Will New Seating Positions Require New Occupant Restraints?

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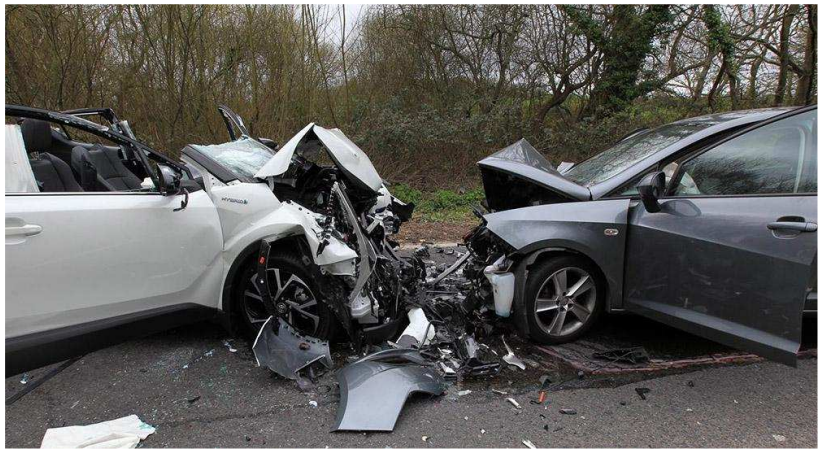
and partly in the two Swedish projects 2017-01945 *"**Assessment of Passenger Safety in Future Cars**"* and 2020-02943 *"**Car Passenger Safety – to the next level**"*, which has received funding from Vinnova, the Swedish Energy Agency, the Swedish Transport Administration and the Swedish vehicle industry through the Strategic Vehicle Research and Innovation (FFI) Program

The two Swedish projects are associated to SAFER, the Vehicle and Traffic Safety Centre at Chalmers

Introduction

Current Vehicles – “Known Problems”

- Many years research in accident data
- Prioritized accident types and load cases (still complex)
  - Front (head-on and oblique), side (barrier and pole), rear-end and pedestrian
  - Legal regulations & Consumer testing (NCAP)
- Developed methods and tools to assess and improve crashworthiness



Future Vehicles – “Unknown Problems”

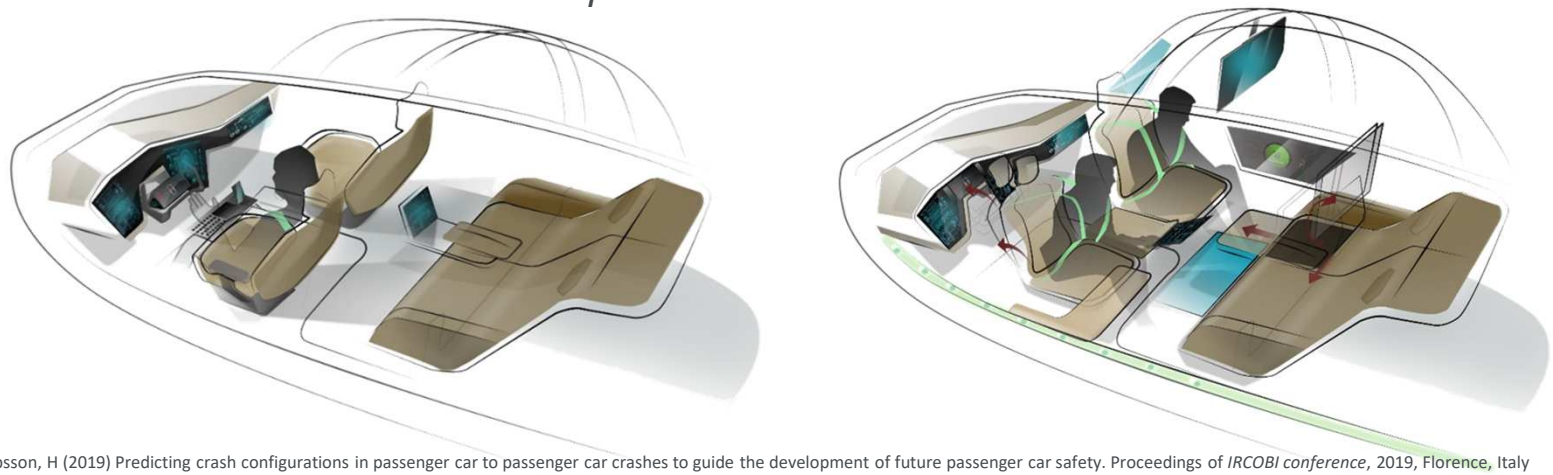
- Highly Automated Vehicles are still on concept level
- There are no accident data
- Can’t prioritize data that don’t exist

We must find methods to predict potential crash scenarios and crash configurations

- Current tools and methods need to be developed and validated

➔ **Potential new ways to assess occupant protection: Virtual Testing**

Conceptual interiors of future vehicles



[1] Östling, M, Lubbe, N and Jeppsson, H (2019) Predicting crash configurations in passenger car to passenger car crashes to guide the development of future passenger car safety. Proceedings of *IRCOBI conference*, 2019, Florence, Italy
[2] Östling, M, Lubbe, N and Jeppsson, H (2019) Predicted crash configurations for Autonomous Driving vehicles in mixed German traffic for the evaluation of occupant restraint system. *VDI-Conference “Vehicle Safety”* 27th and 28th November 2019 in Berlin

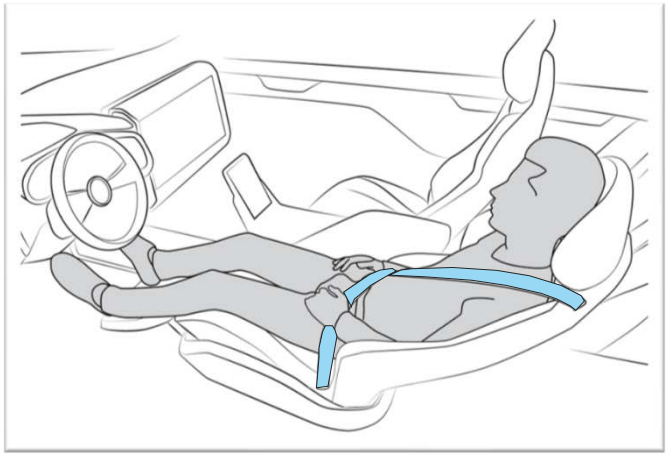
To Save Lives in the Future, We Need To

Identify Operational Design Domain (ODD) including:

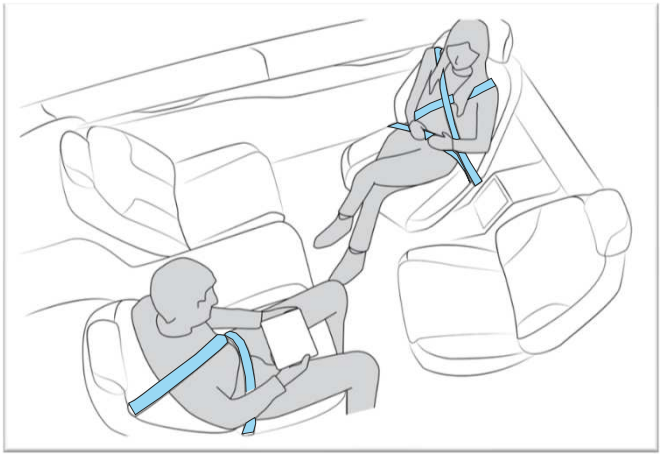
- Operational traffic conditions (Highway, Urban, Rural)
- Understand what type of crashes future vehicle will be exposed to
- **Understand what seated positions the end-user wants**

➔ **Protect all occupants in any alternative planned seating position and selected posture(s)**

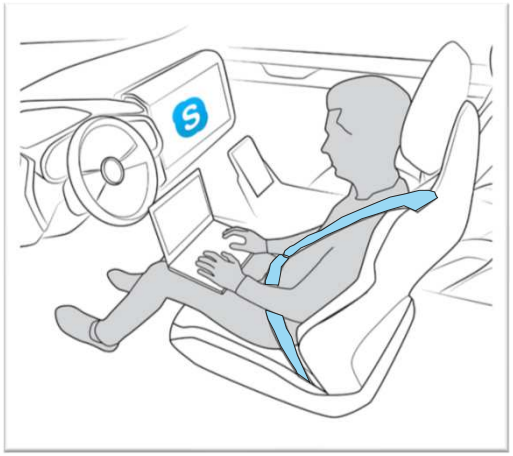
Relaxing



Socializing – Rotated seats



Working



[3] The U.S. Department of Transportation's: Automated driving systems 2.0 a vision for safety, September 2017.

