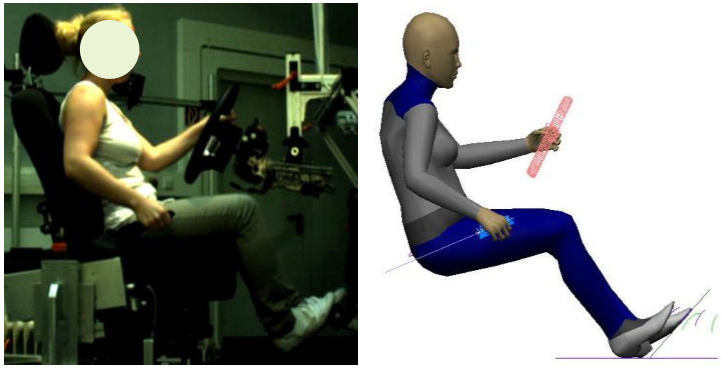
Development of user defined posture prediction models (UDPM) (Raiber, 2015)

- For each key percentile
- Single set of constraints for all percentiles and handbrake locations, start and end

➔ **Successful posture prediction**



Subject posture and prediction (50M)



Subject posture and prediction (50F)

BIOMECHANICAL MODELING

AnyBody Modeling System (AMS)

- Musculoskeletal model
- Rigid body model with 93 rigid bodies (bones), 77 joints and 1114 muscle elements
- Selection of model details, kinematic analyses, inverse dynamics to calculate biomechanical parameters

Model and settings selection

Postures, time constraints, external load

Kinematic analysis

Inverse Dynamics analysis

Biomechanical parameters

AMS modeling process

BIOMECHANICAL MODELING

Model	Selection	Reason
Body model	AAUHuman full body model including Arm and shoulder model, Trunk model (neck Modeled rigid), LegTLEM model	▪ Meets requirements for scope of the study ▪ More complex leg/foot model not required
Muscle model	AnyMuscleModel (strength independent from the actual length and contraction velocity of the muscle)	▪ More robust results than the 3E muscle model (Koch, 2013) ▪ Handbrake application corresponds to relatively low speed and non-extreme muscle length
Geometrical scaling	Non-isometric scaling (cross section scaling of the bone depends on length and mass)	▪ More realistic than isometric scaling
Muscle strength scaling	Body mass scaling (muscle strength correlates to muscle cross-sectional area and mass)	▪ Subjects / corresponding manikins have normal weight ▪ Not required to consider body composition or further parameters
Muscle recruitment	Polynomial criterion with the power of three	▪ physiologically and mathematically reasonable ▪ Crowninshield & Brand (1981) and Arjmand & Shirazi-Adl (2006) found predicted muscle activities match EMG measurements
Application model	Car Driver Model	▪ Includes a model to simulate handbrake application

BIOMECHANICAL MODELING

AnyBody Modeling System (AMS)

- Musculoskeletal model
- Rigid body model with 93 rigid bodies (bones), 77 joints and 1114 muscle elements
- Selection of model details, kinematic analyses, inverse dynamics to calculate biomechanical parameters

Analyses of 214 biomechanical parameters (factors)

- 16 joint angles
- 132 muscle activities (% max. voluntary contraction)
- 49 joint reactions (section forces and moments)
- 11 joint moment measures (caused purely by muscles)
- 6 metabolic power and energy consumption values

