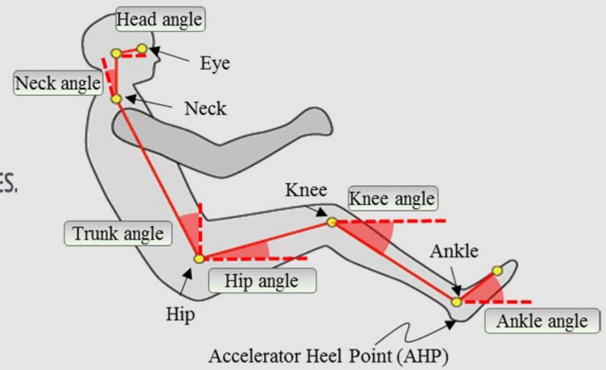
INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

Ergonomic Design Technology Lab

Development of Statistical Models for Predicting a Driver's Hip and Eye Locations



POSTECH
POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY

INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

Ergonomic Design Technology Lab

Seunghoon Lee[1], Jangwoon Park[2], Kihyo Jung[3], Xiaopeng Yang[1], Heecheon You[1]

[1]Department of Industrial and Management Engineering, POSTECH, Pohang, South Korea

[2]Department of Engineering, Texas A&M University–Corpus Christi, Corpus Christi, TX, USA

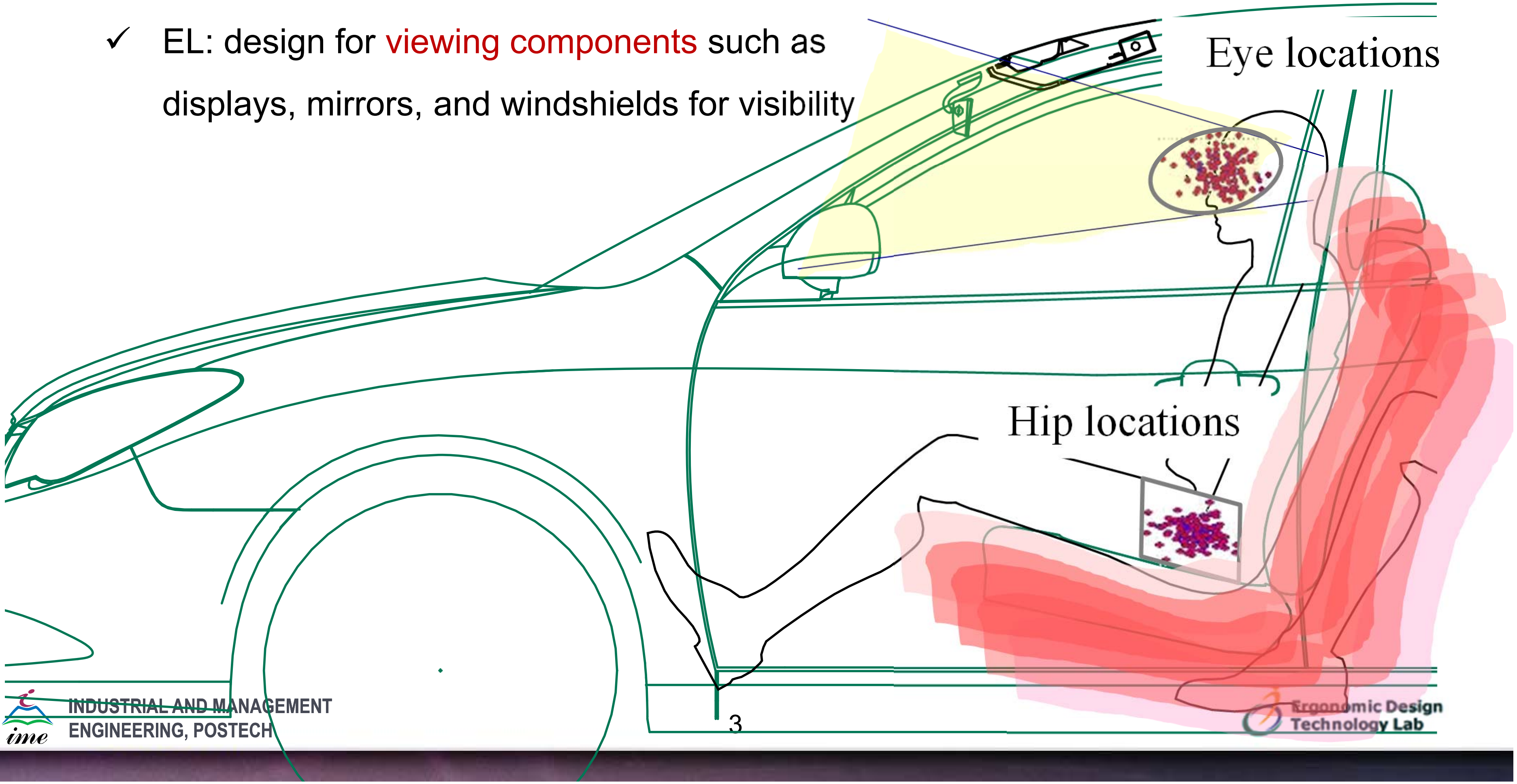
[3]Department of Industrial Engineering, University of Ulsan, Ulsan, South Korea

Global Contributor to Eco-Techno-Humanopia

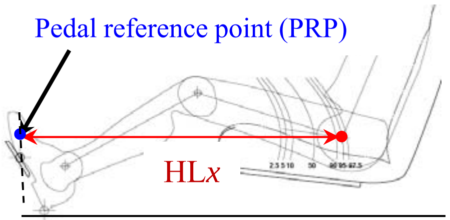
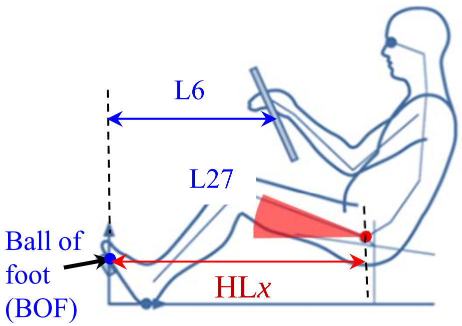
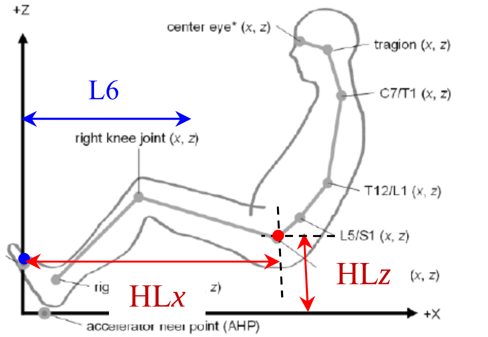
Contents

Driver's Hip & Eye Locations (HL & EL)