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Understand what seated positions the end-user wants

Volunteer studies of the expectations of future vehicles (Sweden and China)

- Comfortable seat with reclined seat back
- Interior with versions of living room seating
- During user studies exploring recline seating, it was observed that:
  - Willingness to recline increase, from 20-25° to 40-45°, with more comfort seats (leg rest and possibility to tilt the seat pan)
  - Reclined positions often led to a lap belt that was placed above the pelvis
  - This unfavourable lap belt position increase the risk for submarining during frontal collisions

[4] Jorlöv, S. et al. (2017) Seating Positions and Activities in Highly Automated Cars – A Qualitative Study of Future Automated Driving Scenarios." In Proceedings of IRCOBI conference. Antwerp, Belgium 2017
[5] Östling M and Larsson A. Occupant Activities and Sitting Positions in Automated Vehicles in China and Sweden. Enhancement of Safety Vehicles (ESV) Eindhoven, Netherlands., June 2019.
[6] Hagberg A and Jodlovsky S. Reclined seating positions for level 4 HAD vehicles A comfort and safety approach. Master Thesis at Chalmers University Sweden 2017

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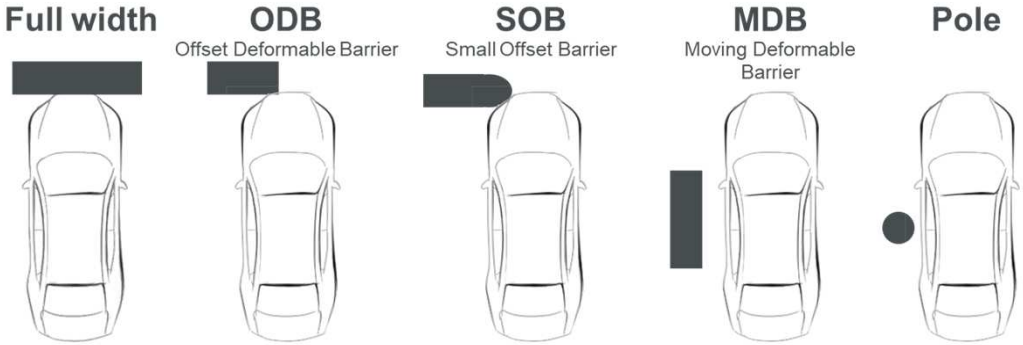
Occupant Protection: Today and Tomorrow

Today

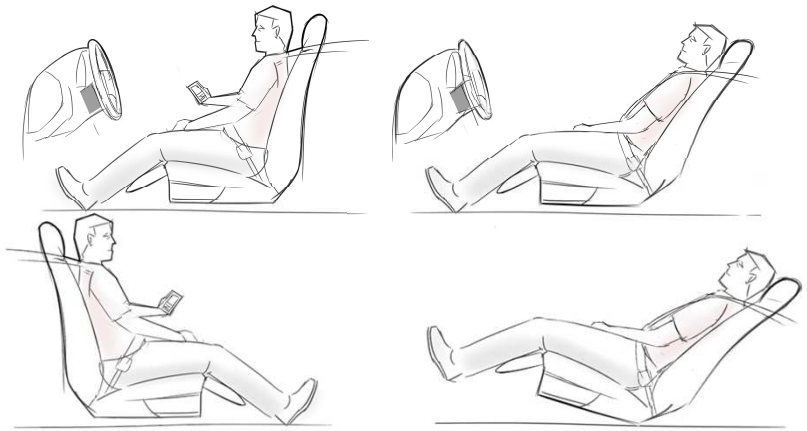
Standardised ATD position

Traditional crash configurations

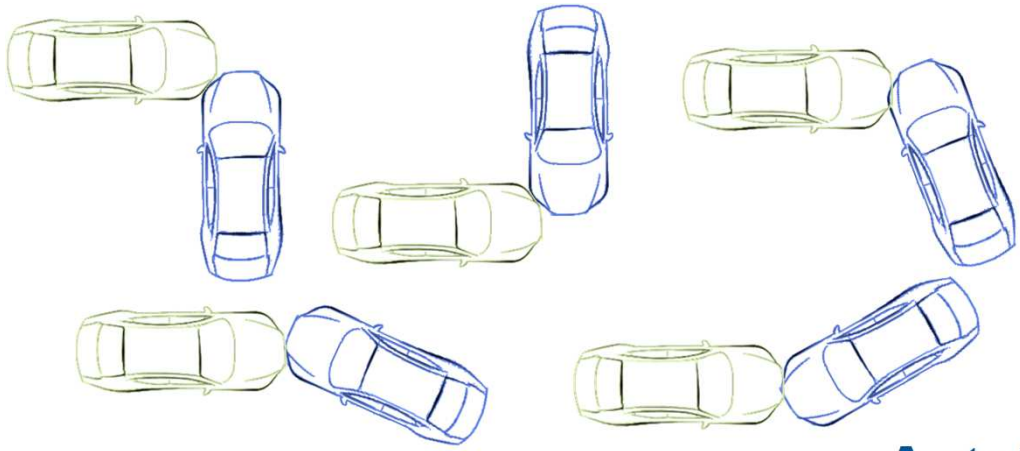


Tomorrow

New seating positions



Potential new crash configurations



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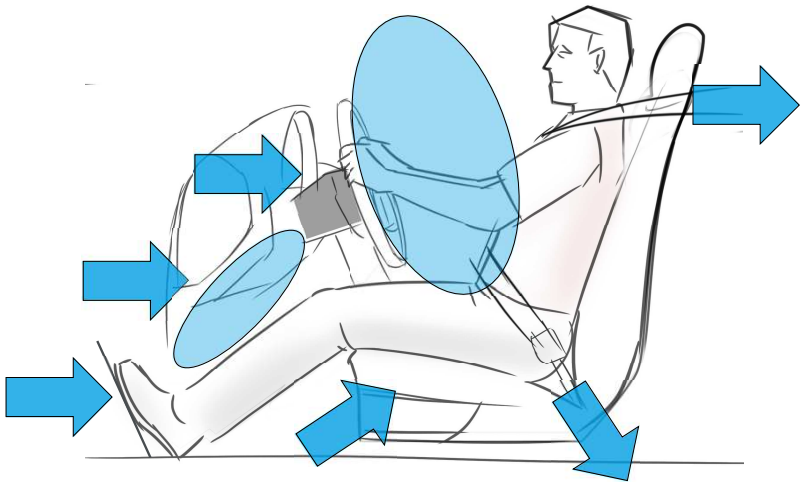
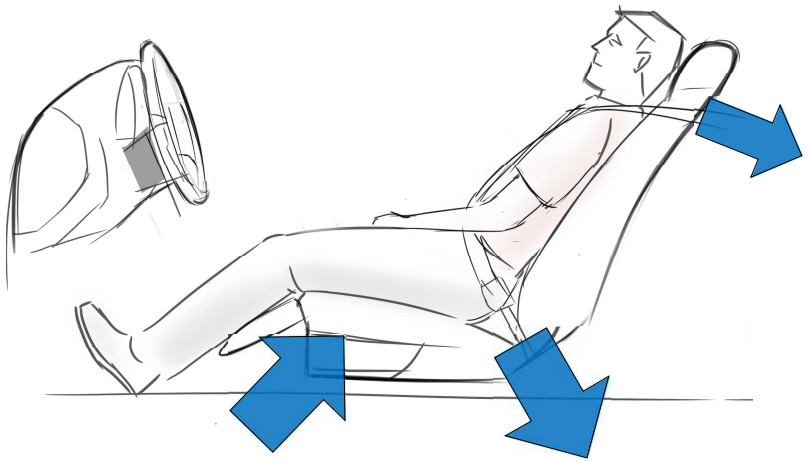
Identified risks with new seating positions

Identified risks with new seating positions

Today's seating position and restraint system

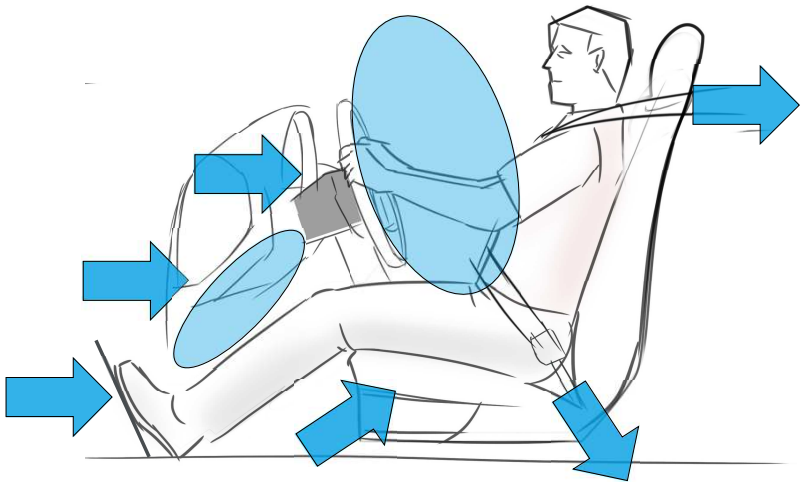


Tomorrow's seating position and restraint system

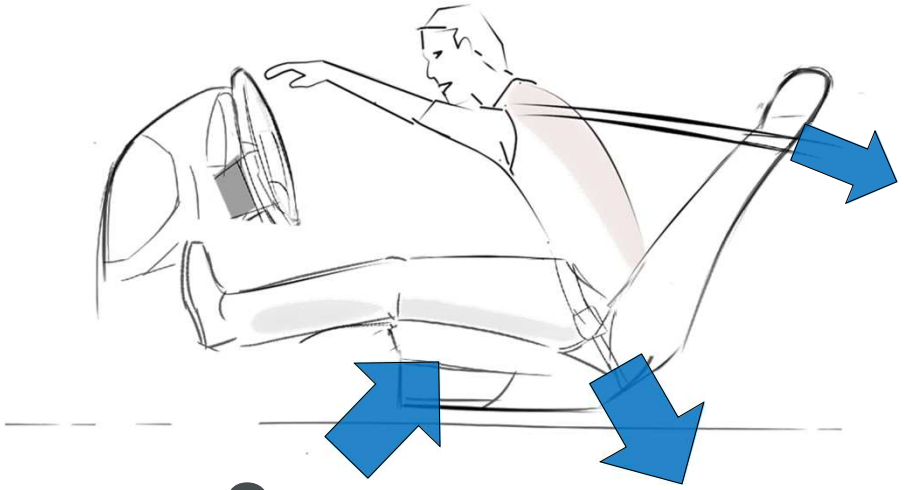


Identified risks with new seating positions

Today's seating position and restraint system



Tomorrow's seating position and restraint system



Consequences?

