Measuring and Modeling Occupant Responses During Abrupt Vehicle Maneuvers

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Abrupt Vehicle Pre-Crash Maneuvers

National Motor Vehicle Crash Causation Survey (2005-2007)

40% of crashes were preceded by a vehicle maneuver. Of these, drivers with passengers >14YO:

- braked **40%**
- steered 20%
- braked and steered **35%**
- other (5%)

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Stockman (2013). NMVCCS Analysis

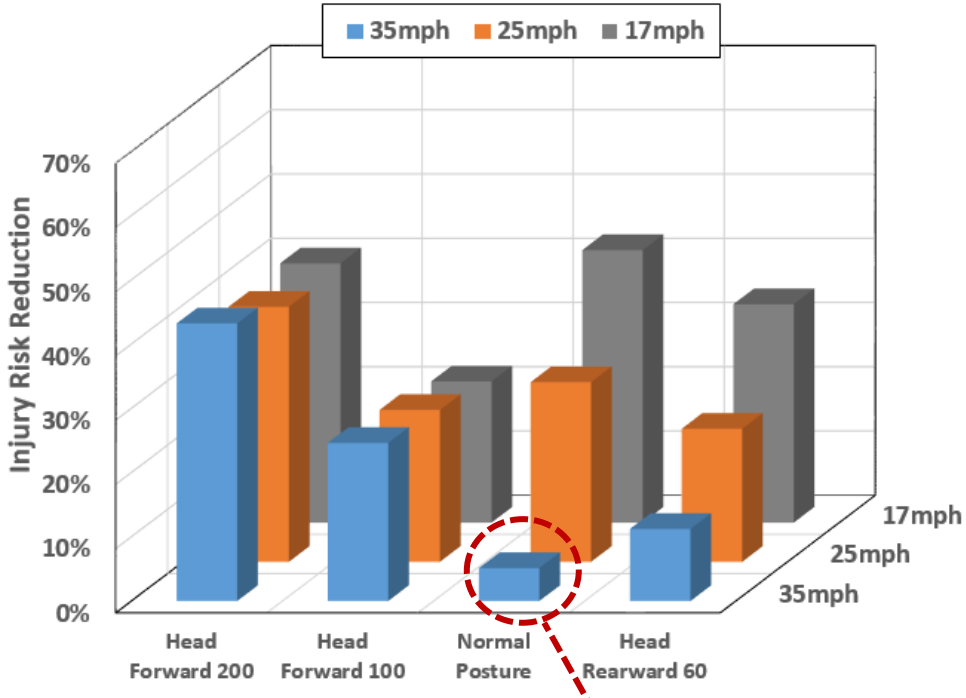
Integrated Safety

Occupant pre-crash posture and crash speed can significantly affect the injury risks in frontal crashes (Hu, et al. 2015)

Normal Pre-crash posture

Head forward 200 mm

Baseline ATD Simulations with different postures



US-NCAP condition

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Objectives

- To gather data on **naturalistic responses of vehicle passengers to vehicle maneuvers**, including hard braking and rapid steering.
- To develop **an efficient, parametric, and active human model** to accurately predict occupant pre-crash kinematics in response to different types of vehicle pre-crash maneuvers.

Previous Studies: In Vehicle Head Tracking

- **Marker-based head tracking**: **+** Suitable to obtain accurate 3D locations
  - Requires excessive hardware to track markers
- **Image-based head tracking**: **+** Can capture naturalistic occupant behaviors
  - Hard to measure accurate 3D locations

Images from **VIRTUAL VEHICLE** (http://www.v2c2.at)

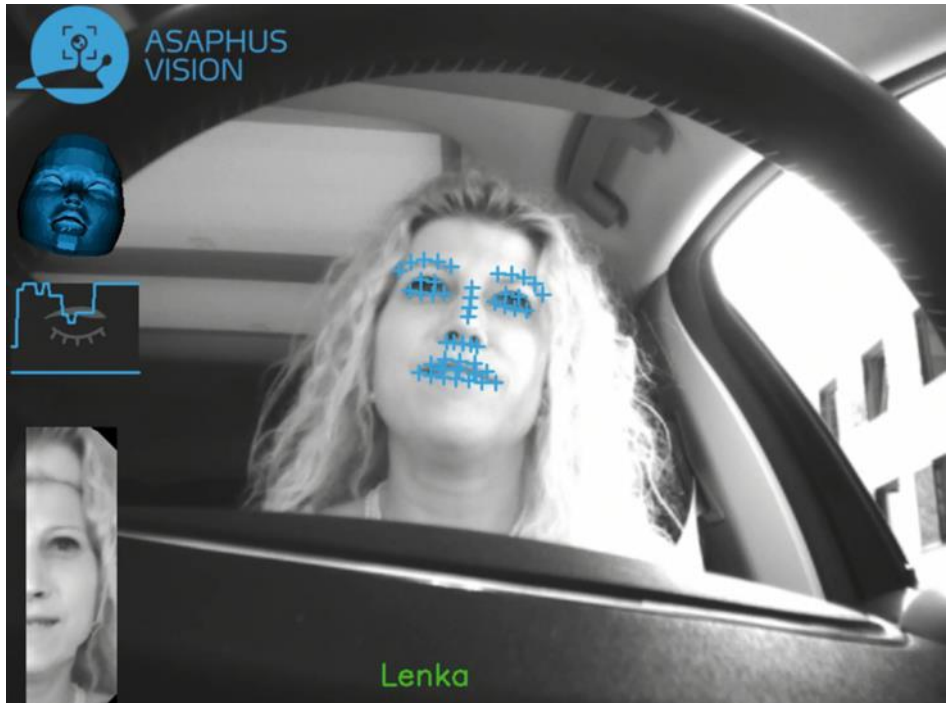

Image-based head tracking Ivantysynova et al. 2015

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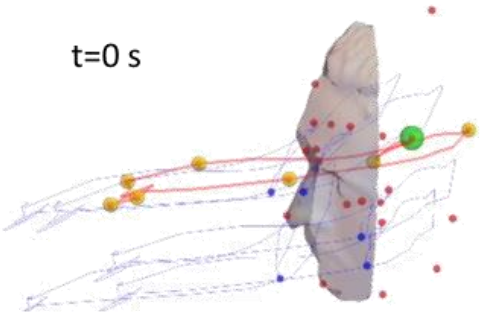
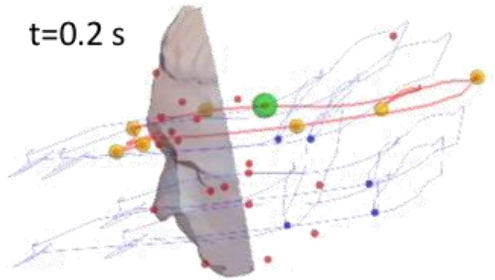
UMTRI Approach

3D Head Scan with Landmarks

Kinect V2 Sensor on Dash

View from Kinect Sensor: All Pixels are 3D Points

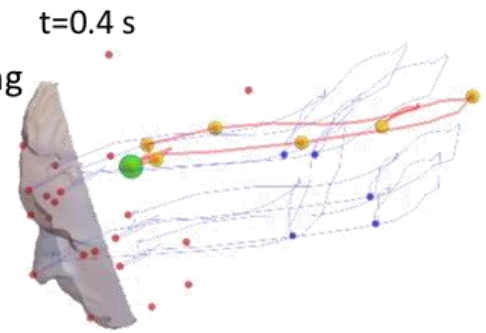




Head Tracking, Braking

Head Tracking, Lane Change

Head Tracking Output Showing Landmark and Head CG Trajectory



Belt and Torso Points Can be Tracked in 3D

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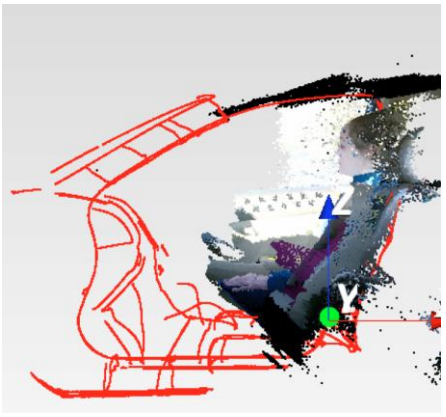
UMTRI Head Tracking Process