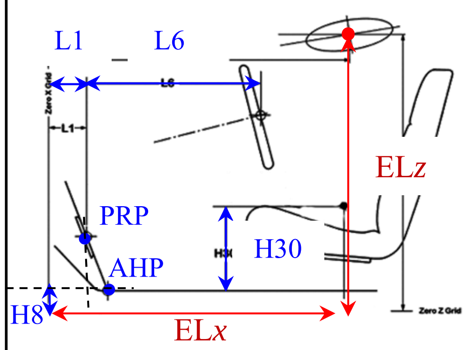
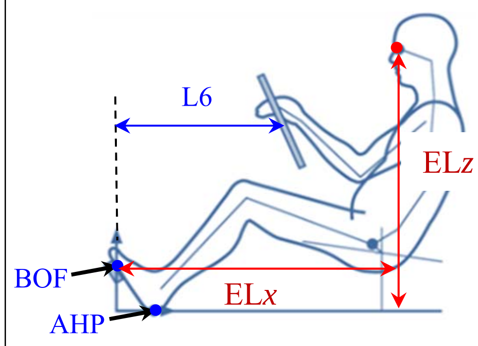
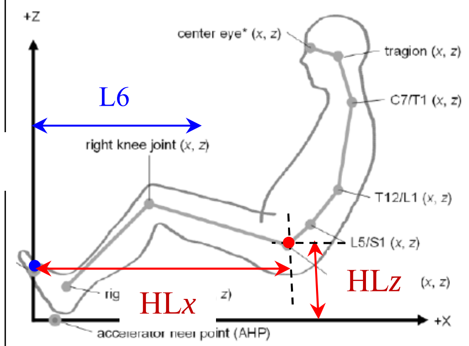
- HL & EL of a driver are important design reference points to provide good reach, visibility, comfort, and clearance for the driver (SAE J1100, 2005)
  - ✓ HL: design for neutral position and adjustment range of a seat for reach
  - ✓ EL: design for viewing components such as displays, mirrors, and windshields for visibility



Statistical HL Prediction Models

		SAE J1517 (2011)	Reed et al. (2002)	Park et al. (2016)
Figure				
Prediction model		$HLx_{2.5} = 687.1 + 0.895 \times H30 - 0.0021 \times H30^2$ $HLx_{97.5} = 936.6 + 0.614 \times H30 - 0.0019 \times H30^2$	$HLx = 84.8 + 0.4659 \times S - 430.1 \times SHS - 0.1732 \times H30 + 0.4479 \times L6 - 1.04 \times L27$	$HLx = 9446 - (5.190 \times S) - (5.060 \times BMI) - (16970 \times SHS) - (2.750 \times Age) - (0.365 \times H30) + (0.465 \times L6_{re}) + (10.50 \times S \times SHS) + (0.109 \times BMI \times Age)$ $HLz = 276.0 - (680.0 \times SHS) + (4.540 \times BMI) - (5.550 \times Age) + (0.906 \times H30) - (5.760 \times 10^{-2} \times BMI \times Age) + (12.90 \times SHS \times Age)$
Predictors	Human	-	S (stature) SHS (sitting height/stature)	S, SHS, BMI, Age
	Package Layout	H30 (seat height)	H30, L6 (SW to BOFx)	H30, L6
	Seat	-	L27 (fixed cushion angle)	-
Performance	adj. R^2	Not Available	0.78	HLx = 0.68 HLz = 0.95
	RMSE (mm)	Not Available	35.9	HLx = 33.3 HLz = 17.3

Statistical **EL Prediction Models**

		SAE J941 (2010)	Reed et al. (2002)	Park et al. (2016)
Figure				
Prediction model		ELx = L1 + 664 + 0.587 × L6 – 0.176 × H30 – 0.176 × t ELz = H8 + 638 + H30	ELx = – 836.6 + 0.5842 × S + 916.6 × SHS – 0.1559 × H30 + 0.6101 × L6 ELz = – 836.6 + 0.5842 × S [illegible] + 0.6101 × L6	ELx = 340.0 + 0.355 × S + 2.820 × BMI – 0.413 × H30 + 0.550 × L6 ELz = – 432.0 + 0.347 × S [illegible] H30
Variables	Human	-	S, SHS	S, SHS, BMI
	Package Layout	L1(PRPx coordinate), L6, H8(AHP z coordinate), H30	L6, H30	L6, H30
	Seat	-	-	-
Performance	adj. R^2	Not Available	ELx = 0.71 ELz = 0.89	ELx = 0.56 ELz = 0.94
	RMSE (mm)	Not Available	ELx = 50.9 ELz = 21.8	ELx = 46.1 ELz = 19.0

Limitations

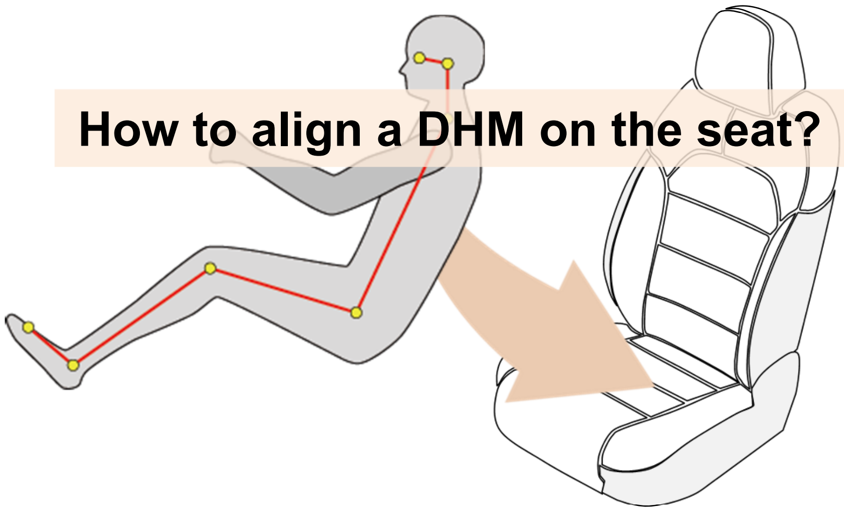
- The models do not consider body segment lengths and driving posture
- The models do not consider various seat adjustment functions
- The SAE model does not provide the information of model performance

Digital Human Models

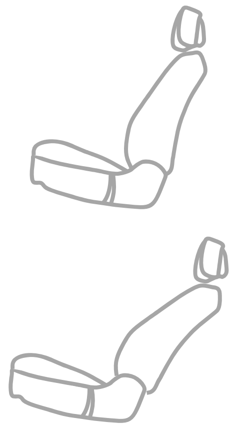
- Digital human models (DHMs) of specific body sizes (e.g., 5^{th} %ile female, 50^{th} %ile male) were used in vehicle ergonomics and safety studies
- Recently, studies have been actively conducted on DHMs considering individual differences in body size, sitting position, and sitting strategy.
  - ⇒ Need HP & EP prediction models considering various body sizes, sitting postures, and seat configurations