Identified risks with new seating positions

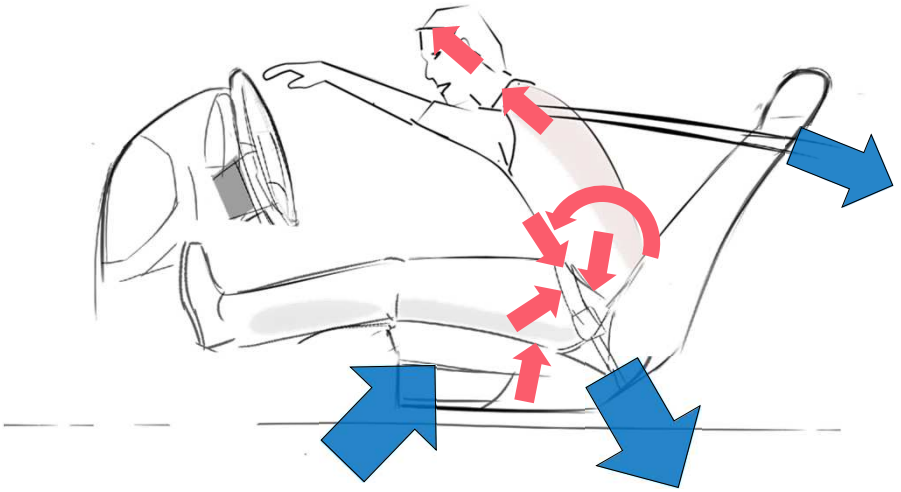
I. Reclined posture with a rearward rotated pelvis increases the risk of submarining

II. Reclined upper body and absence of a knee bolster that support the lower body increase the forces to the lumbar spine

III. and pelvis

IV. Absence of head restraining airbags increase head accelerations and neck tension forces

V. Body dynamics may induce compression forces in the neck



Risk Mitigation

Part I Submarining

Submarining

Several parameters influence the risk of submarining:

- Initial position of the occupant
  - Example slouched or reclined seated posture
- Initial slack in the belt system, pretensioner
  - Electrical and pyrotechnical
- The relative position between the lap belt and the occupant
  - Example position of the lap belt anchorages or shape of the abdomen
- Seat pan design, geometry and stiffness
- Knee bolster (or knee airbag)
- **Individual variation in seated position (pelvis angle) and pelvis shape**
- **Crash severity where submarining is more likely in high speed crashes**

[7] Leung Y. et al. (1982). Submarining Injuries of 3 Pt. Belted Occupants in Frontal Collisions—Description, Mechanisms and Protection. SAE Transactions
[8] Richard O. et al. (2015) "Occupant restraint optimisation in frontal crash to mitigate the risk of submarining in out-of-position situation" Proceedings of the IRCOBI Conference Lyon, France 2015.
[9] Richardson R. et al. (2020) Pelvis Kinematics and Injuries of Reclined Occupants in Frontal Impacts. Proceedings of the IRCOBI Conference, Munich, Germany, 2020.
[10] Richardson R. et al. (2020) Kinematic and Injury Response of Reclined PMHS in Frontal Impacts. Stapp Car Crash Journal, Vol. 64, November 2020.
[11] Izumiyama T. et al (2018). The Analysis of an Individual Difference in Human Skeletal Alignment in Seated Posture and Occupant Behavior Using HBM. Proceedings of IRCOBI conference, Athens, Greece 2018.
[12] Poplin G.S. et al. (2015) Nature and etiology of hollow-organ abdominal injuries in frontal Crashes. 2015, Accident Analysis and Prevention 78, 51–57

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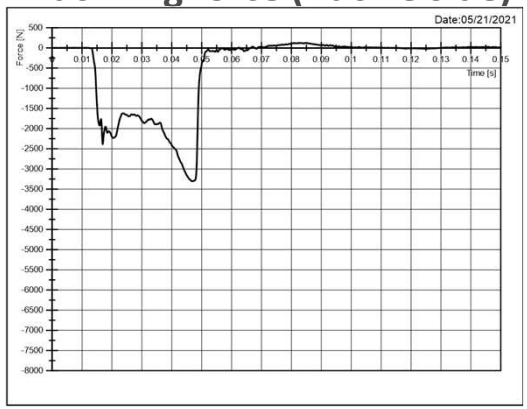
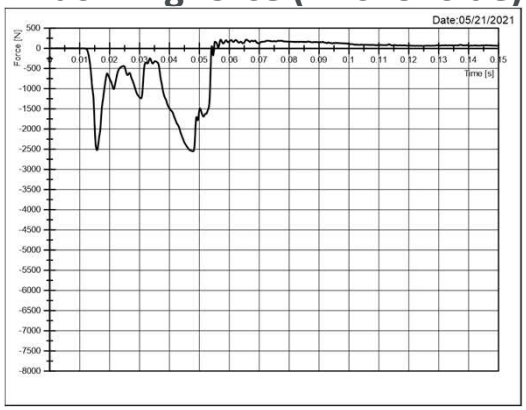
Reclined Posture, Shoulder and Lap Belt Pretensioner

Technical definition of submarining by Euro NCAP AOP 9.1.2:
"*The modifier is applied when a sudden drop in any of the two iliac forces measured is seen within 1ms and when the submarining is confirmed on the high-speed film*"

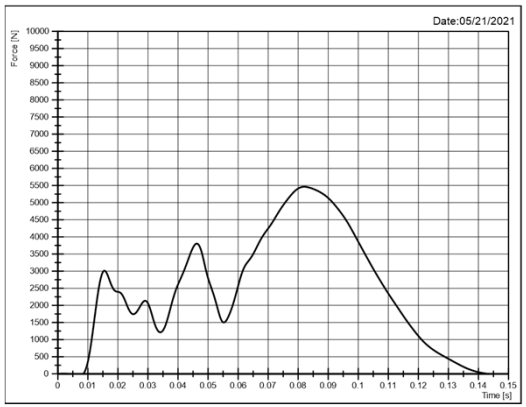
Iliac wing force (Buckle side)



Iliac wing force (Anchor side)



Lap belt force measured at anchor side



[13] Östling M et al. (2017) Potential future seating positions and the impact on injury risks in a Learning Intelligent Vehicle (LIV). VDI-Tagung Fahrzeugsicherheit, Berlin, Germany 2017.

2017

Reclined Posture, Shoulder and Lap Belt Pretensioner

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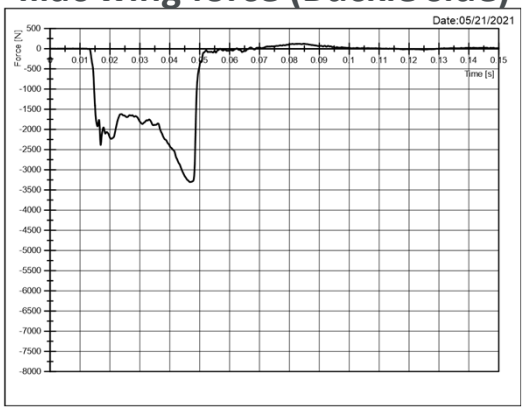
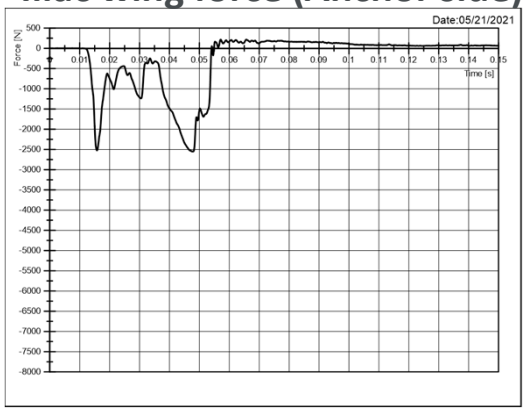
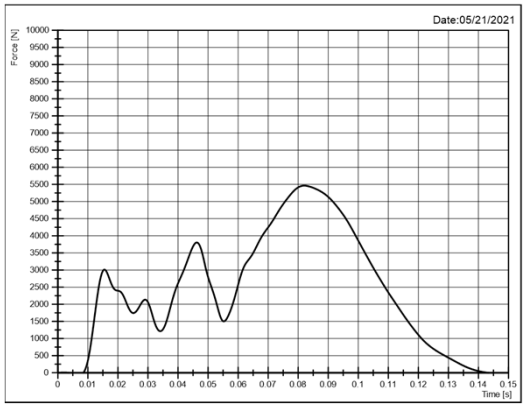
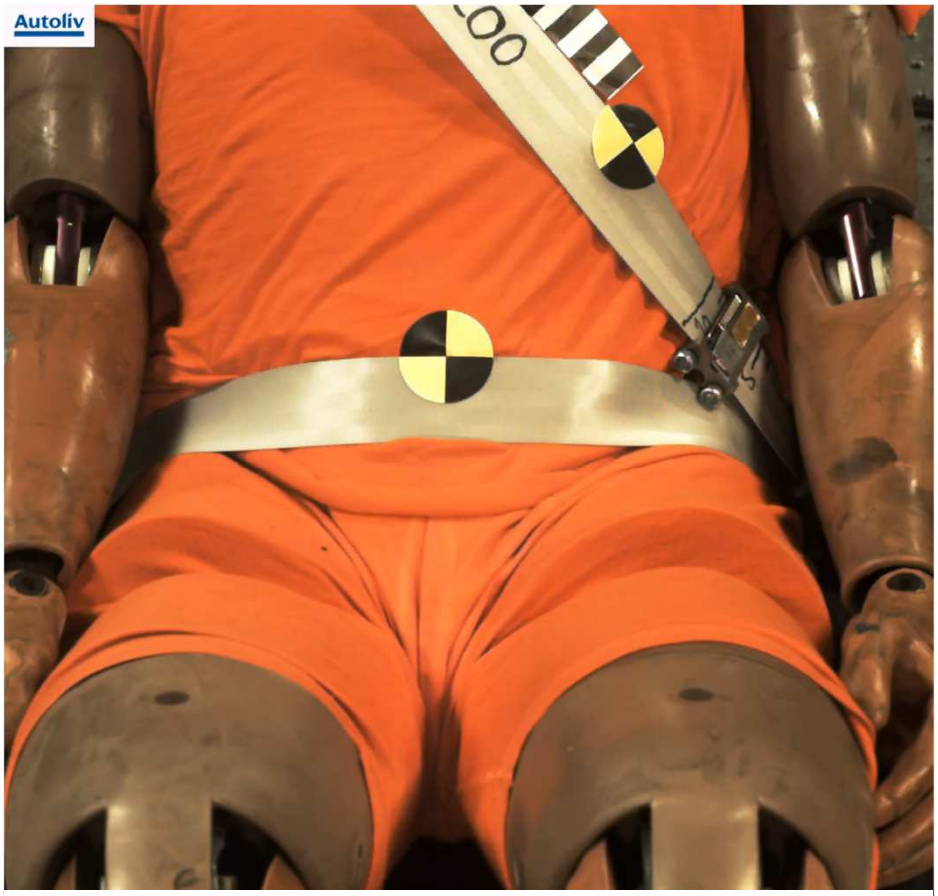