1

Depth Data Acquisition

Collect depth images of an occupant using ToF camera

2

Depth Points Conversion

Convert depth pixel data to 3D point cloud model using camera parameters

3

Align to Vehicle Coordinate

Align converted depth points to the vehicle coordinate following the SAE standard

4

Depth Data Filtering

Leave the points in the area of interest and remove the noise

5

Model Fitting to Depth Point Sets

Fit a 3D head scan model to each depth point set to track head dynamics

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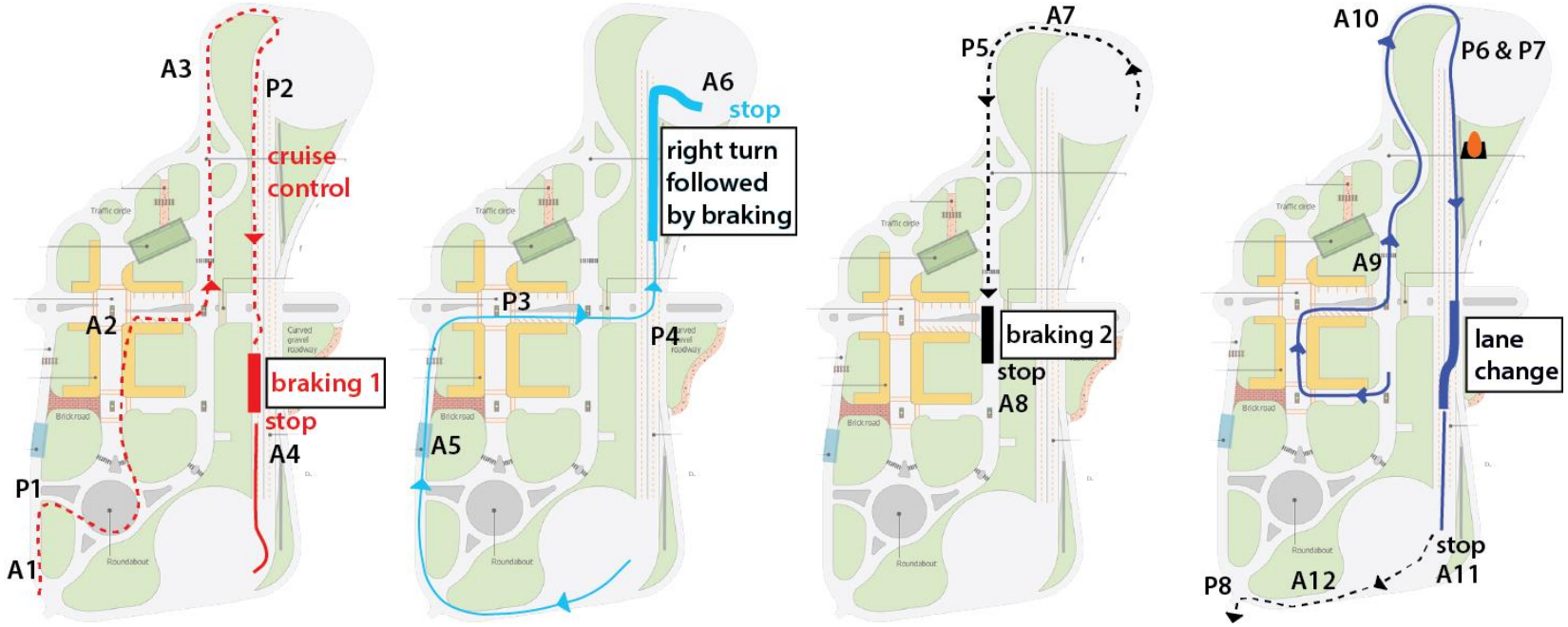
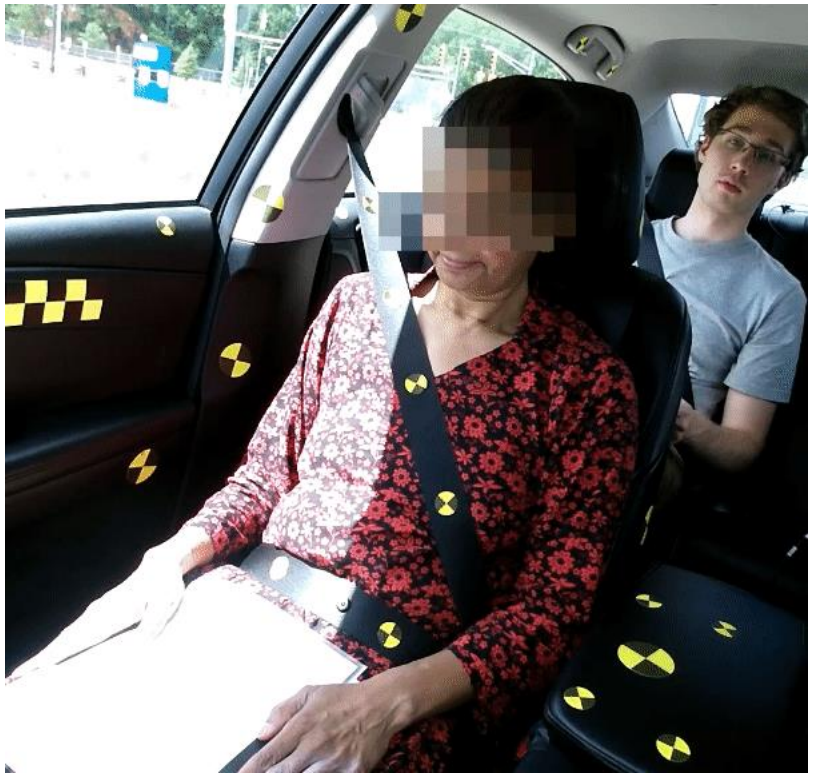
Vehicle Maneuvers

- Braking abruptly while traveling straight (B1)
- Turning sharply followed by abrupt braking (T1)
- Braking abruptly on a surface street (B2)
- Quick lane-change to the right (L1)



Toyota Series Data Collection

- A total of 348 trials (up to 4 events for 87 subjects) were conducted
- Subjects were asked to answer questions during testing as a distraction