Various driving postures

Various body sizes



Various seat configurations

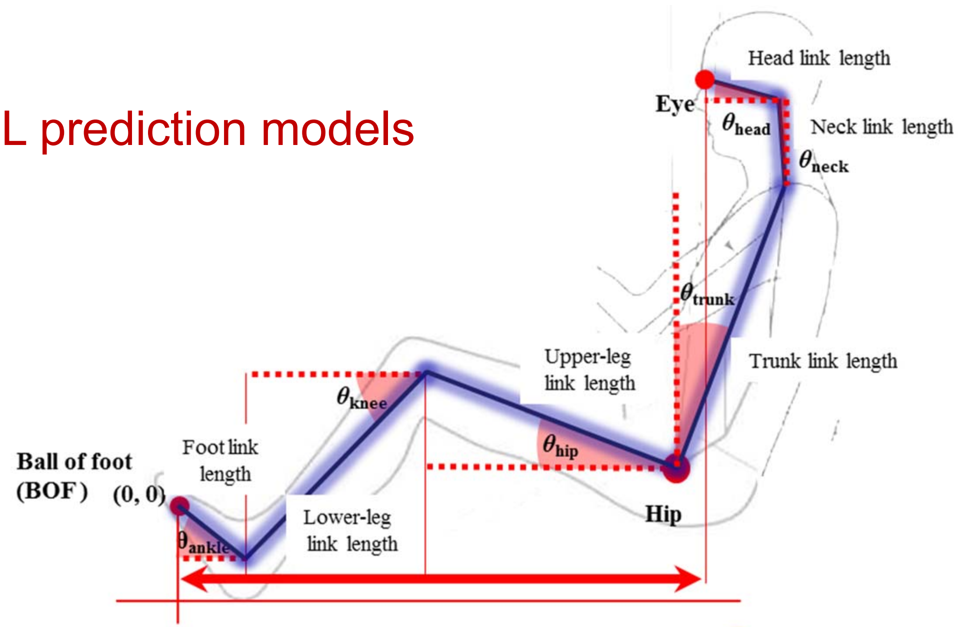


Objectives of the Study

Development of Statistical Models

for Predicting a Driver's Hip and Eye Locations

1) Measurement of hip and eye locations of drivers in various sizes, postures, and seat configurations
2) Development of statistical HL & EL prediction models
   - Driving posture-based models
   - Seat configuration-based models
3) Evaluation and Validation of the HL & EL prediction models

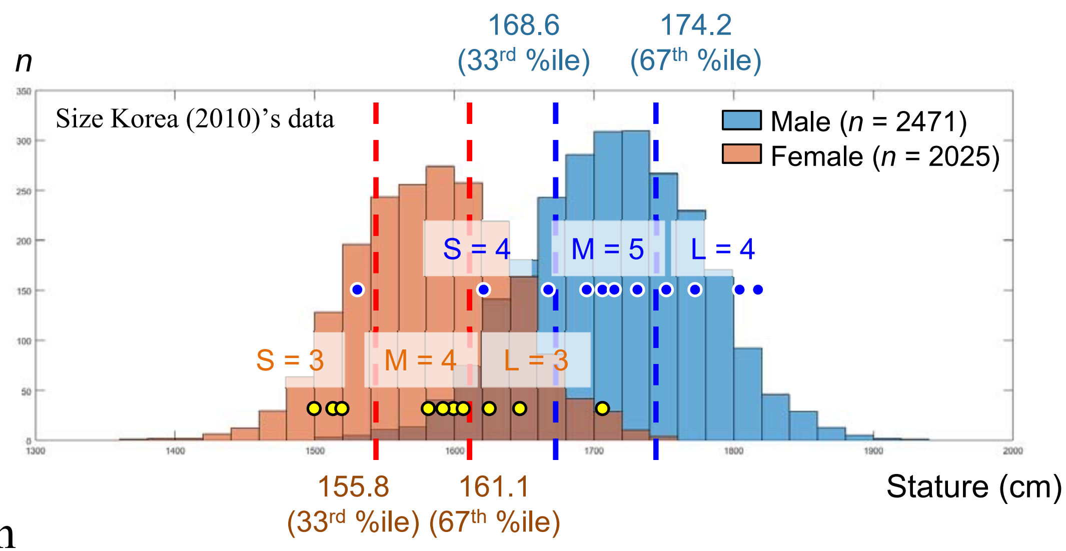


Participants

- Recruited 23 participants
  - ✓ Gender: 10 females, 13 males
  - ✓ Age: 20s ~ 50s (29.2 ± 7.3)
  - ✓ Stature groups: small (≤ 33rd %ile), medium (33rd ~ 67th %ile), and large (≥ 67th %ile) groups of stature by referring to 2010 Size Korea anthropometric data

	Male		Female	
	Size Korea	Experiment	Size Korea	Experiment
M	171.4	171.1	158.4	159.7
SD	6.1	8.4	5.6	6.6
Min	-	152.2	-	150.4
Max	-	183.0	-	172.8
MD				
paired *t*-test	$t(2459) = 2.18$, $p = 0.91$		$t(2016) = 2.26$, $p = 0.54$	

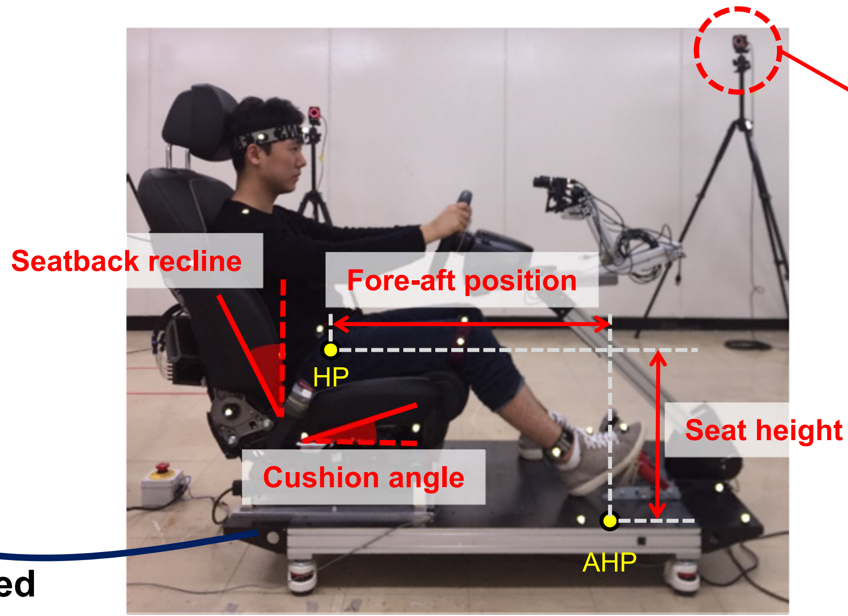
⇒ Mean heights were found similar with Korean population



Apparatus

- ❑ Seating buck
  - ✓ EQ 900 power adjustable seat (Hyundai-Kia Motors, Republic of Korea)
  - ✓ G27 racing wheel and pedals (Logitech, Swiss)
- ❑ Motion analysis system Osprey (Motion Analysis Co., Santa Rosa: CA, USA)
- ❑ PC-based seat control system

Interconnected



8 Osprey cameras

Driving Simulation Experiment: Procedure

- Duration per participant: **60 min**

Preparation (15 min):
- Informed consent (5 min)
- ↓ Body size measurement (5 min) (stature, sitting height, body weight)
- ↓ Marker attachment (5 min)