Iliac wing force (Anchor side)



Lap belt force measured at anchor side





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2017

Reclined Posture, Shoulder and Double Lap Belt Pretensioner

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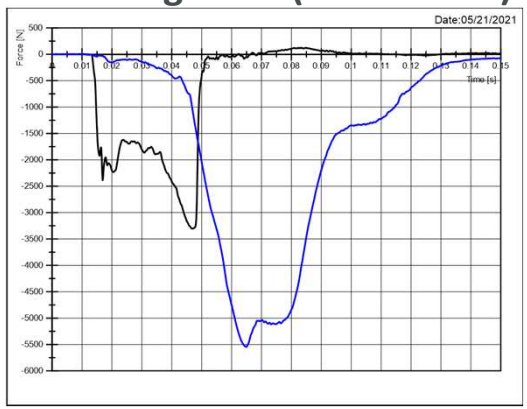
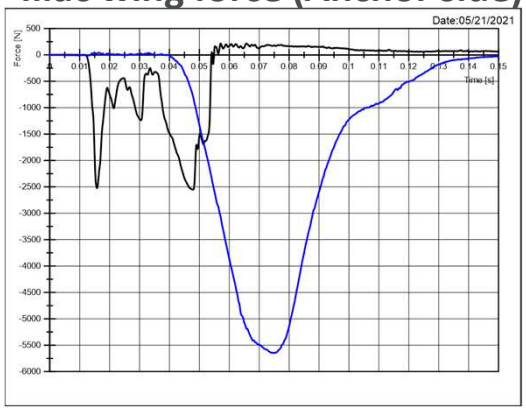
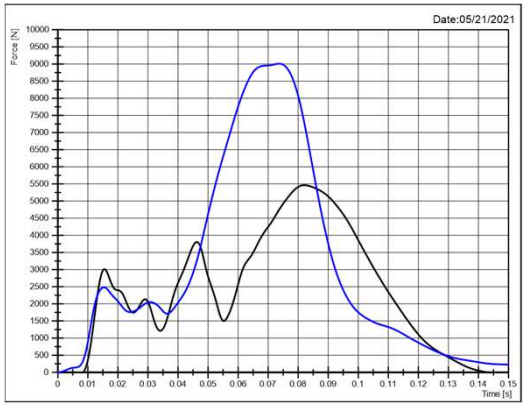
Iliac wing force (Buckle side)



Iliac wing force (Anchor side)



Lap belt force measured at anchor side



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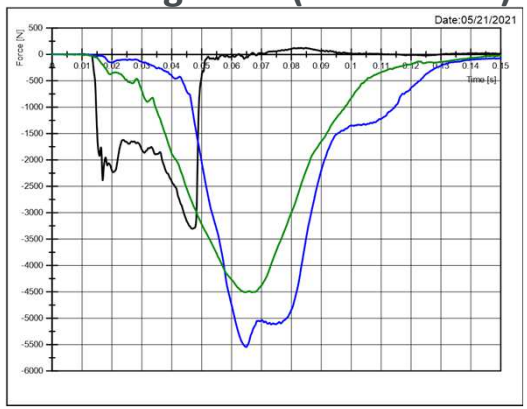
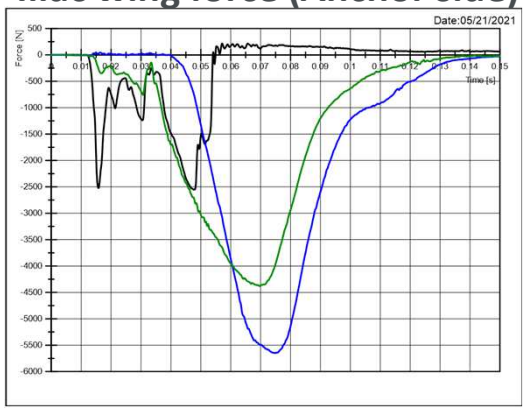
Reclined Posture, Shoulder and Double Lap Belt Pretensioner + PRC 2017

Technical definition of submarining by Euro NCAP AOP 9.1.2:
"*The modifier is applied when a sudden drop in any of the two iliac forces measured is seen within 1ms and when the submarining is confirmed on the high-speed film*"

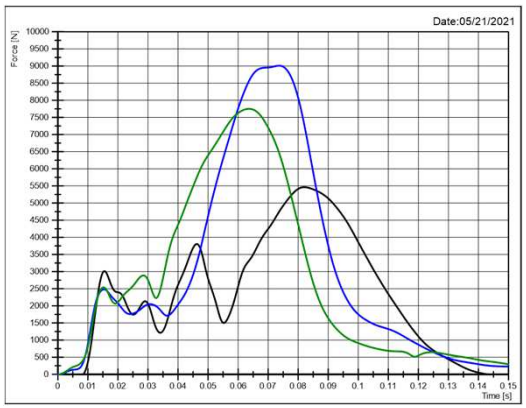
Iliac wing force (Buckle side)

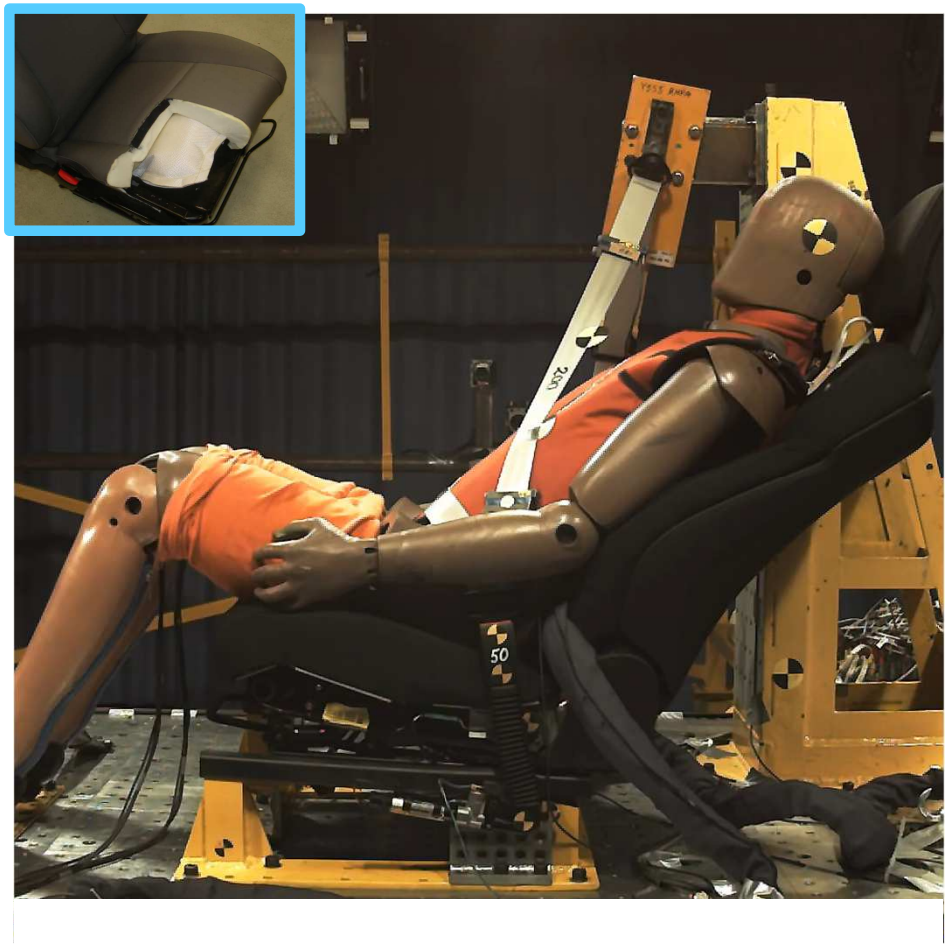


Iliac wing force (Anchor side)