Hard brake x2

Turn and Brake

Lane Change

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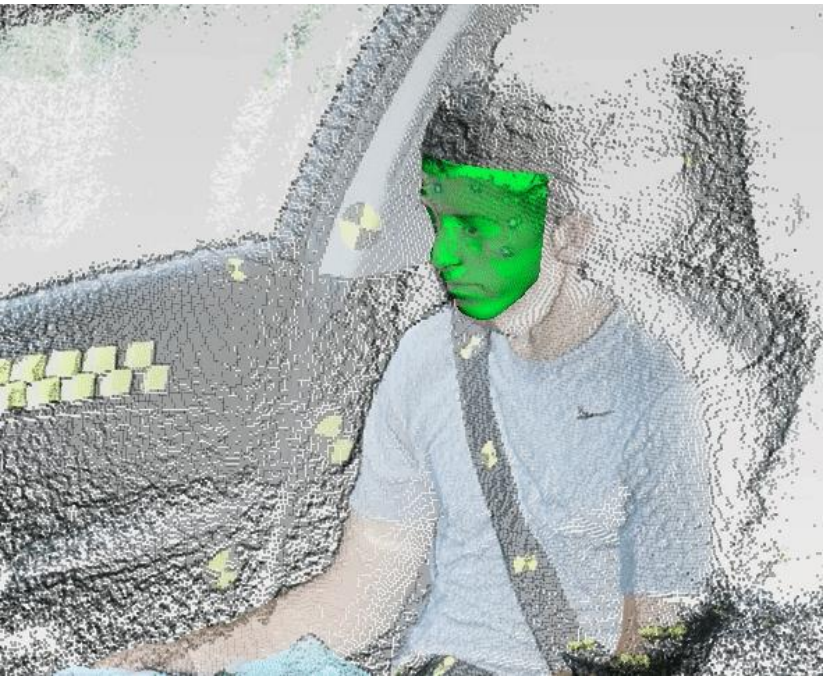
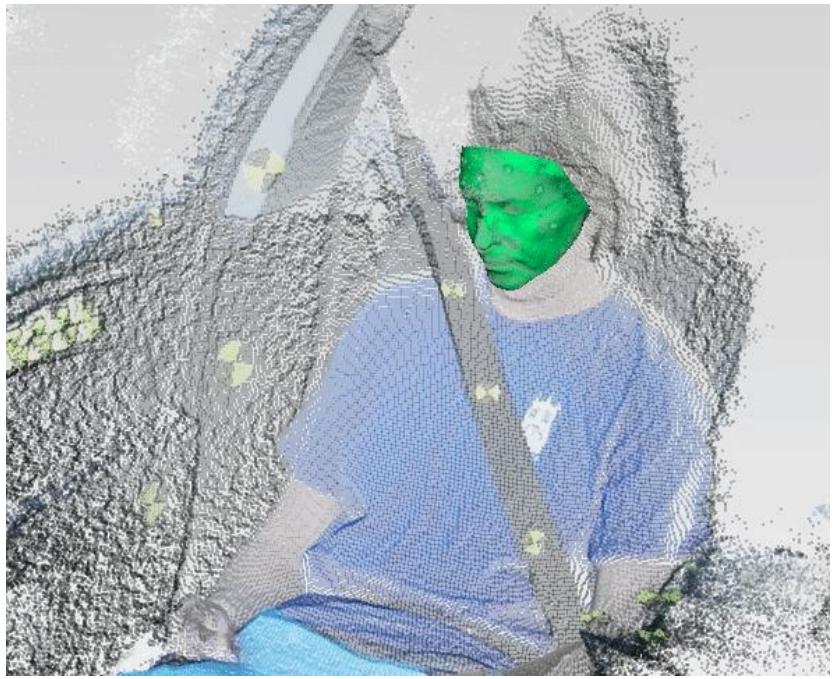
Head Tracking Examples