↓

Exercise (10 min)

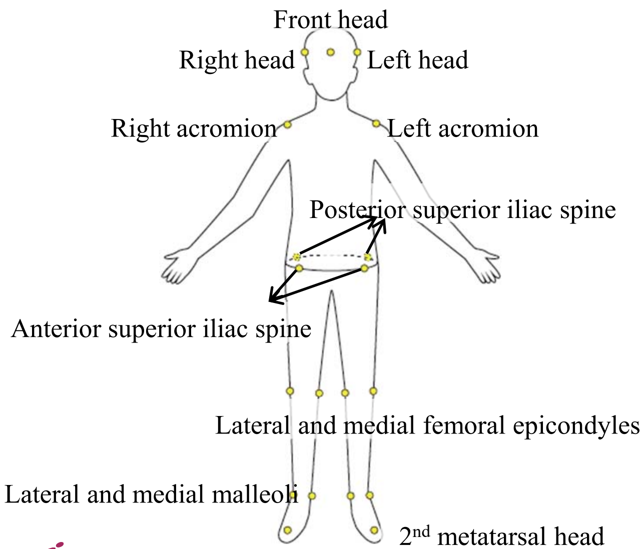
↓

Driving session (30 min) — 1 repetition = 15 min, 2 times:
- Seat adjustment (5 min)
- ↓ Maintenance driving (5 min) (posture measurement)
- ↓ Rest (5 min)

↓

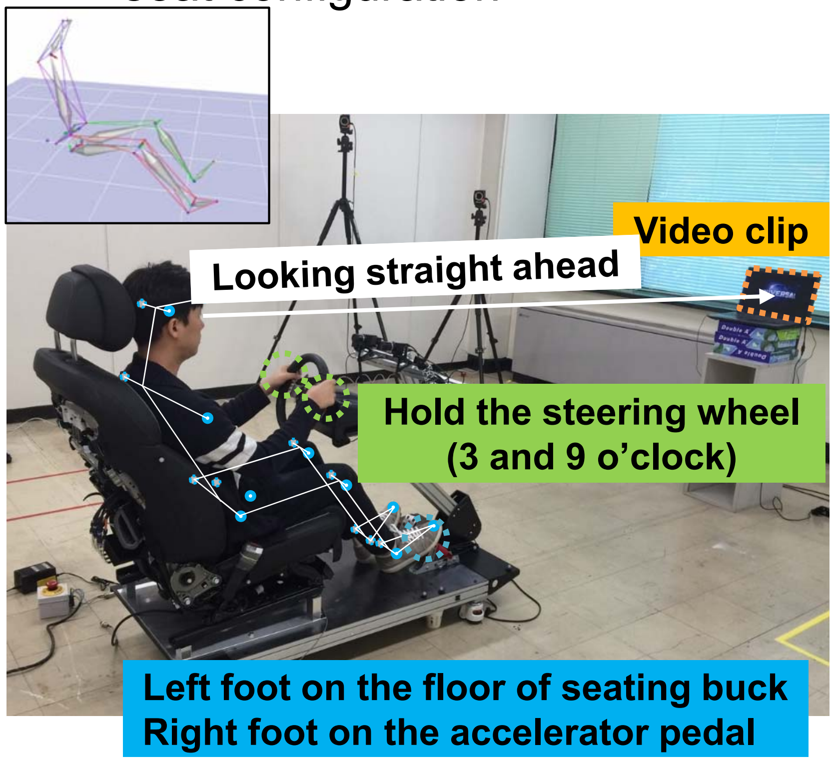
Debriefing (5 min)

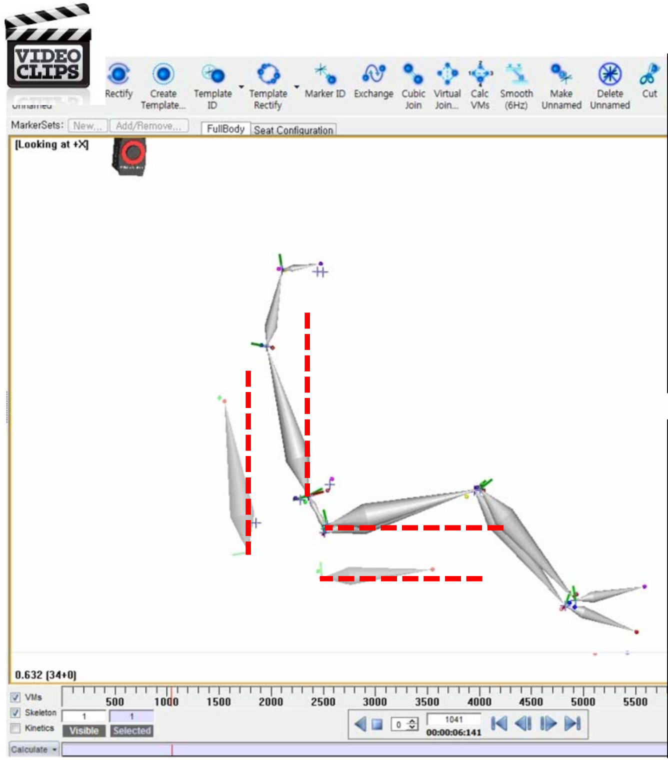
19 reflective markers (ϕ = 1.2 cm) attached to the body

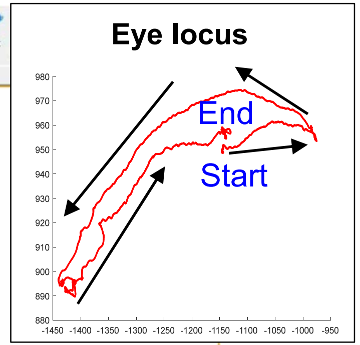


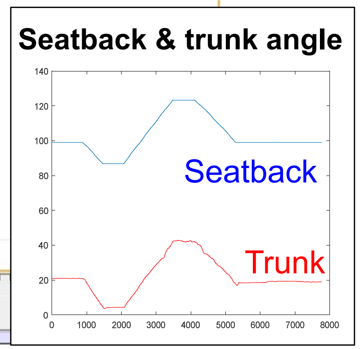
Driving Posture Measurement

- Driving postures and seat configurations were measured while the seat changes its fore-aft seat position (± 60 mm), seat height (± 25 mm), seatback recline angle (± 5°), and seat cushion angle (± 2.5°) from the driver's preferred seat configuration