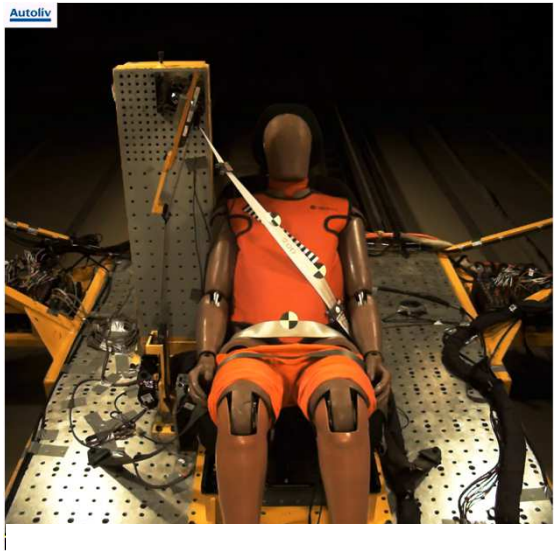
Lap belt force measured at anchor side





Conclusion – THOR 50M Testing

- We have identified a risk, proposed a solution and evaluated it in mechanical sled test with THOR 50M
  - Submarining can be avoided with double lap belt pre-tensioner
  - High lap belt force and long pelvis displacement can be reduced with pelvis restrain cushion (PRC)
- Are we done?
  - THOR is not a human
  - What about the loading to the spine and pelvis?
  - Development of a generic test set-up with a seat integrated belt

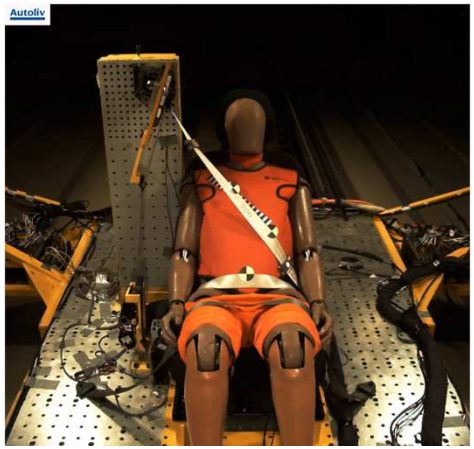


Risk Mitigation

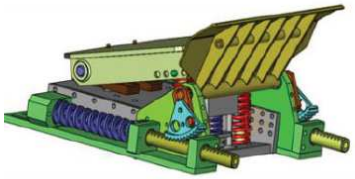
Part II Lumbar Spine and Pelvis

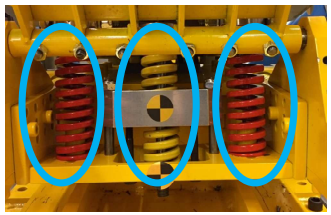
Development of Generic Test Set-up

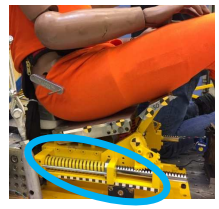
- Production seat
- B-pillar mounted belt guide



- Generic semi rigid seat, tuneable geometry and stiffness (Uriot et al. 2015)
- Seat integrated belt guide







[14] Uriot J et al. (2015) Reference PMHS Sled Tests to Assess Submarining. Stapp Car Crash Journal. Vol 59, 2015.

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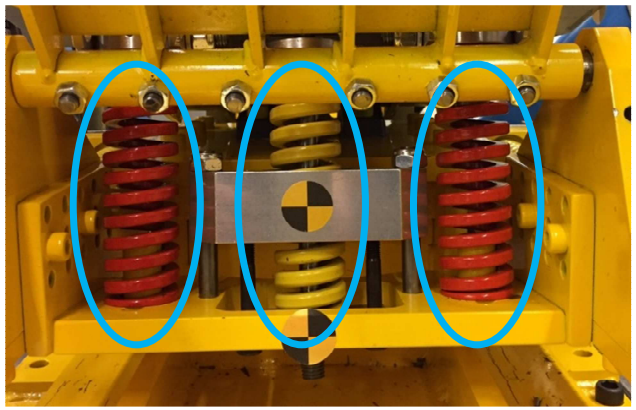
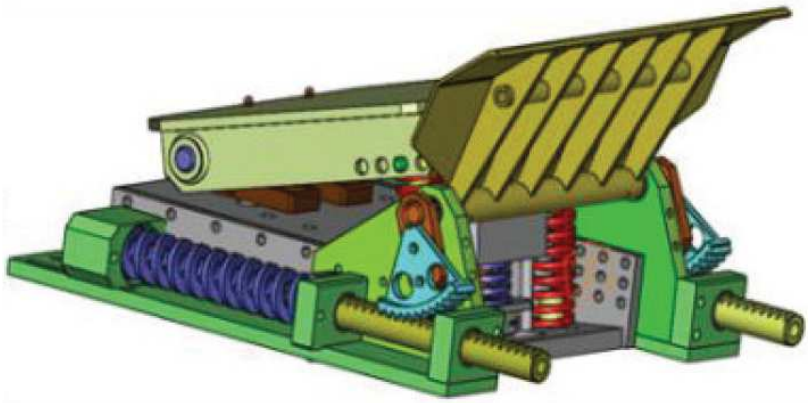
Development of Generic Test Set-up

2018

Model	Seat Pan Side Springs	Seat Pan Center Spring	Anti Submarining Ramp Springs
Default från Uriot et al. 2015	123 N/mm	365 N/mm	123 N/mm
Autoliv physical test set-up	**132 N/mm**	**379 N/mm**	**128 N/mm**





[14] Uriot J et al. (2015) Reference PMHS Sled Tests to Assess Submarining. Stapp Car Crash Journal. Vol 59, 2015.

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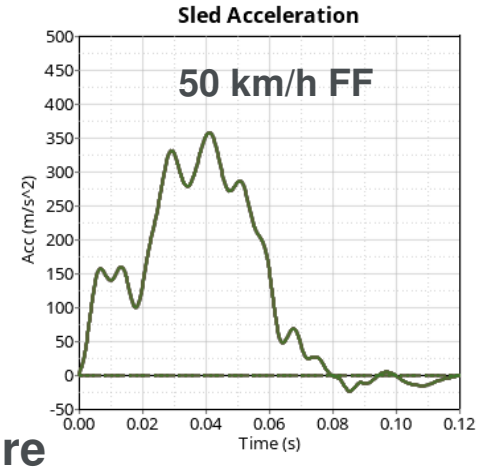
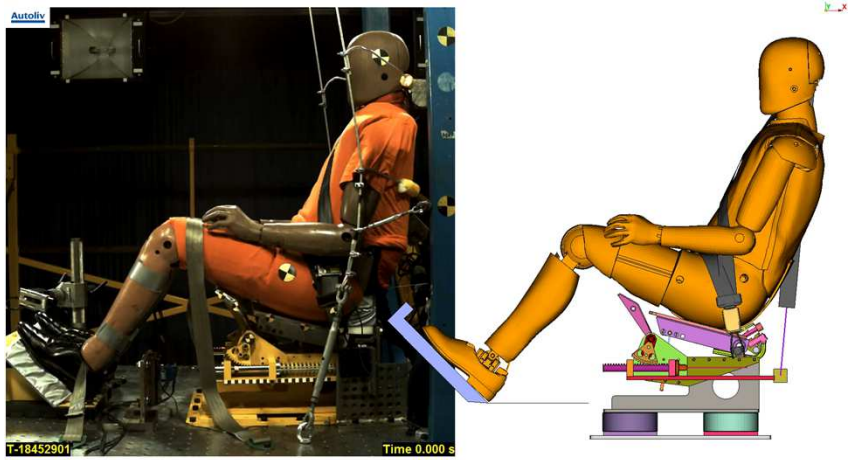
Development of Generic Test Set-up

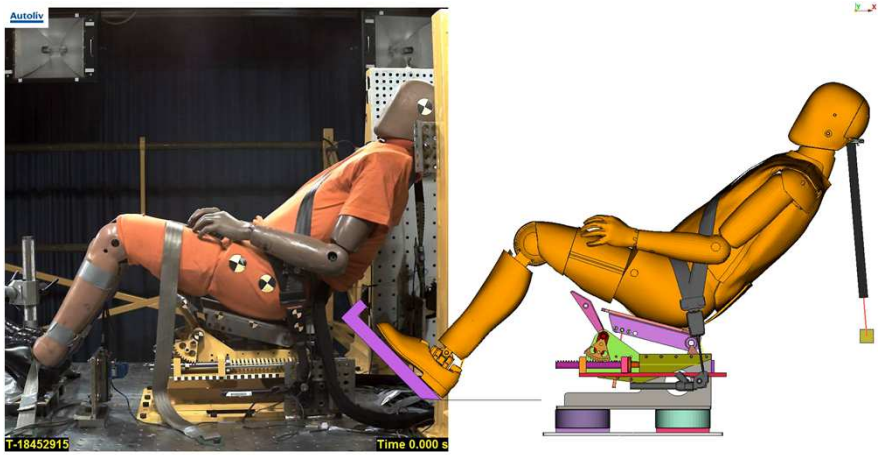
- Sled test with HIII M50 and THOR M50: upright and reclined
- CAE model validated to upright and reclined THOR 50M tests