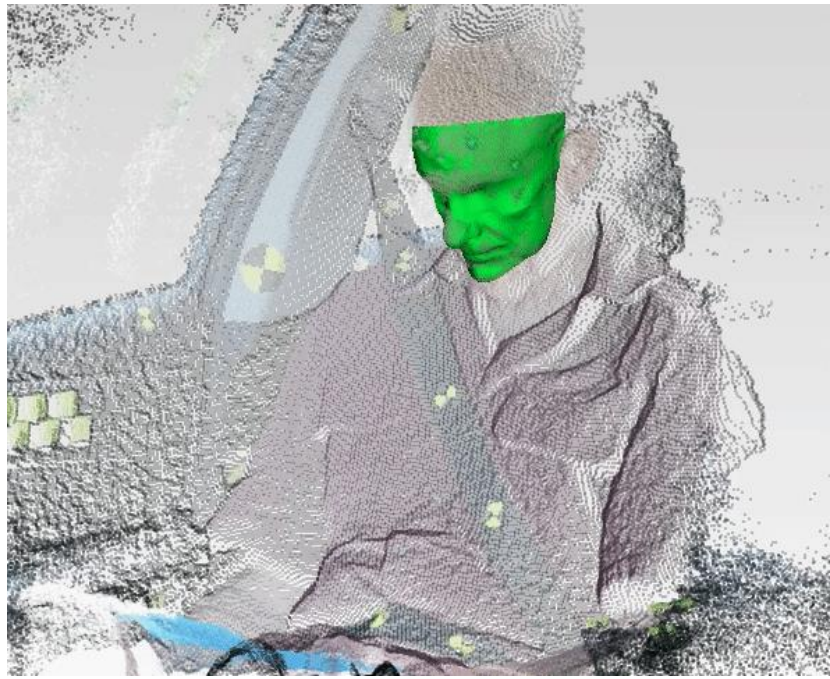
BRAKE



TURNING



LANE CHANGING



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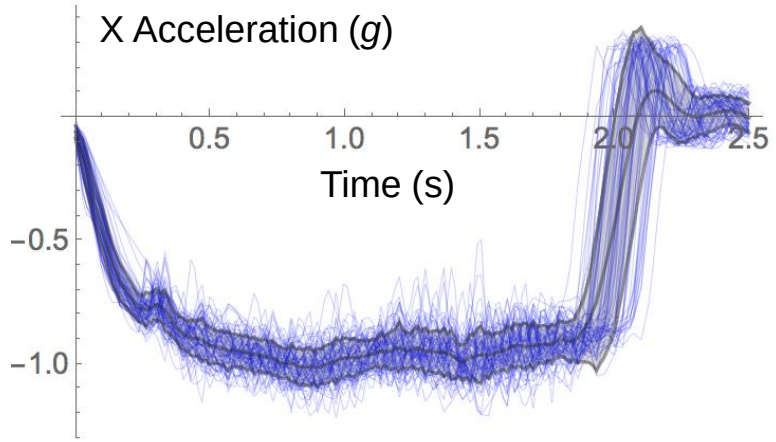
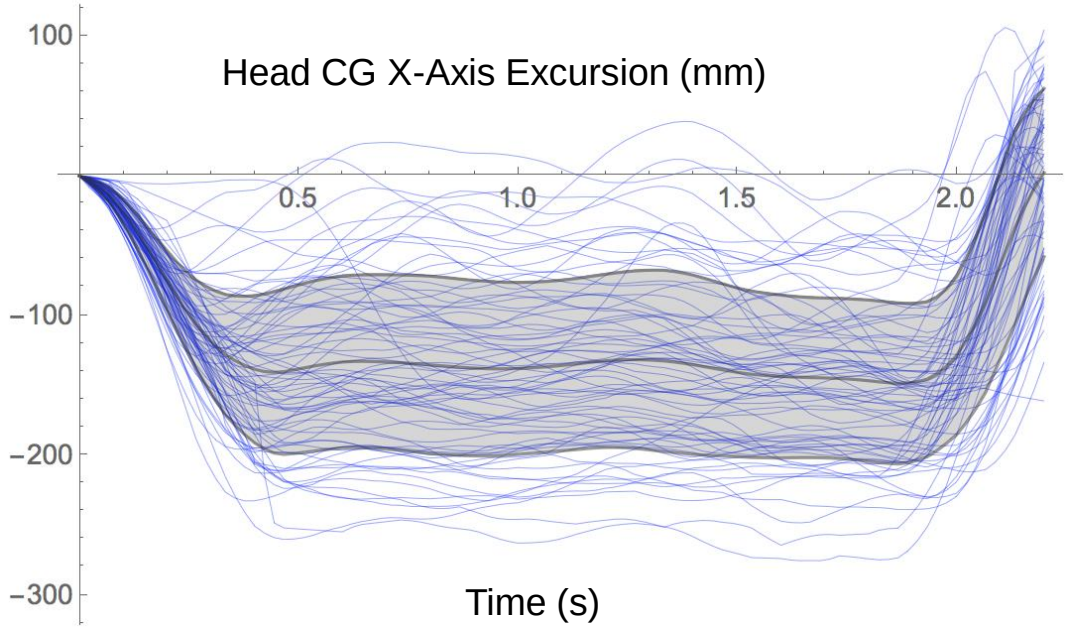
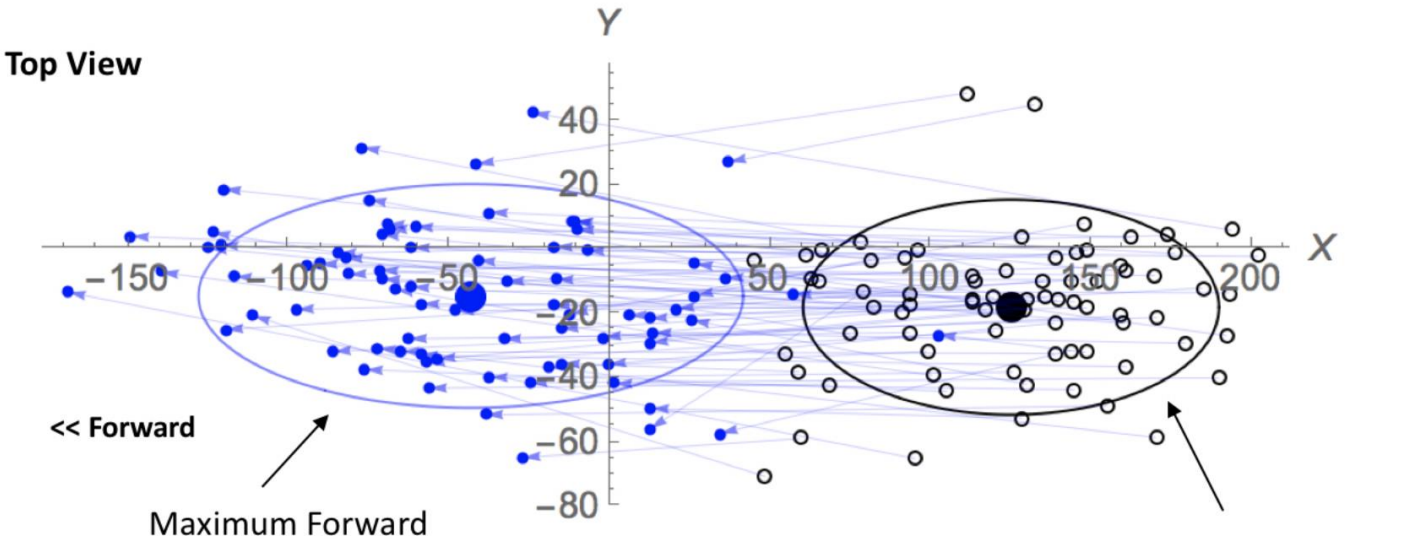
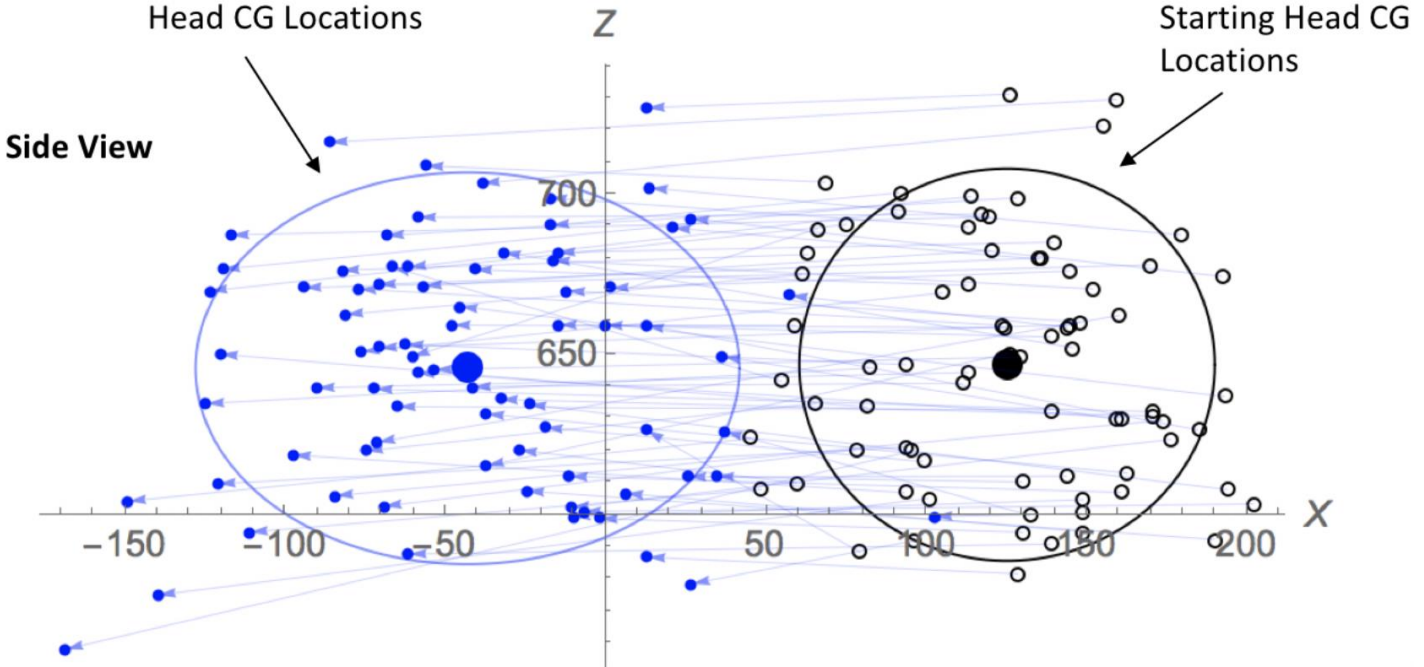
Results: Braking

Mean (sd) of maximum excursion = 135 (62) mm









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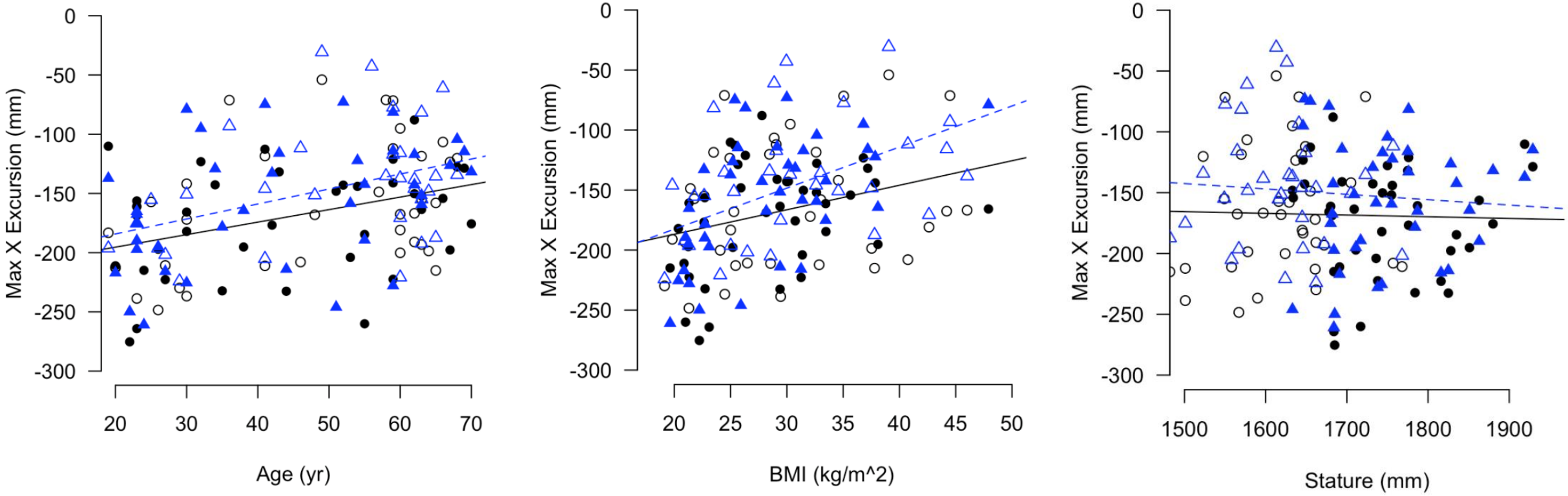
Results: Effects from Human Characteristics

Age, BMI, and Stature Effects on Max Head Excursions in braking events



The first braking event is shown as circles and a solid regression line; the second event is triangles and a dashed line. Data from male and female participants are shown as filled and open symbols, respectively.