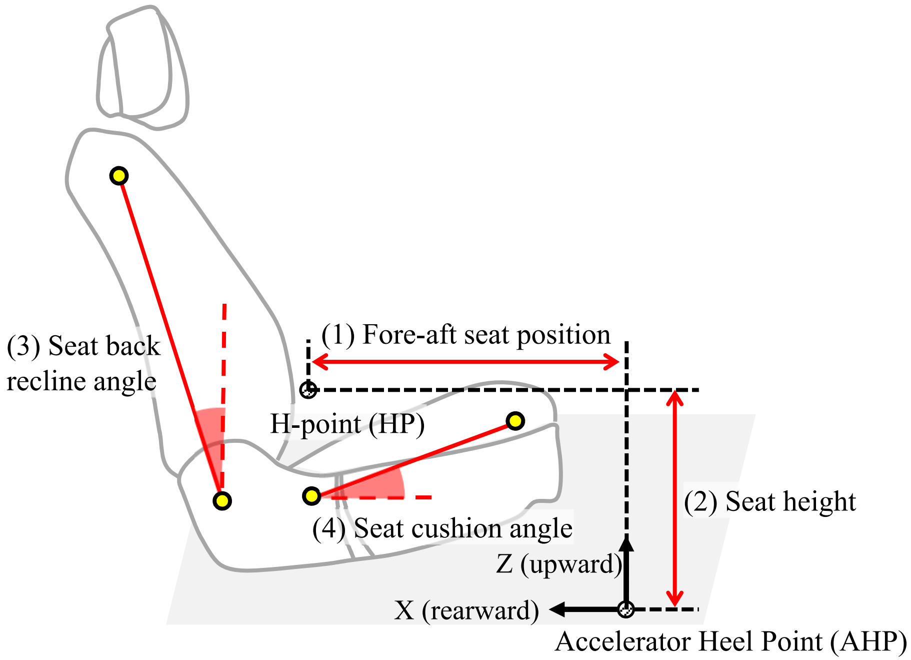


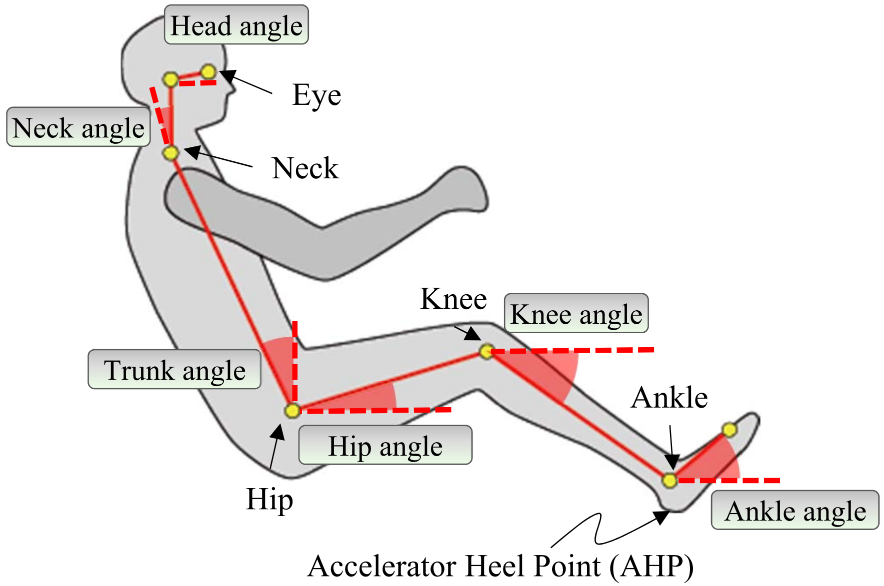




Data of Sitting Posture & Seat Configuration

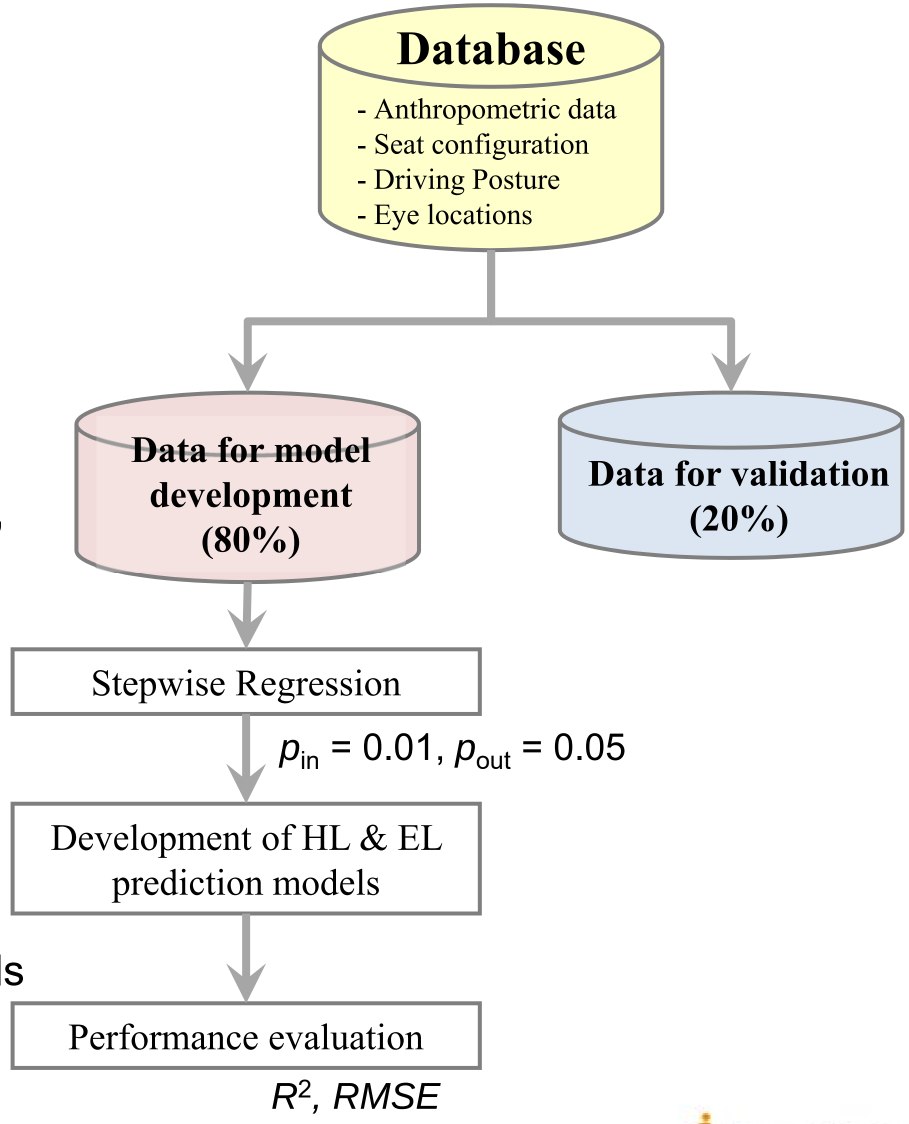
- The origin of the 2D coordinate system was located in the accelerator heel point (AHP) (SAE J1100, SAE, 2009)
- Driving postures and seat configurations were calculated on the sagittal plane





Model Development

- Stepwise regression method was applied to find an initial set of predictors (p_{in} = .01, p_{out} = .05)
- If estimated performance (adj. R^2) does not increase by more than 2%, it is excluded from predictors
- Validation set
  - ✓ Validation of the developed model
  - ✓ Comparison with the existing models