Model and settings selection

Postures, time constraints, external load

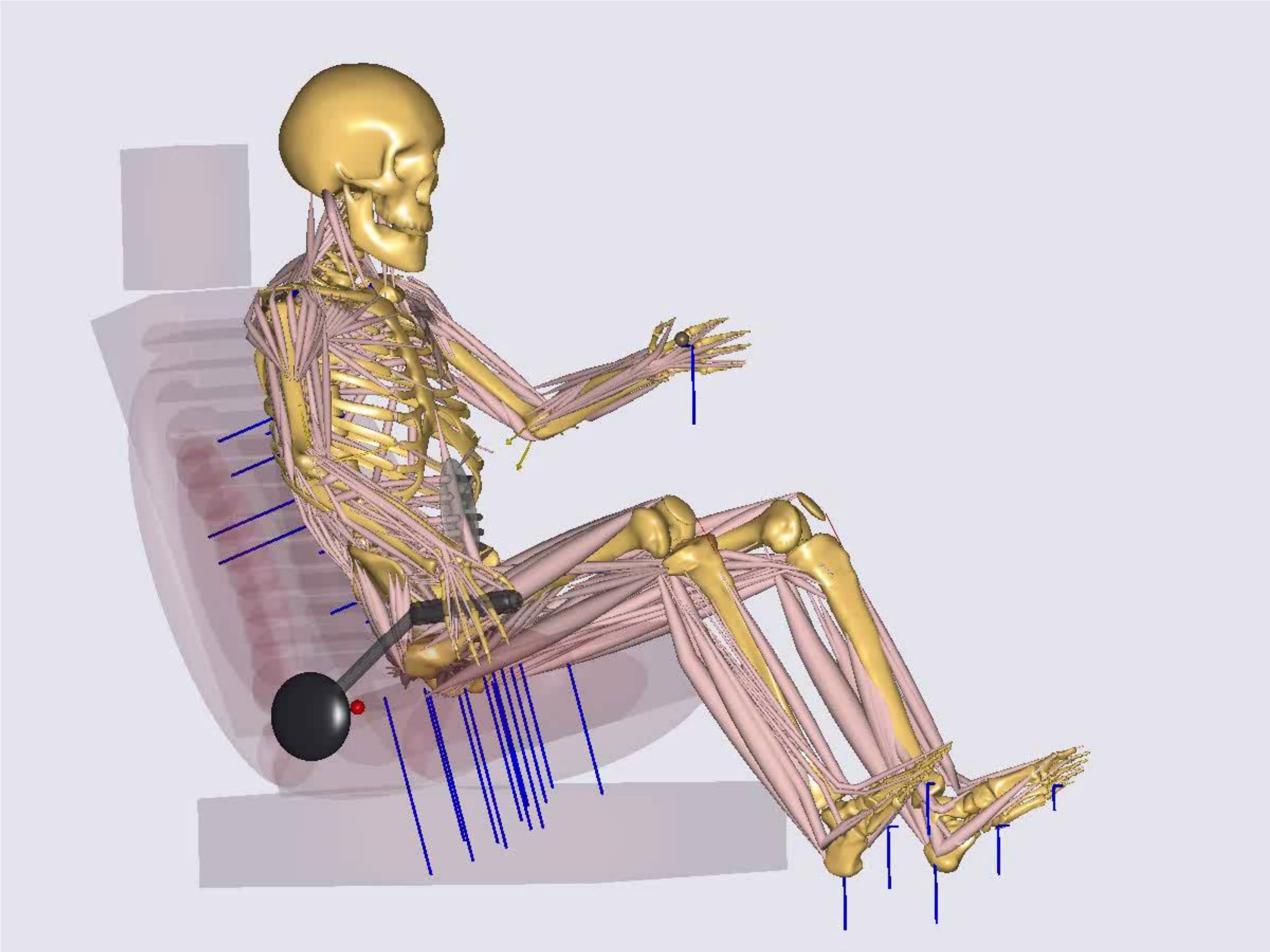
Kinematic analysis

Inverse Dynamics analysis

Biomechanical parameters

AMS modeling process

BIOMECHANICAL MODELING



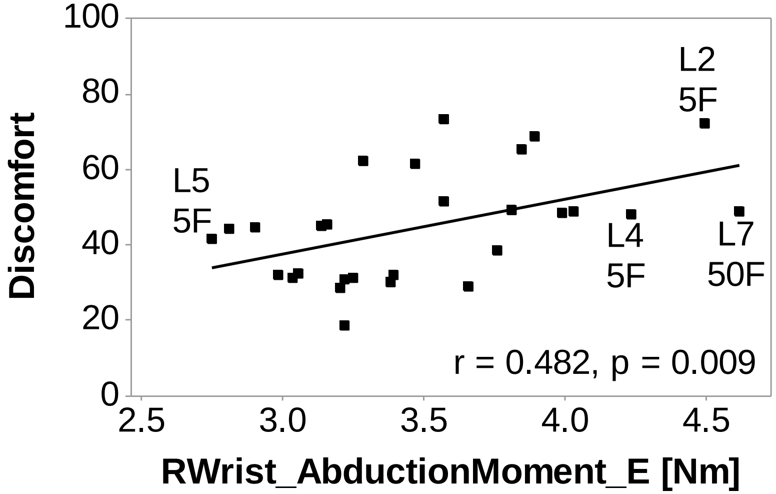
BIOMECHANICAL MODELING

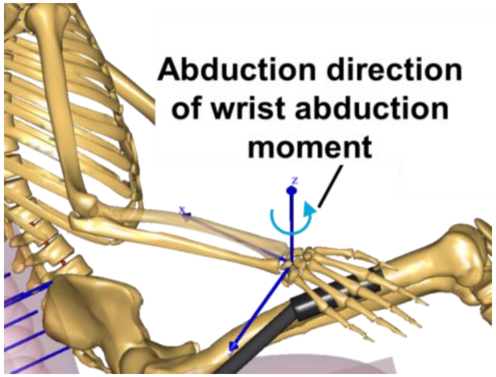
Analysis

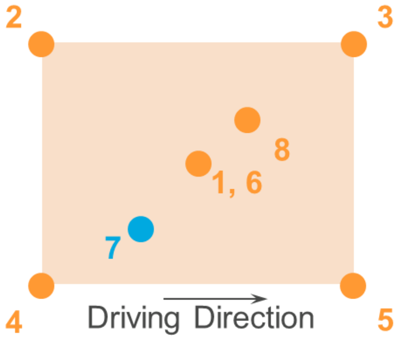
- Correlation of factors and their squared values to target discomfort
- For three time steps (start S, force F, end E), 7 handbrake locations, 4 key percentiles
- In each factor group: moderate to good ($0.54<r<0.72$) and highly significant ($p < 0.01$) correlations for best correlating factors

Example correlation

- Right wrist abduction moment at the end time step
- Abduction moment ↑ ➔ discomfort ↑







DISCOMFORT MODELING

Development of a discomfort prediction model by multiple regression

- Pre-selection of factors correlating significantly to discomfort
- Stepwise regression* with 200+ factors for 7 handbrake locations and 4 key percentiles
- Each steps leads to an increase of r^2_{adj} and a decrease of the standard error (S)
- 9 predictors, all with significant contribution
- $r^2 = 96.18$ % , $r^2_{adj} = 94.27$ %

Contribution to explanation of discomfort variation

- Joint reactions & joint moment measures, end time step: 82 %
- Joint angles, end time step: 7%
- Muscle activities and metabolic power values, start and force time step: 7%

Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
r^2 [%]	52.30	75.62	82.00	85.57	89.09	91.83	94.38	95.35	96.18
r^2_{adj} [%]	50.47	73.67	79.75	83.06	86.60	89.50	92.42	93.39	94.27
S	10.30	7.51	6.59	6.03	5.36	4.75	4.03	3.76	3.50