Upright posture



Reclined posture



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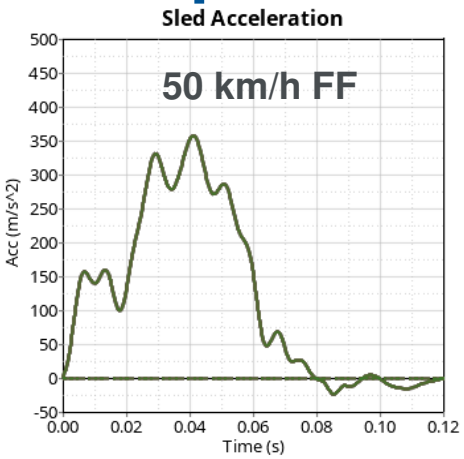
2019

UVA PMHS in Reclined Postures in a Generic Test Set-up

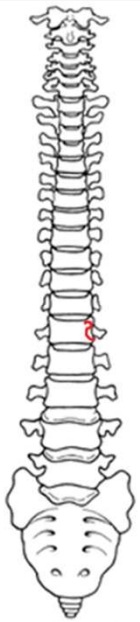
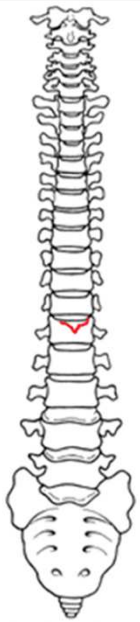
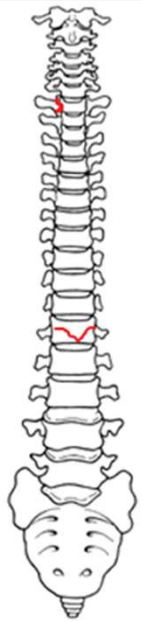
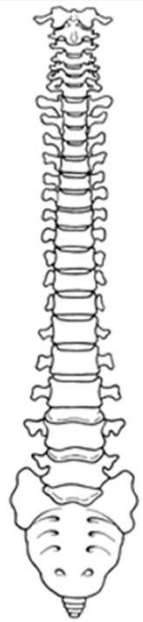
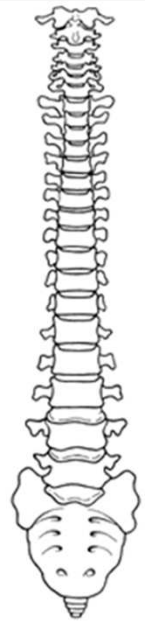
Aim:

- Verify “anti-submarining belt system” for humans
- Evaluate risks for lumbar spine and pelvis fractures
- (Generate kinematic data for HBM and ATD evaluations)



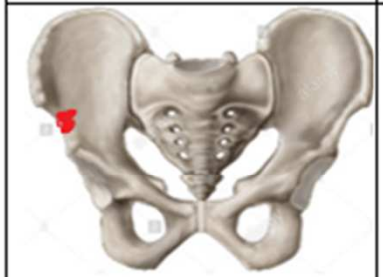
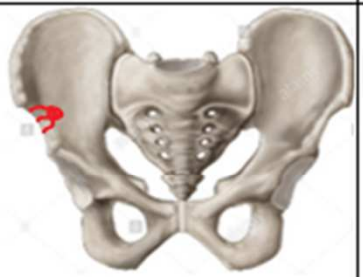
[15] Richardson R. et. al (2019) Test methodology for evaluating the reclined seating environment with human surrogates. The 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Eindhoven, Netherlands, June 10-13, 2019.

Recorded injuries spine: L1 fractures

Age	66	53	72	25	55
	S0529	S0530	S0531	S0532	S0533
	930	630	901	662	815
					
	3 column burst fracture at L1	Single column compression fracture at L1	Two column burst fracture at L1 Transverse process fracture at T1/T2		

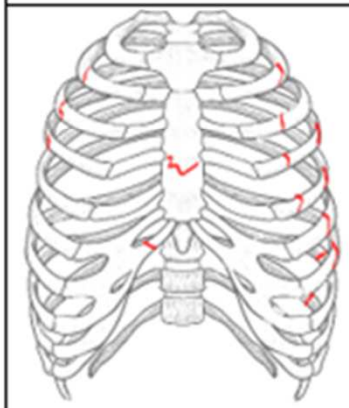
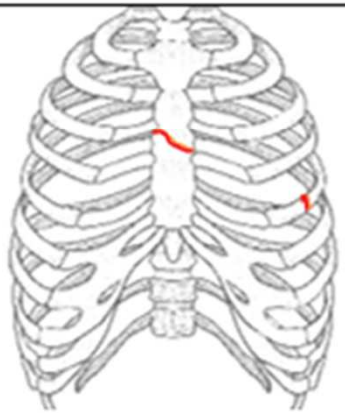
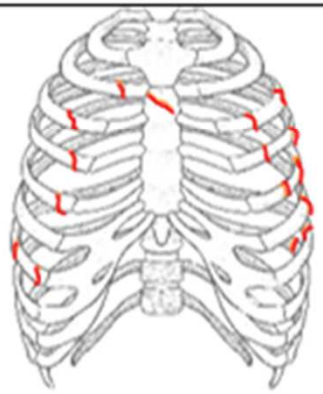
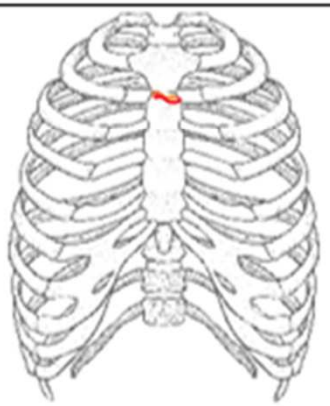
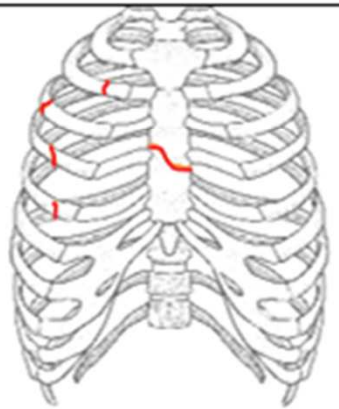
[10] Richardson R et al. (2020) Kinematic and Injury Response of Reclined PMHS in Frontal Impacts. Stapp Car Crash Journal, Vol. 64, November 2020.

Recorded injuries pelvis: Iliac wing fractures

Age	66	53	72	25	55
	S0529	S0530	S0531	S0532	S0533
	930	630	901	662	815
					
	Comminuted displaced fracture of right anterior iliac wing involving both ASIS and AIIS		Comminuted displaced and apex medially angulated fracture of right anterior iliac wing involving both ASIS and AIIS		

[10] Richardson R et al. (2020) Kinematic and Injury Response of Reclined PMHS in Frontal Impacts. Stapp Car Crash Journal, Vol. 64, November 2020.

Recorded injuries chest: Sternum and rib fractures

Age	66	53	72	25	55
	S0529	S0530	S0531	S0532	S0533
	930	630	901	662	815
					
	23 rib fractures Sternal fracture	1 fracture Sternal fracture	18 rib fractures Sternal fracture	No rib fractures Sternal fracture	6 rib fractures Sternal fracture

[10] Richardson R et al. (2020) Kinematic and Injury Response of Reclined PMHS in Frontal Impacts. Stapp Car Crash Journal, Vol. 64, November 2020.

Conclusion – PMHS testing

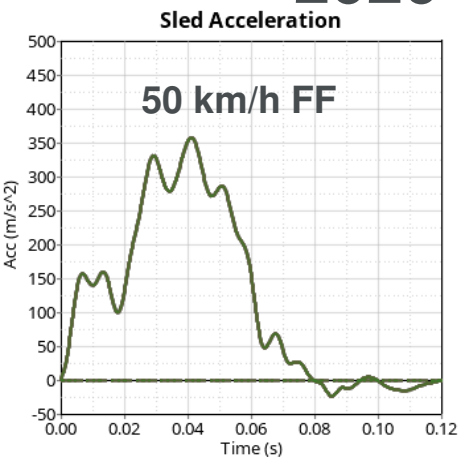
- Submarining can be avoided but then
  - Fractures to: lumbar spine and pelvis (sternum, ribs)
  - (No cervical spine fractures)
- New challenge: Evaluate and minimize risk for new injuries
  - Create and validate the right tools
  - Develop countermeasures for potential injuries related to reclined posture
  - (Develop injury risk functions for lumbar spine and pelvis fractures)
- (Initial position and kinematic corridors available to validate HBM in a new loading condition)