Prediction Models: Summary

- Posture based: R^2 = .85 (.68 ~ .90), *RMSE* = 19.8 (14.2 ~ 26.3) mm
- Seat configuration based: R^2 = 0.81 (.55 ~ .96), *RMSE* = 18.9 (16.8 ~ 21.5) mm

Category	HL & EL	Regression Equation	Adjusted R^2	*RMSE* (mm)
Posture based Models	Hip_x *re*BOF	$133 + \{0.316 \times FL \times \cos(\theta_{ankle})\} + \{1.01 \times LL \times \cos(\theta_{knee})\} + \{0.996 \times UL \times \cos(\theta_{hip})\}$	0.90	26.3
	Hip_z *re*AHP	$221 + \{0.0438 \times FL \times \sin(\theta_{ankle})\} - \{0.504 \times LL \times \sin(\theta_{knee})\} - \{0.622 \times UL \times \sin(\theta_{hip})\}$	0.68	15.6
	Eye_x *re*BOF	$110 + \{0.256 \times FL \times \cos(\theta_{ankle})\} + \{0.981 \times LL \times \cos(\theta_{knee})\} + \{0.950 \times UL \times \cos(\theta_{hip})\} + \{0.918 \times TL \times \sin(\theta_{trunk})\} + \{1.06 \times NL \times \sin(\theta_{neck})\} - \{0.307 \times HL \times \cos(\theta_{head})\}$	0.91	23.0
	Eye_z *re*AHP	$245 + \{0.0843 \times FL \times \sin(\theta_{ankle})\} - \{0.481 \times LL \times \sin(\theta_{knee})\} - \{0.343 \times UL \times \sin(\theta_{hip})\} + \{0.880 \times TL \times \cos(\theta_{trunk})\} + \{0.924 \times NL \times \cos(\theta_{neck})\} + \{0.861 \times HL \times \sin(\theta_{head})\}$	0.89	14.2
Seat configuration based Models	Hip_x *re*BOF	$-104 + \{105 \times S\} + \{1.01 \times L53\}$	0.91	17.7
	Hip_z *re*AHP	$-50.9 + \{8.23 \times S\} + \{0.907 \times H30\} + \{115 \times \sin(\theta_{Cushion})\}$	0.55	19.5
	Eye_x *re*BOF	$221 - \{87.4 \times S\} + \{1.04 \times L53\} - \{693 \times \cos(\theta_{Seatback})\}$	0.96	21.5
	Eye_z *re*AHP	$-646 + \{440 \times S\} + \{0.826 \times H30\} + \{588 \times \sin(\theta_{Cushion})\}$	0.82	16.8

Posture-Based Models: Hip$_x$ *re*BOF & Hip$_z$ *re*AHP

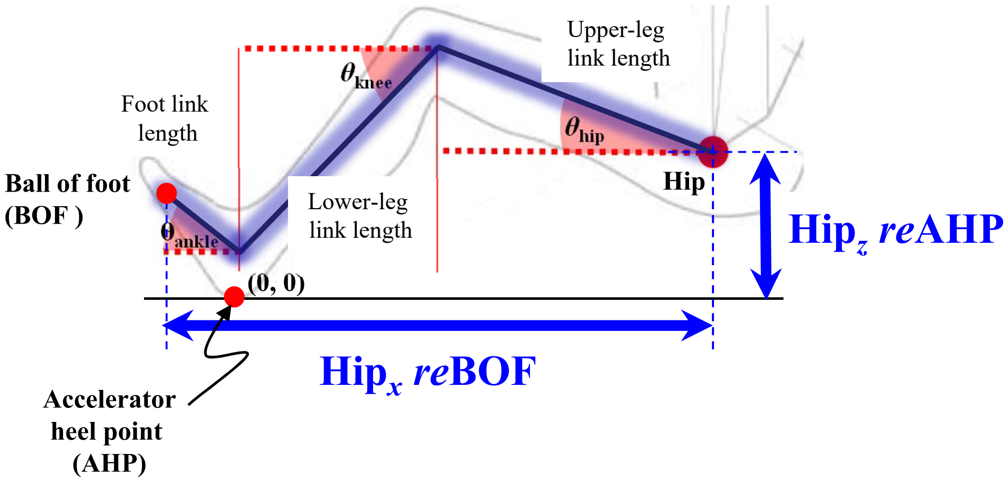
Hip$_x$ *re*BOF = 133 + {0.316 × FL × cos (θ_{ankle})} + {1.01 × LL × cos (θ_{knee})} + {0.996 × UL × cos (θ_{hip})}

Adj. R^2 = 0.90; *RMSE* = 26.3 mm

Hip$_z$ *re*AHP = 221 + {0.0438 × FL × sin (θ_{ankle})} – {0.504 × LL × sin (θ_{knee})} – {0.622 × UL × sin (θ_{hip})}

Adj. R^2 = 0.68; *RMSE* = 15.6 mm

(n = 23)



where: BOF = Ball of foot
AHP = accelerator heel point,
FL = foot link length,
LL = lower-leg link length,
UL = upper-leg link length,
θ_{hip} = hip angle,
θ_{knee} = knee angle,
θ_{ankle} = ankle angle

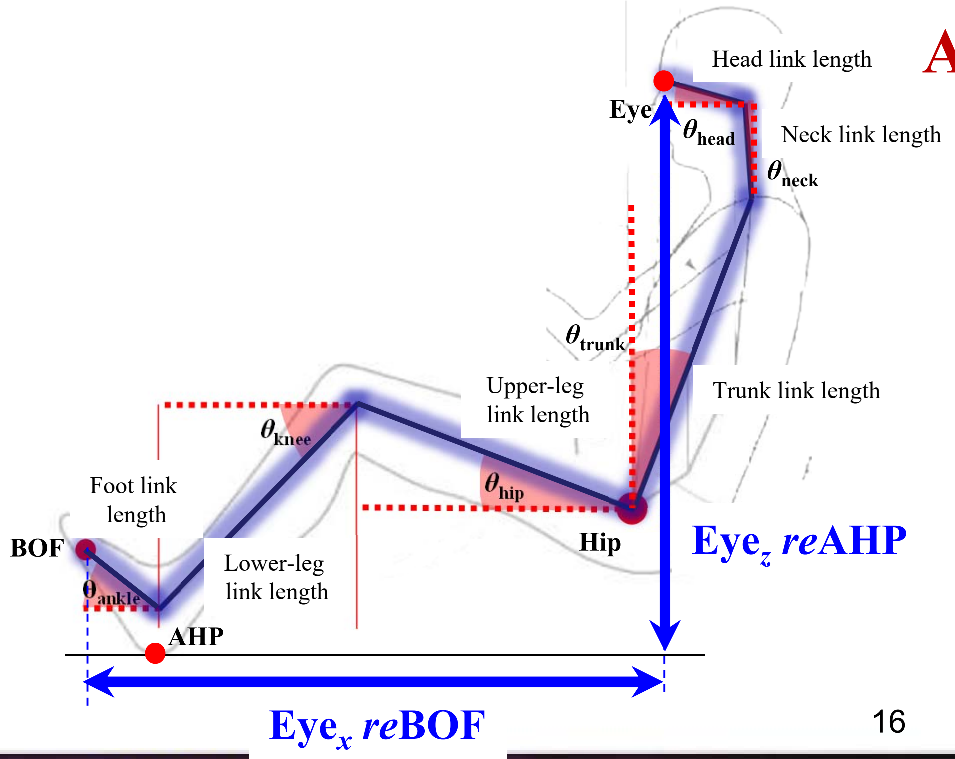
Posture-Based Models: Eye$_x$ *re*BOF & Eye$_z$ *re*AHP