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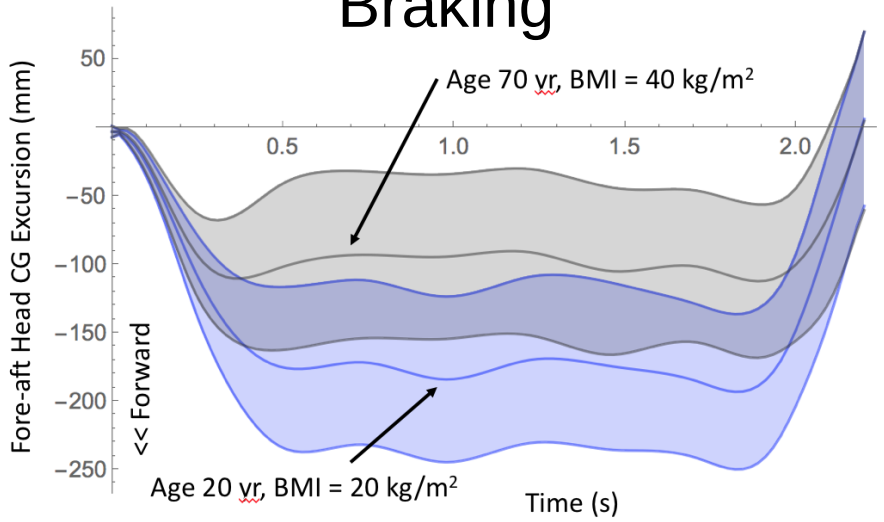
Head Excursion Corridors

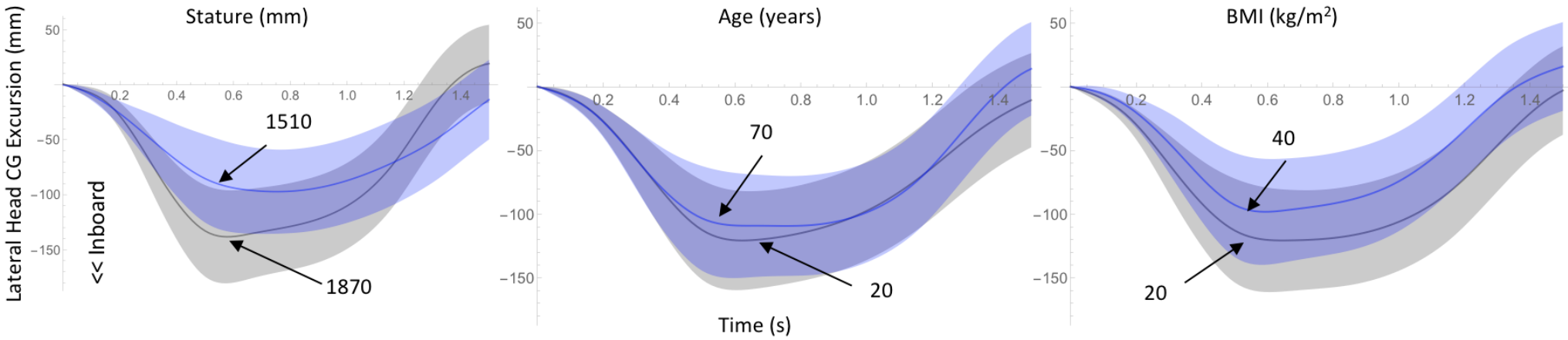
Head Excursion Corridors through Functional Analysis

- Age
- Stature
- BMI

Braking



Lane Change



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Discussion

- Responses are highly variable and not strongly related to passenger characteristics
- The results do not support simple scaling of responses by body size
- “Surprise” did not have strong systematic effects within the limitations of this experiment

Ongoing NHTSA-funded Testing

Quantify the effects of occupant sizes, vehicle type, and relative awareness

- Effects of vehicle type
- Effects of initial posture and position
- Effects of lateral support
- Older children 13-16 YO

2016 Toyota Avalon

2018 Ford F-150

2018 Dodge Caravan

NHTSA Pilot Study Results

Vehicle	B1	B2	L1
Minivan	-162 (54)	-133 (54)	-126 (51)
Passenger Car	-112* (39)	-93* (49)	-110 (49)
Pickup Truck	-176 (46)	-120 (37)	-140 (68)
Overall Mean Across Vehicles	-150 (47)	-115^ (47)	-125 (56)
UMTRI Toyota Study Reed et al. (2018)	-135 (62)	-115 (51)	-118 (40)

† Negative braking excursions are forward; negative lane-change excursions are inward.
* Significantly smaller than in the other vehicles ($p<0.01$)
^ Significantly smaller than in the first exposure ($p<0.01$)

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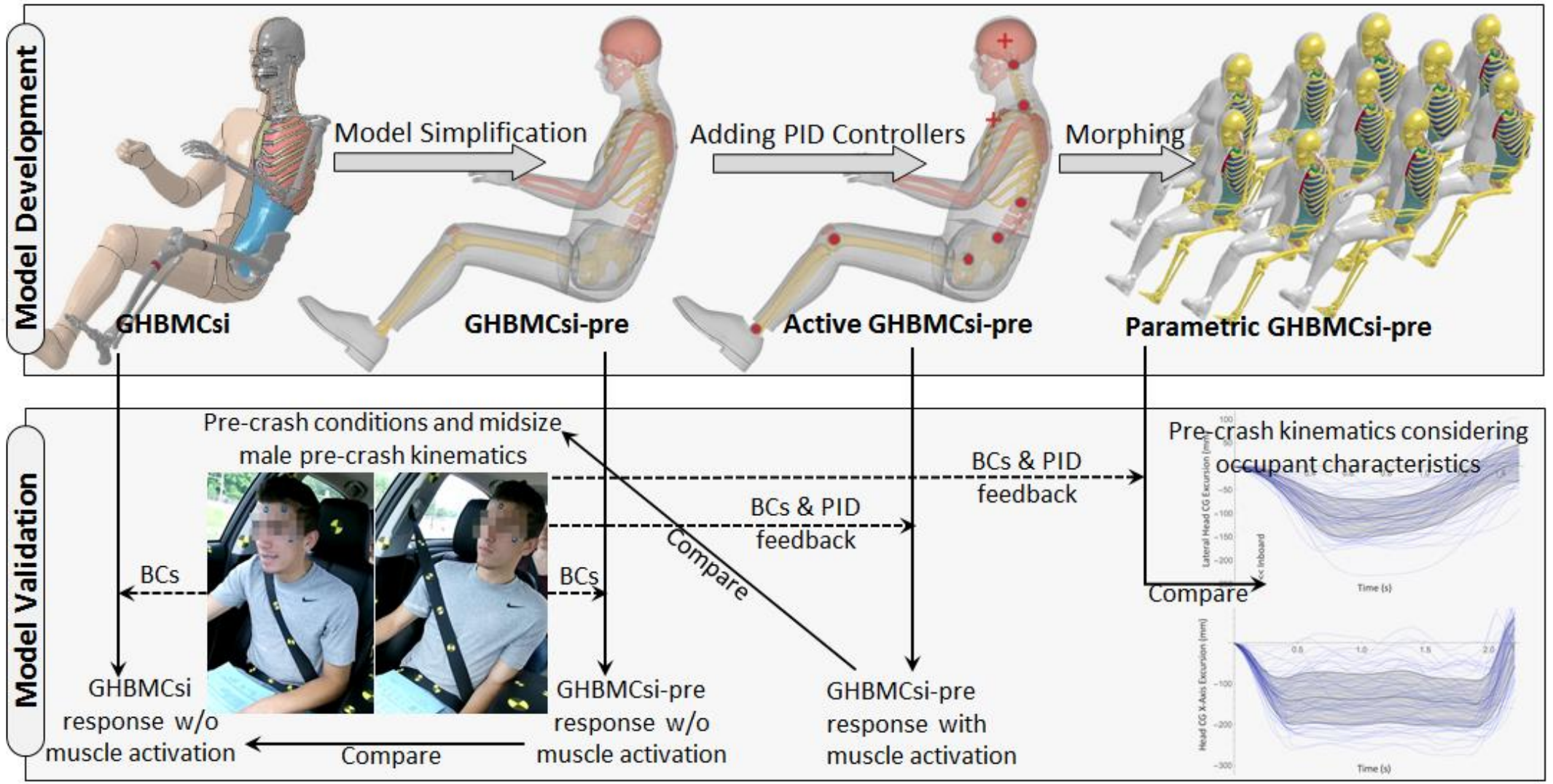
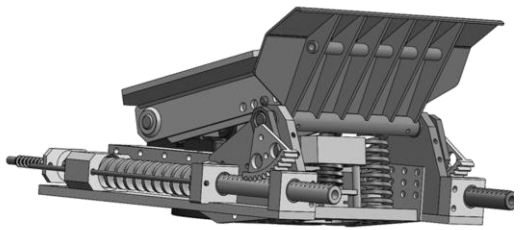
Human Model Development and Validation