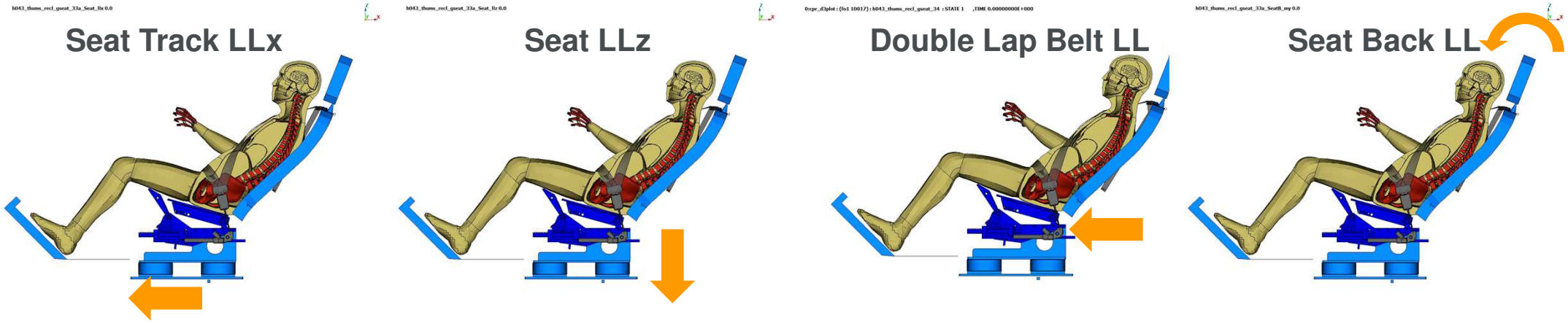
Evaluate influence of countermeasure

2020

SAFER HBM was correlated to the reclined PMHS tests

Investigation of the influence of four “conceptual” countermeasures to lumbar spine compression force and ASIS forces





[16] Mroz K. et al. (2020) Effect of Seat and Seat Belt characteristics on the Lumbar Spine and Pelvis Loading of the SAFER Human Body Model in reclined Postures. Proceedings of the IRCOBI Conference, Munich, Germany, 2020

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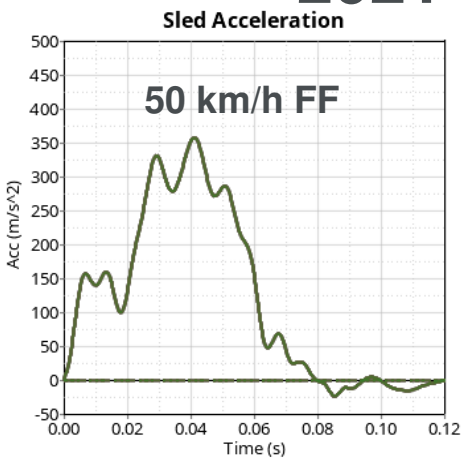
Seat track load limiter

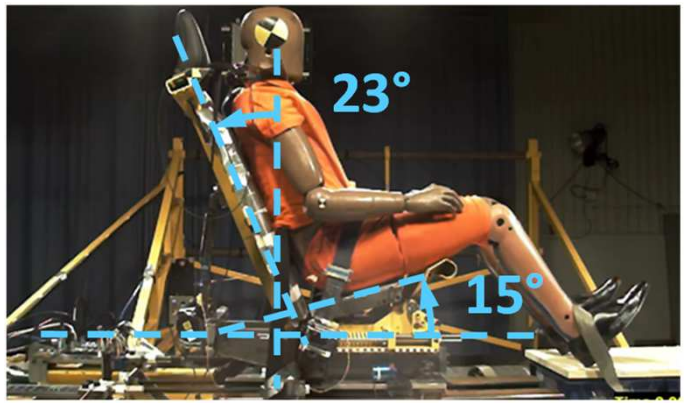
2021



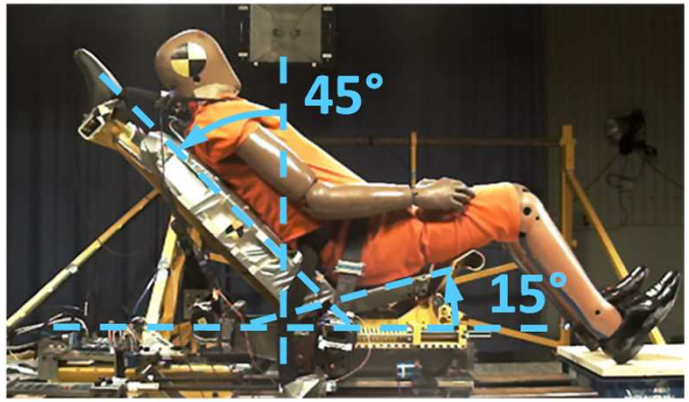
THOR-50M was used to evaluate the influence of a *seat track load liming* device on lumbar spine compression force in frontal impacts for three different seating positions

The target was to reduce the lumbar spine compression force for reclined occupants to same level of upright occupants, yet without increasing any other injury measurements

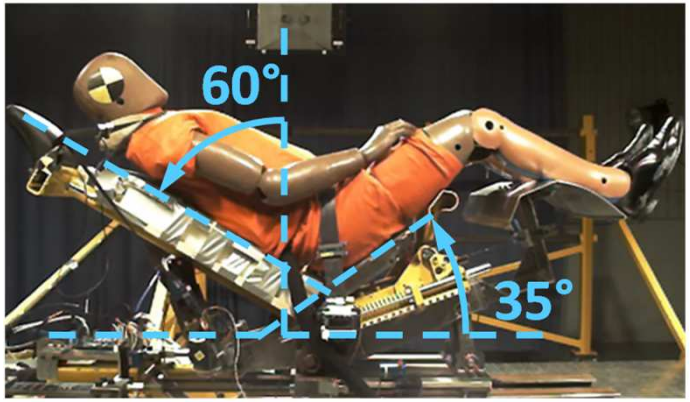
Upright



Reclined



Relaxed



[17] Östling M. et al. (2021) The Influence of a Seat Track Load Limiter on Lumbar Spine Compression Forces in Relaxed, Reclined, and Upright Seating Positions: A Sled Test Study using THOR-50M Under review for the IRCOBI Conference, Munich, Germany, 2021

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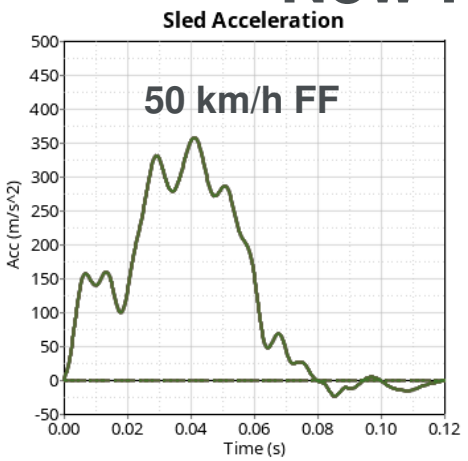
Double lap belt load limiter

Now !

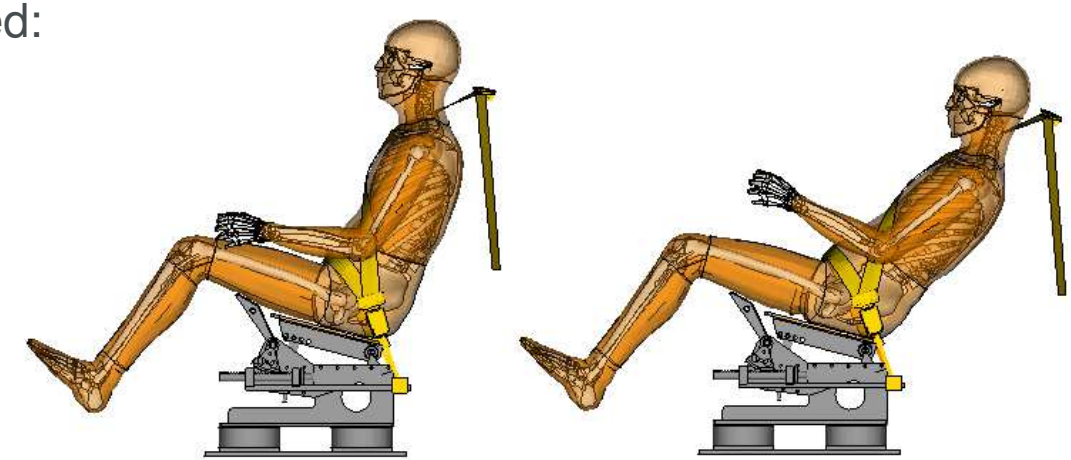


SAFER HBM was used to investigate the influence of lap belt load limiter systems in upright and reclined postures

Belt system with pretensioner and load limiter on the shoulder belt, and pretensioners (buckle and end bracket) on the lap belt

Four different lap belt systems will be compared:

- No load limiters
- Buckle load limiter
- End bracket load limiter
- Both buckle and end bracket load limiters



Upright Reclined

[18] Richard O, Uriot J, Trosseille X, Sokolowski M: Occupant restraint optimisation in frontal crash to mitigate the risk of submarining in out-of-position situation, IRCOBI Conference 2015 Lyon, France