Eye$_x$ *re*BOF = 110 + {0.256 × FL × cos (θ_{ankle})} + {0.981 × LL × cos (θ_{knee})} + {0.950 × UL × cos (θ_{hip})} + {0.918 × TL × sin (θ_{trunk})} + {1.06 × NL × sin (θ_{neck})} – {0.307 × HL × cos (θ_{head})}

Adj. R^2 = 0.91; *RMSE* = 23.6 mm

Eye$_z$ *re*AHP = 245 + {0.0843 × FL × sin (θ_{ankle})} – {0.481 × LL × sin (θ_{knee})} – {0.343 × UL × sin (θ_{hip})} + {0.880 × TL × cos (θ_{trunk})} + {0.924 × NL × cos (θ_{neck})} + {0.861 × HL × sin (θ_{head})}

Adj. R^2 = 0.89; *RMSE* = 14.2 mm



where: BOF = ball of foot,
AHP = accelerator heel point,
FL = foot link length,
LL = lower-leg link length,
UL = upper-leg link length,
TL = trunk link length,
NL = neck link length,
HL = head link length,
θ_{hip} = hip angle,
θ_{knee} = knee angle,
θ_{ankle} = ankle angle,
θ_{trunk} = trunk angle,
θ_{neck} = neck angle,
θ_{head} = head angle,

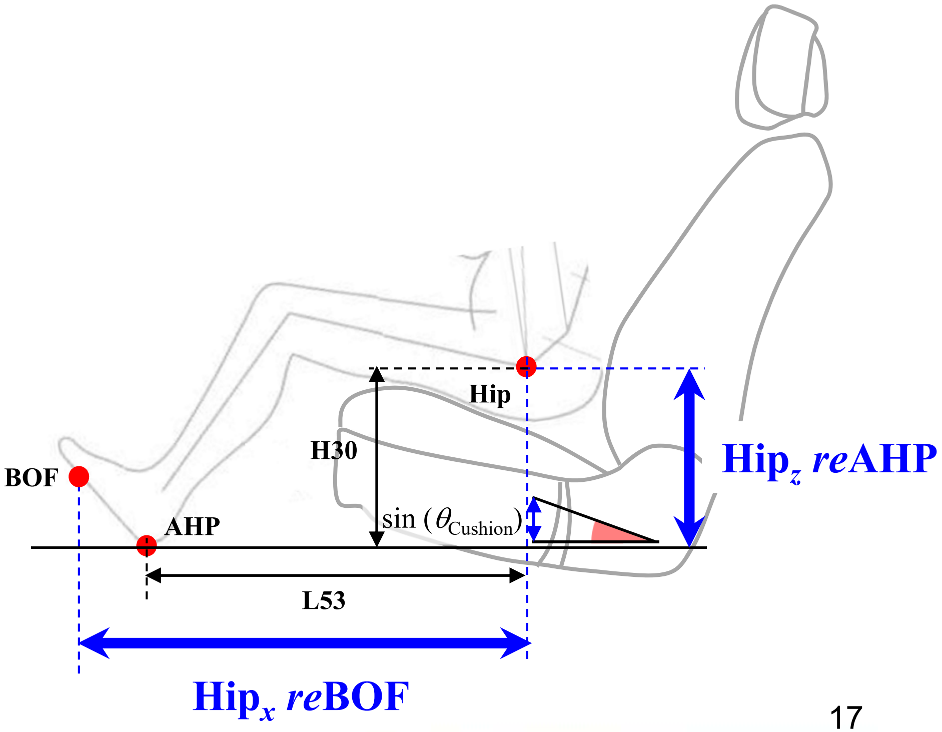
Seat-Based Models: Hip_x *re*BOF & Hip_z *re*AHP

Hip_x *re*BOF = – 104 + {105 × S} + {1.01 × L53}

Adj. R^2 = 0.91; *RMSE* = 17.7 mm

Hip_z *re*AHP = – 50.9 + {8.23 × S} + {0.907 × H30} + {115 × sin ($\theta_{Cushion}$)}

Adj. R^2 = 0.55; *RMSE* = 19.5 mm



where: BOF = Ball of foot,
AHP = Accelerator Heel Point,
S = Stature
L53 = Horizontal AHP-Hip length,
H30 = Vertical AHP-Hip length,
$\theta_{seatpan}$ = cushion angle

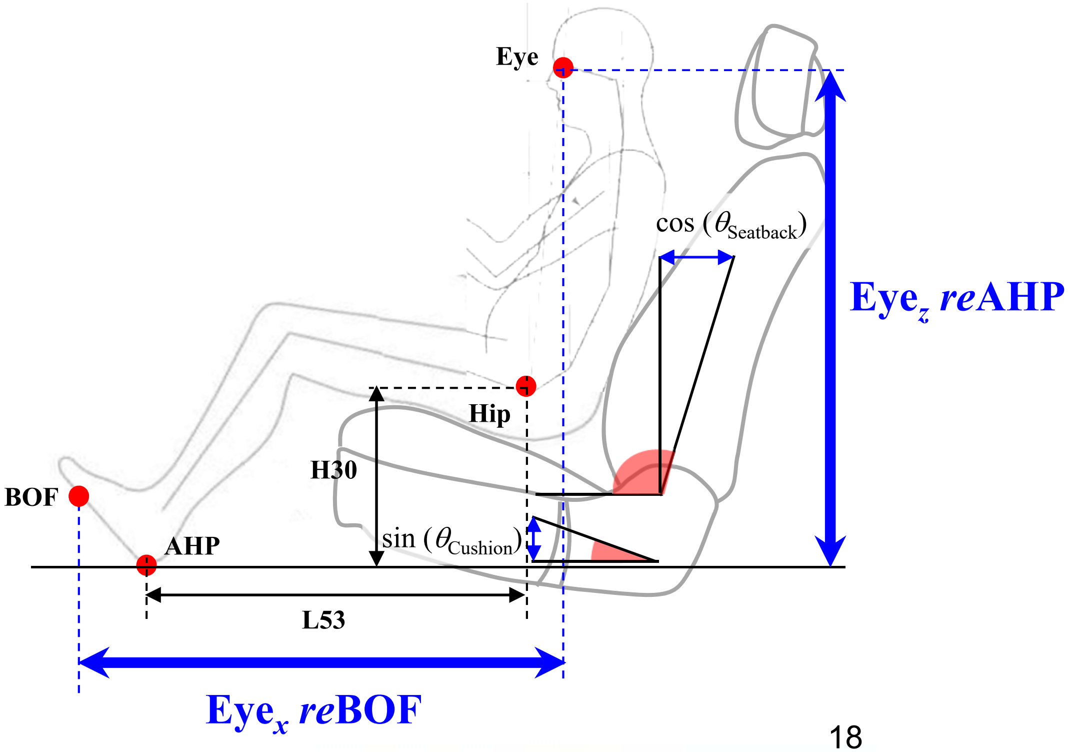
Seat-Based Models: Eye$_x$ *re*BOF & Eye$_z$ *re*AHP