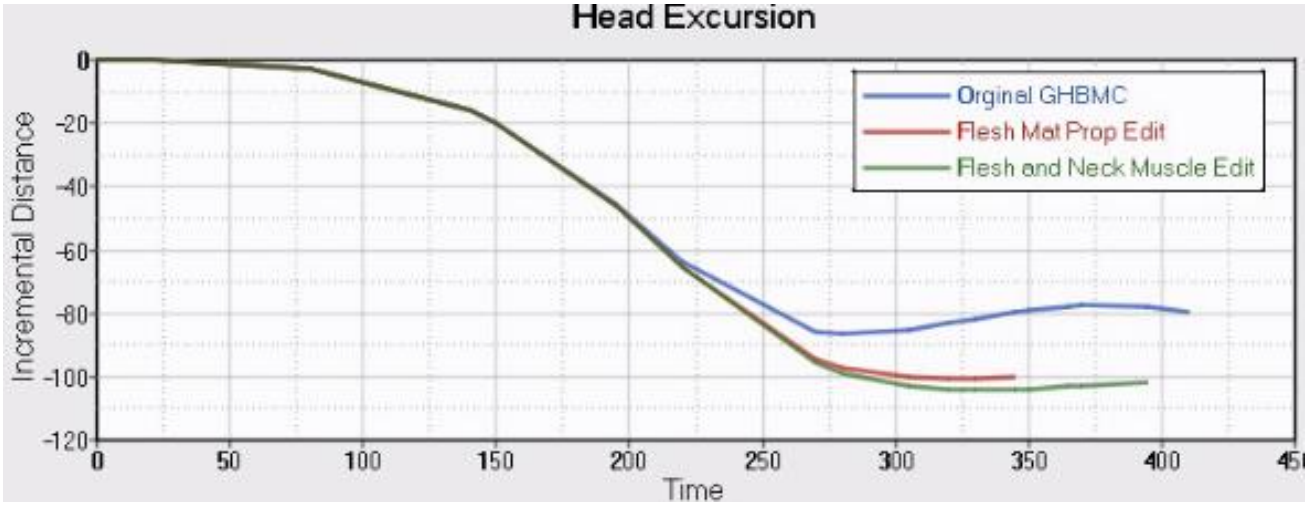


Pre-Crash Braking with GHBMCsi

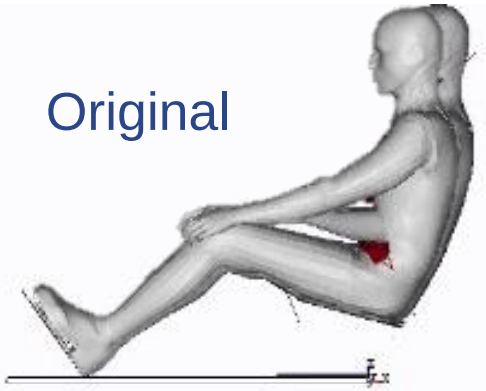
- ~1-g braking for 2 seconds
- ~50 hours of simulation time on a cluster with 16 cores
- Semi-rigid seat was used
- Results in less head excursion, not matching volunteer data
- Attempted slightly changing material properties



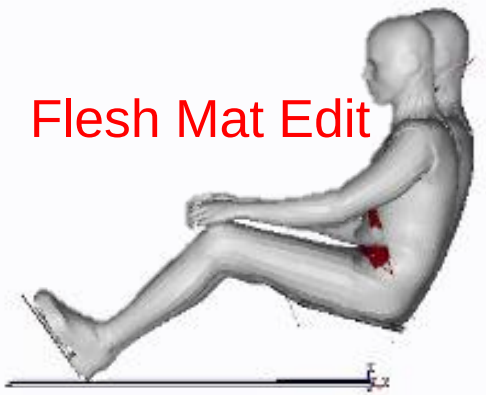
Semi-Rigid Seat
Uriot et al. 2015 Stapp



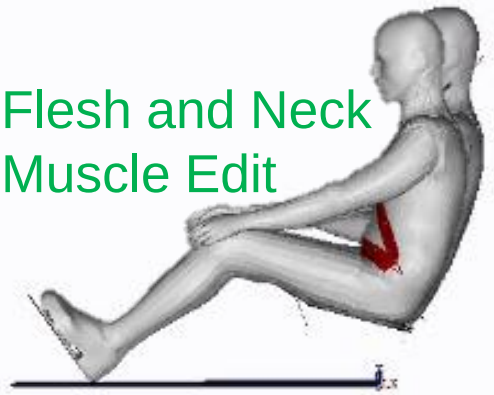
Original



Flesh Mat Edit



Flesh and Neck Muscle Edit



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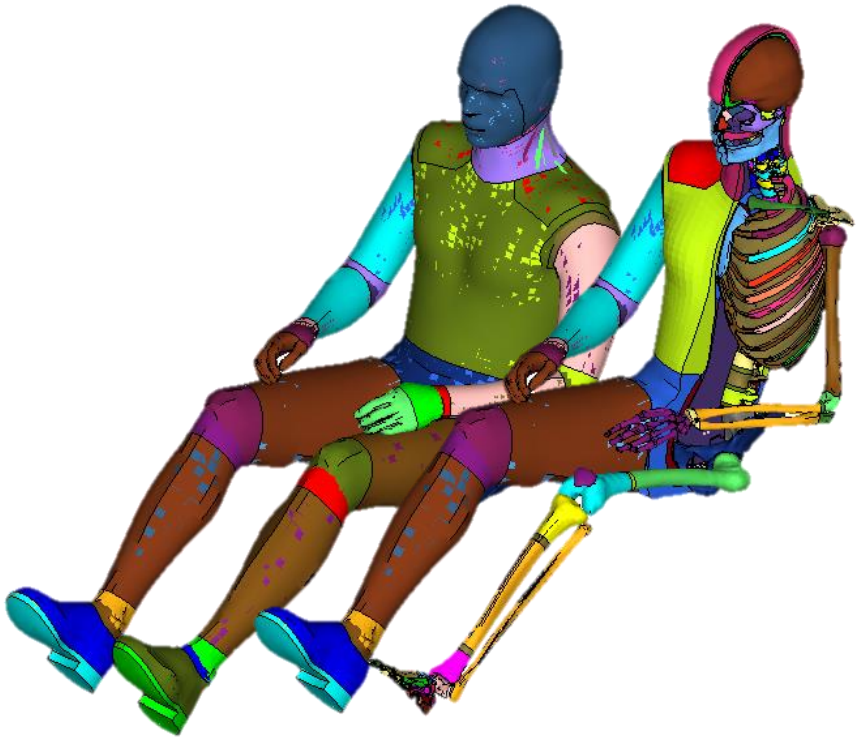
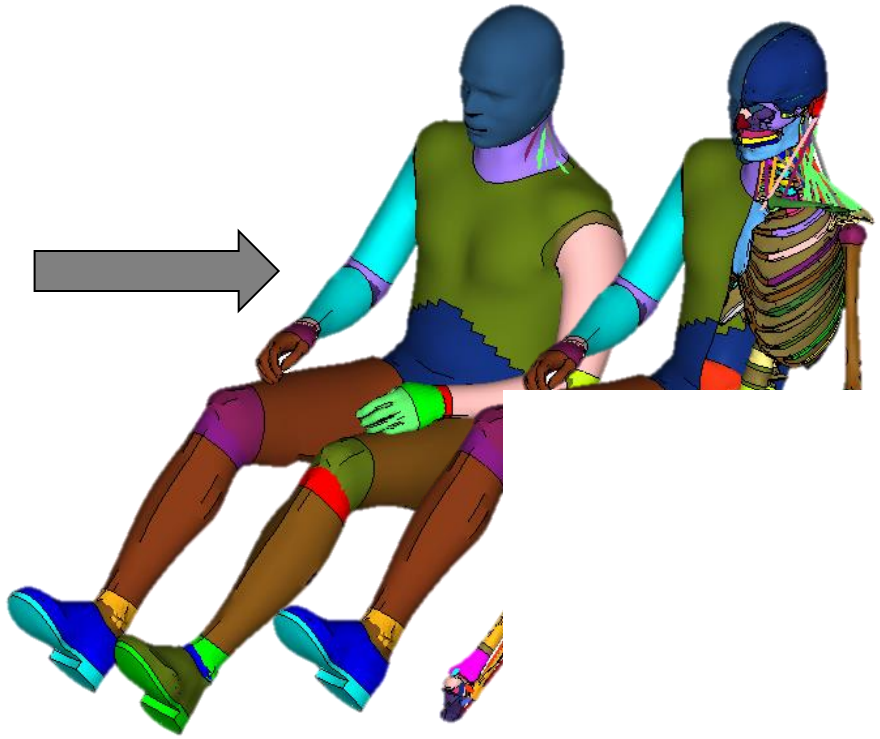
GHBMCsi Simplification