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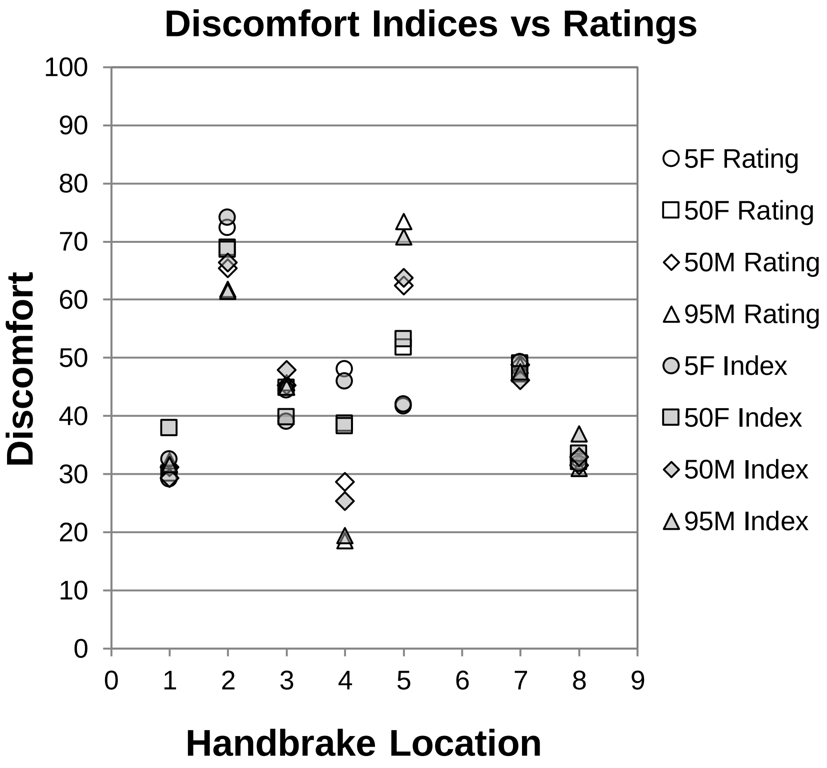
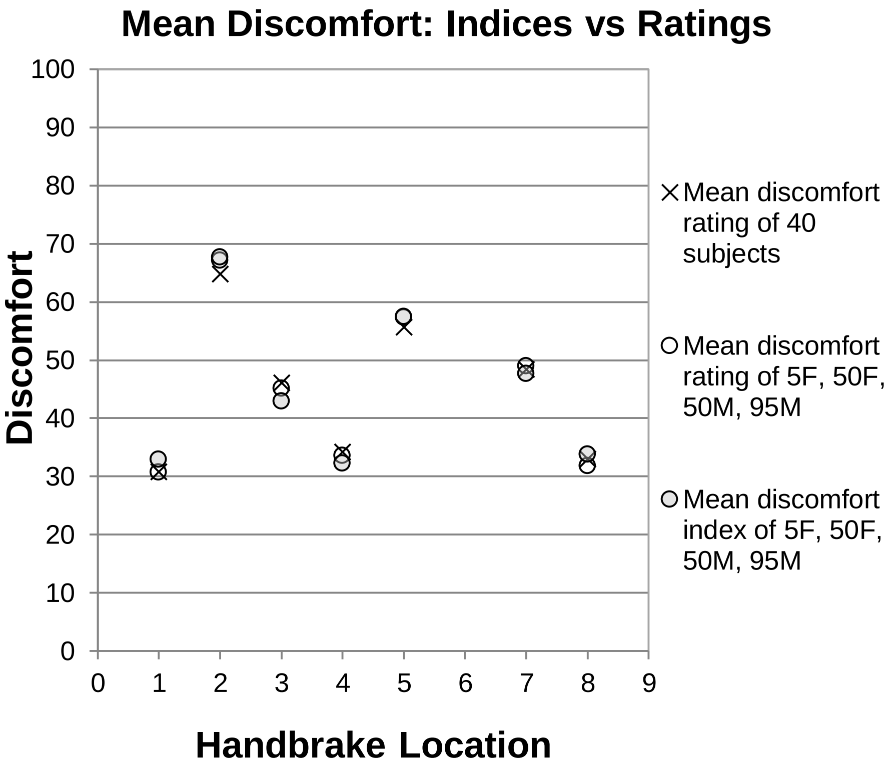
*„α to enter“ and „α to remove“: 0.1

DISCOMFORT MODELING

Prediction quality

- Good alignment of predicted discomfort (index) and study derived discomfort (rating)
- Mean discomfort index of 5F, 50F, 50M, 95M represents mean discomfort of subjects