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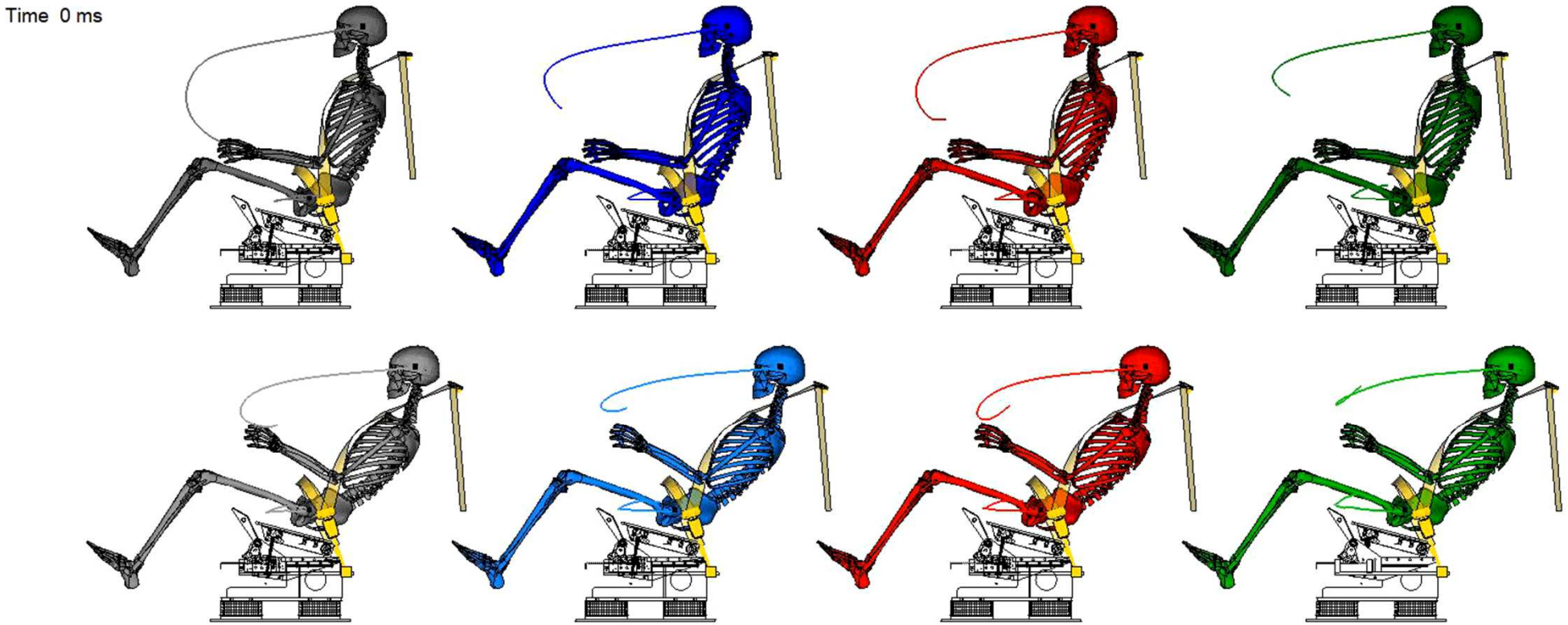
Animation – Left Side View

Upright

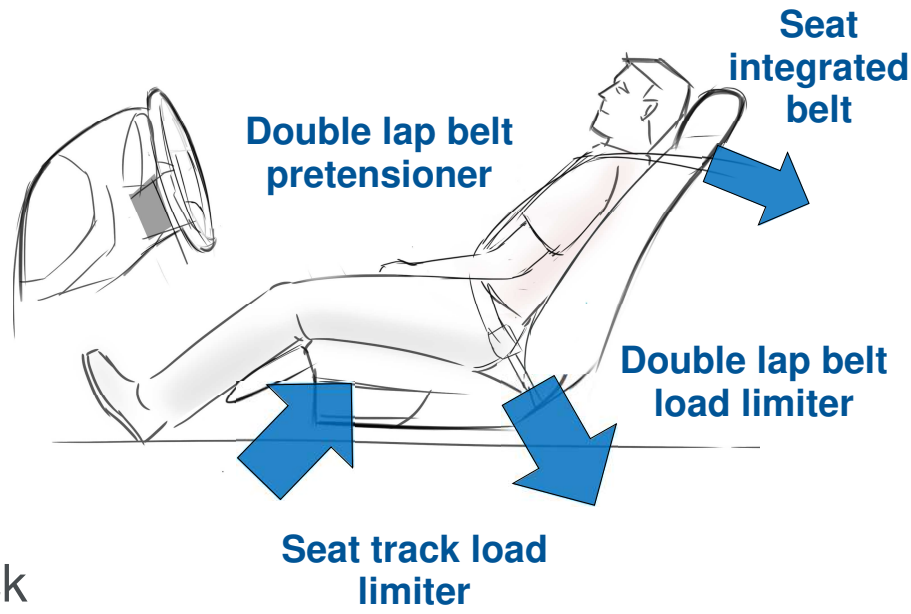
Reclined



Will New Seating Positions Require New Occupant Restraints?

- ✓ Reclined posture with a rearward-rotated pelvis increases the risk of submarining
- ✓ Reclined upper body and absence of a knee bolster that support the lower body increase forces to the lumbar spine
- ✓ and pelvis
- ✓ Absence of head restraining airbags increase head accelerations and neck tension forces
- ✓ Body dynamics induce compression forces in the neck

Seat Centric Restraint System



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Thank you for your attention

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Publications

Predicted future crashes:

[[1] Östling, M, Lubbe, N and Jeppsson, H (2019) Predicting crash configurations in passenger car to passenger car crashes to guide the development of future passenger car safety. Proceedings of IRCOBI conference, 2019, Florence, Italy

[2] Östling, M, Lubbe, N and Jeppsson, H (2019) Predicted crash configurations for Autonomous Driving vehicles in mixed German traffic for the evaluation of occupant restraint system. VDI-Conference “Vehicle Safety” 27th and 28th November 2019 in Berlin

Related but not included in this presentation

[x] Puthan P, Thalya P, Lubbe N (2018) Active and passive safety passenger car technologies: Potentials to save lives in India. Proceedings of IRCOBI Asia Conference, 2018, Lonavala, India.

[x] Puthan P, Östling M, Jeppsson H, Lubbe N (2018) Passive Safety Needs for Future Cars: Predicted Car Occupant Fatalities in the USA. Proceedings of FISITA World Automotive Congress, 2018, Chennai, India.

[x] Lubbe N, Jeppsson H, Ranjbar A, Fredriksson J, Bärgman J, Östling M (2018) Predicted road traffic fatalities in Germany: The potential and limitations of vehicle safety technologies from passive safety to highly automated driving. Proceedings of IRCOBI conference, 2018, Athens, Greece.

[x] Östling M, Lubbe N, Jeppsson H and Puthan P (2019) Passenger car safety beyond ADAS: Defining remaining accident configuration as future priorities. Proceedings of 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV), 2019, Eindhoven, The Netherlands.

[x] Östling M., Puthan P., Jeppsson H., Lubbe, N. and Sunnevång, C. (2018) Future passive safety needs: Predicted injury patterns and possible countermeasures. International Symposium on Sophisticated Car Safety Systems - airbag 2018, Mannheim, 26-28 November 2018.

Publications

Will New Seating Positions Require New Occupant Restraints?

[3] The U.S. Department of Transportation's: Automated driving systems 2.0 a vision for safety, September 2017.

[4] Jorlöv, S. et al. (2017) Seating Positions and Activities in Highly Automated Cars – A Qualitative Study of Future Automated Driving Scenarios." In Proceedings of IRCOBI conference. Antwerp, Belgium 2017

[5] Östling M and Larsson A. Occupant Activities and Sitting Positions in Automated Vehicles in China and Sweden. Enhancement of Safety Vehicles (ESV) Eindhoven, Netherlands. June 2019.

[6] Hagberg A and Jodlovsky S. Reclined seating positions for level 4 HAD vehicles A comfort and safety approach. Master Thesis at Chalmers University Sweden 2017

[7] Leung Y. et al. (1982). Submarining Injuries of 3 Pt. Belted Occupants in Frontal Collisions—Description, Mechanisms and Protection. SAE Transactions

[8] Richard O. et al. (2015) "Occupant restraint optimisation in frontal crash to mitigate the risk of submarining in out-of-position situation" Proceedings of the IRCOBI Conference Lyon, France 2015.

[9] Richardson R. et al. (2020) Pelvis Kinematics and Injuries of Reclined Occupants in Frontal Impacts. Proceedings of the IRCOBI Conference, Munich, Germany, 2020.

[10] Richardson R. et al. (2020) Kinematic and Injury Response of Reclined PMHS in Frontal Impacts. Stapp Car Crash Journal, Vol. 64, November 2020.

[11] Izumiyama T. et al (2018). The Analysis of an Individual Difference in Human Skeletal Alignment in Seated Posture and Occupant Behavior Using HBM. Proceedings of IRCOBI conference, Athens, Greece 2018.

[12] Poplin G.S. et al. (2015) Nature and etiology of hollow-organ abdominal injuries in frontal Crashes. 2015, Accident Analysis and Prevention 78, 51–57

[13] Östling M. et al. (2017) Potential future seating positions and the impact on injury risks in a Learning Intelligent Vehicle (LIV). VDI-Tagung Fahrzeugsicherheit, Berlin, Germany 2017.

[14] Uriot J. et al. (2015) Reference PMHS Sled Tests to Assess Submarining. Stapp Car Crash Journal. Vol 59, 2015.

[15] Richardson R. et. al (2019) Test methodology for evaluating the reclined seating environment with human surrogates. The 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Eindhoven, Netherlands, June 10-13, 2019.

[16] Mroz K. et al. (2020) Effect of Seat and Seat Belt characteristics on the Lumbar Spine and Pelvis Loading of the SAFER Human Body Model in reclined Postures. Proceedings of the IRCOBI Conference, Munich, Germany, 2020

[17] Östling M. et al. (2021) The Influence of a Seat Track Load Limiter on Lumbar Spine Compression Forces in Relaxed, Reclined, and Upright Seating Positions: A Sled Test Study using THOR-50M . Under review for the IRCOBI Conference, Munich, Germany, 2021

[18] Richard O. et al. Occupant restraint optimisation in frontal crash to mitigate the risk of submarining in out-of-position situation, IRCOBI Conference 2015 Lyon, France


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