GHBMCsi

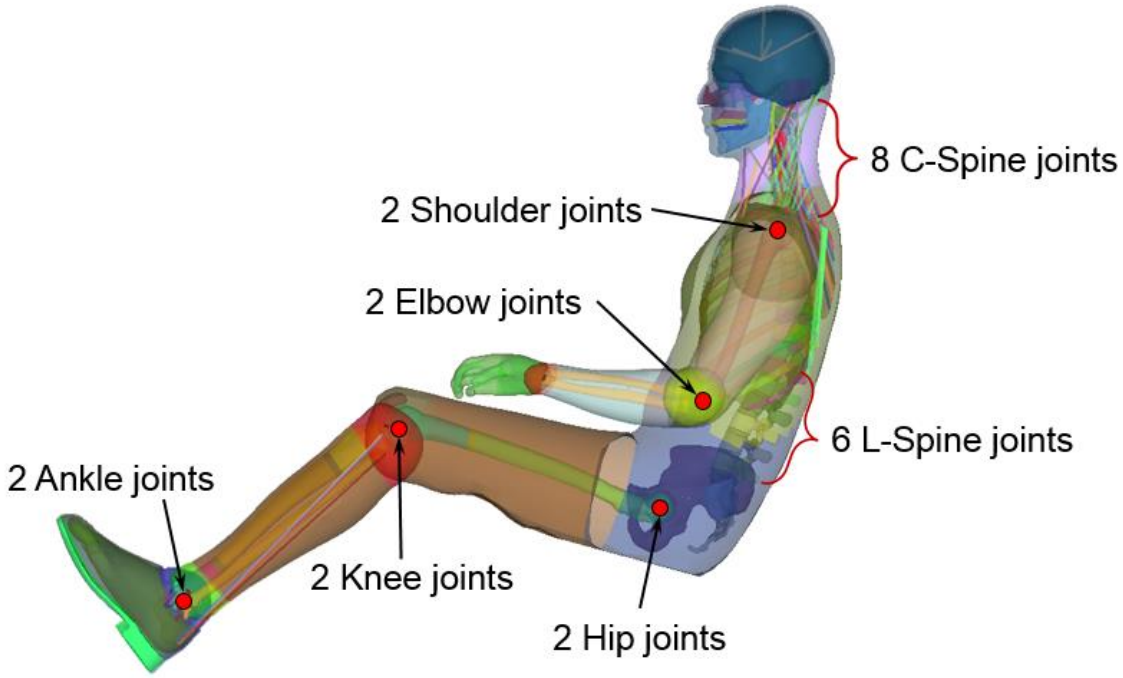


GHBMCsi-pre



	GHBMCsi	GHBMCsi-pre
Nodes	296,324	213,810
Elements	358,916	269,262
Rigid Elements	201,976	254,204
Deformable Elements	156,748	15,058