Discomfort Indices vs Ratings


Mean Discomfort: Indices vs Ratings

RESULTS

Established procedure

Vehicle & handbrake geometry, force-travel curve of handbrake

↓

Posture modeling in RAMSIS for 5F, 50F, 50M, 95M

↓

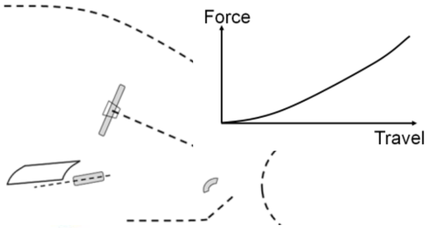
Modeling in AMS to calculate biomechanical parameters for 5W, 50W, 50M, 95M

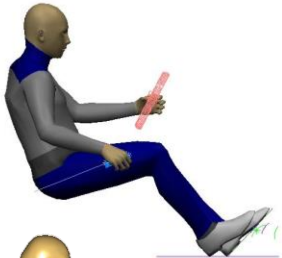
↓

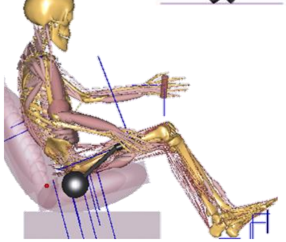
Calculation of discomfort with regression equation for 5F, 50F, 50M, 95M

↓

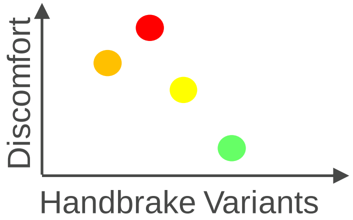
Comparison of different handbrake variants







$$Discomfort\ index = 34.3 + 3.67\ RElHuUl\_AxMom\_E + 0.000162\ RAcrCl\_InfSupFo\_E^2 + 10.2\ RWristAbdMom\_E + \ldots..$$



SUMMARY & CONCLUSIONS

Very good prediction quality ($r^2 = 96.18$, $r^2_{adj} = 94.27$)

- Comparison to literature
  - Discomfort, perceived muscle efforts
  - For reach to or application of control elements
  - Based on e.g. glenohumeral moment, joint angles, geometrical factors, body height
  - $r^2 = 0.5$ to 0.96 (Jung & Choe, 1996; Kee, 2002; Dickerson et al., 2006; Wang & Trasbot, 2011)

Successful development of a procedure

- To simulate handbrake application postures and predict discomfort
- By application of DHMs and mathematical modeling
- Procedure meets the requirements
  - Reliable and user-friendly
  - DHMs commonly used by automotive manufacturers

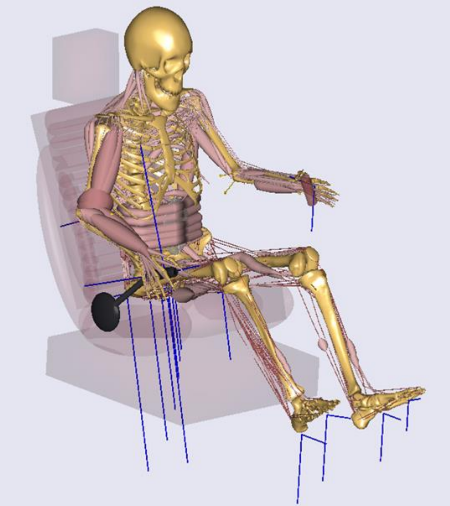
OUTLOOK

Application of established procedure in vehicle development

Aspect	Limitations of this study		Potential future research
Subjects	▪ 18 - 80 years ▪ BMI < 30 ▪ From Cologne	➡	▪ > 80 years, age groups ▪ BMI > 30 ▪ From other regions
Handbrake ▪ Location ▪ Design (geometry) ▪ Application force & angle	▪ Passenger vehicles ▪ Conventional ▪ Slight Slope	➡	▪ Commercial vehicles ▪ Unique ▪ Steep slope / max. angle
Control element	Handbrake	➡	Other control elements
Additional parameters	No measurement and simulation	➡	Measurement and simulation of additional parameters, study of their influence on discomfort

Go Further

THANK YOU
FOR
YOUR ATTENTION



Go Further

BACK-UP

BACK-UP

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