GHBMCsi-pre Joints

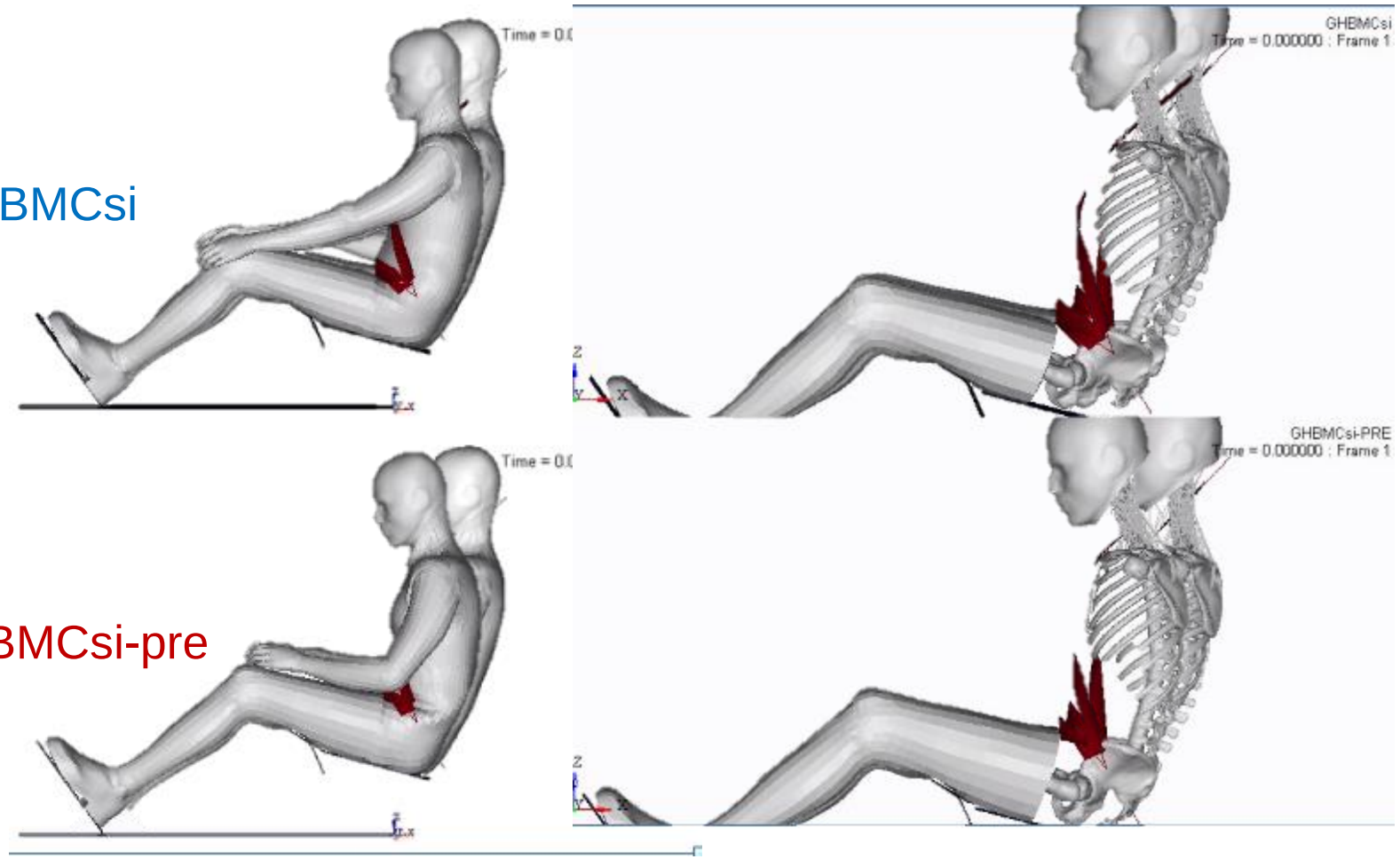


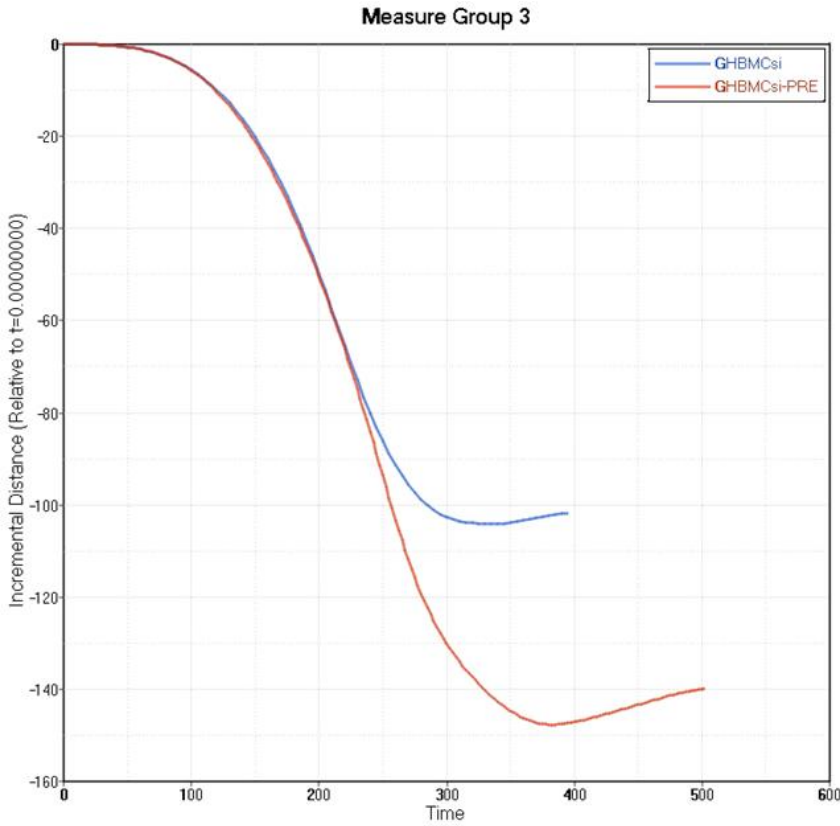
GHBMCsi-pre Simulation

Computation time reduced from 12 hr to 1 hr on 16 cores for a 502 ms simulation

GHBMCsi

GHBMCsi-pre





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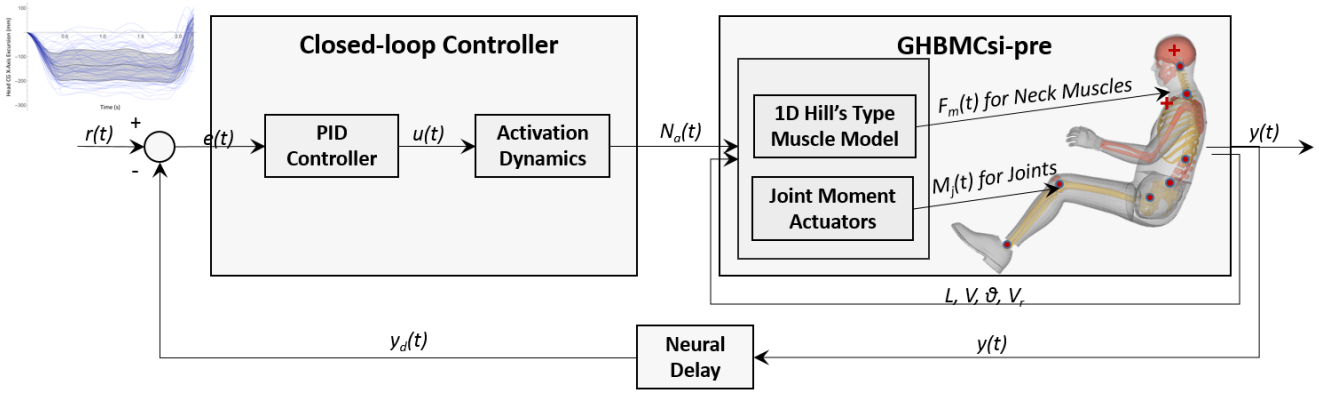
On-going NHTSA-funded Modeling Work

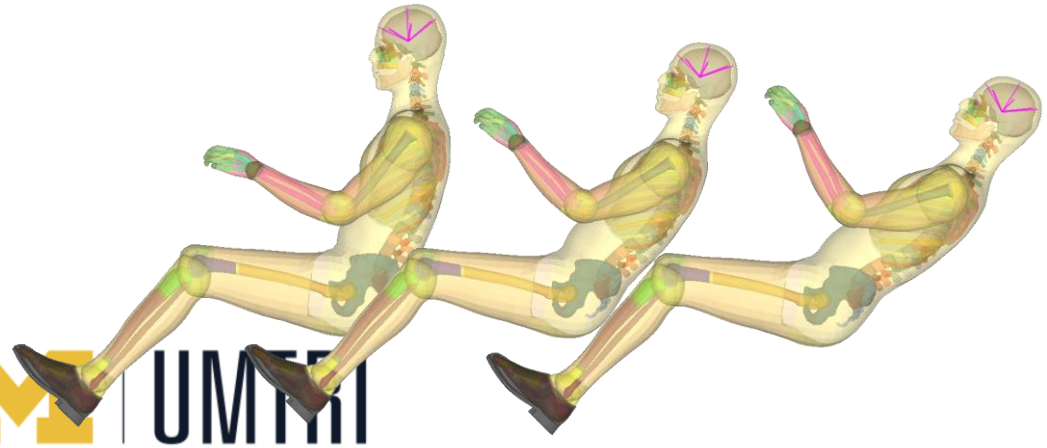
- PID controller for muscle activation

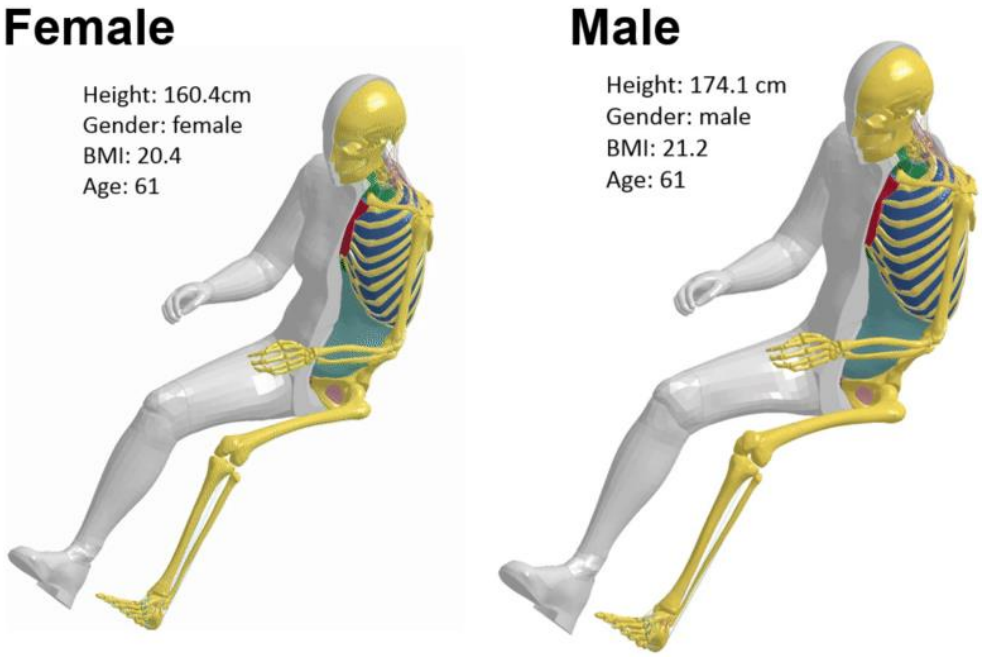
$$u(t) = k_p \cdot e(t) + k_i \cdot \int_0^t e(\tau)d\tau + k_d \cdot \frac{de(t)}{dt}$$

where $e(t) = r(t) - y(t)$



- RBF Mesh Morphing for generating a diverse set of human models





Summary

- A series of studies were conducted and are being conducted using instrumented vehicles on a test track to quantify vehicle-maneuver-induced posture changes.
- The data show high variability across individuals, with only a small fraction of that variability explained by occupant characteristics.
- These data are being used to tune and validate an efficient, parametric, active human model for pre-crash simulations.

Acknowledgement

- Early subject testing was funded by the Toyota Collaborative Safety Research Center http://www.toyota.com/csrc/
- Ongoing subject testing and modeling were funded by NHTSA

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