Eye$_x$ *re*BOF = 221 – {87.4 × S} + {1.04 × L53} – {693 × cos ($\theta_{Seatback}$)}

Adj. R^2 = 0.96; *RMSE* = 21.5 mm

Eye$_z$ *re*AHP = – 646 + {440 × S} + {0.826 × H30} + {588 × sin ($\theta_{Cushion}$)}

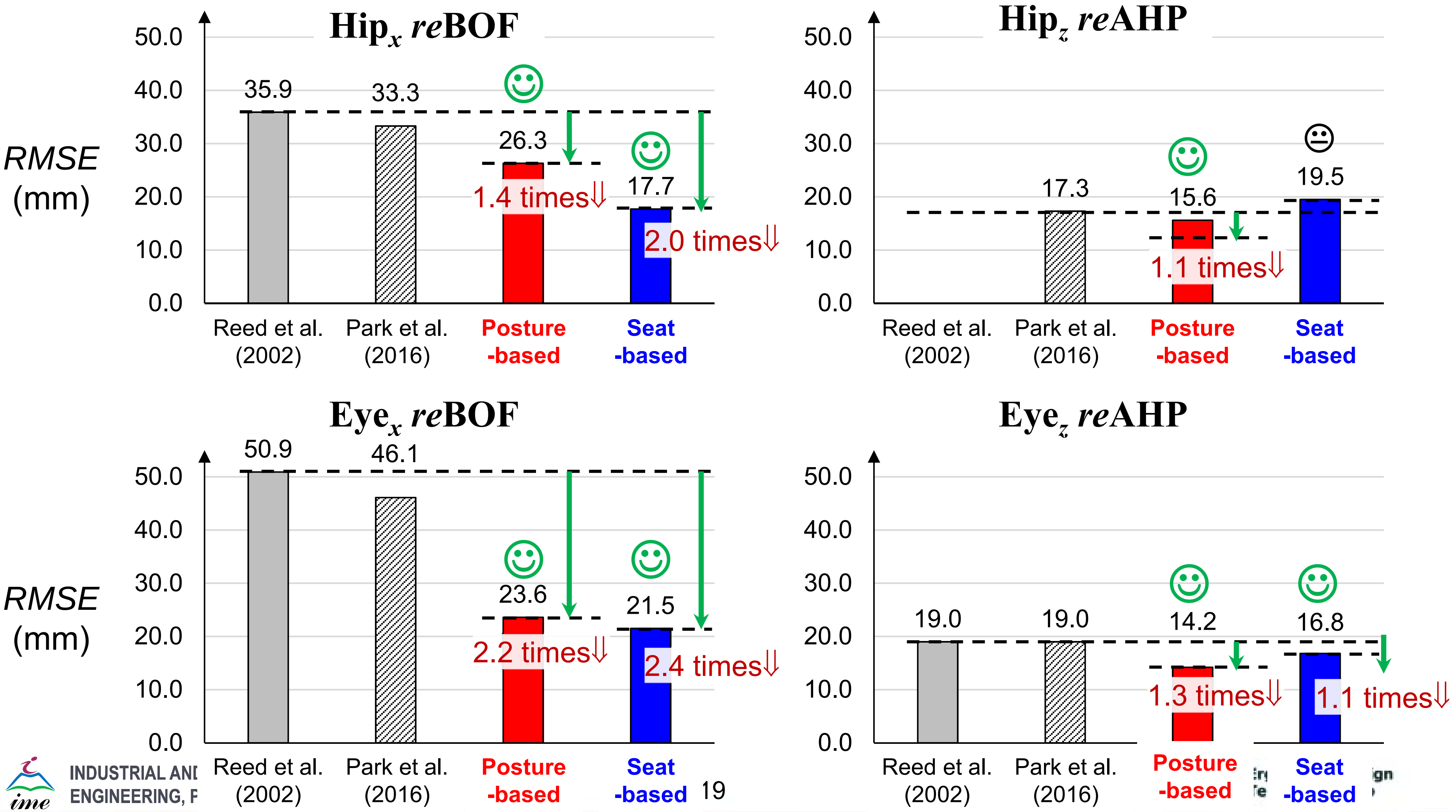
Adj. R^2 = 0.82; *RMSE* = 16.8 mm



where: BOF = Ball of foot,
AHP = Accelerator Heel Point,
S = Stature
L53 = Horizontal AHP-Hip length,
H30 = Vertical AHP-Hip length,
$\theta_{seatback}$ = seatback angle,
$\theta_{seatpan}$ = cushion angle

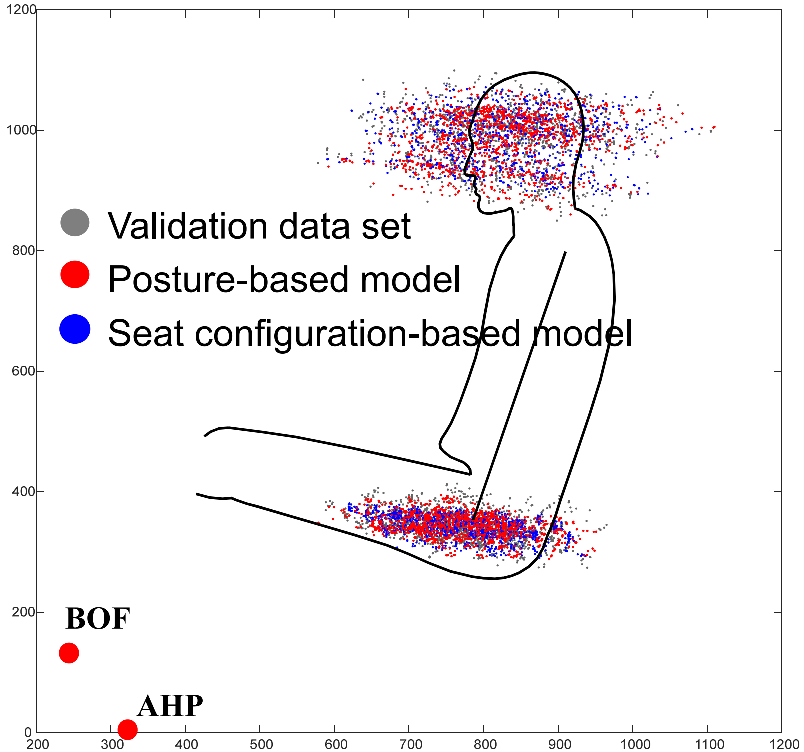
Performance Comparison: *RMSE* (mm)

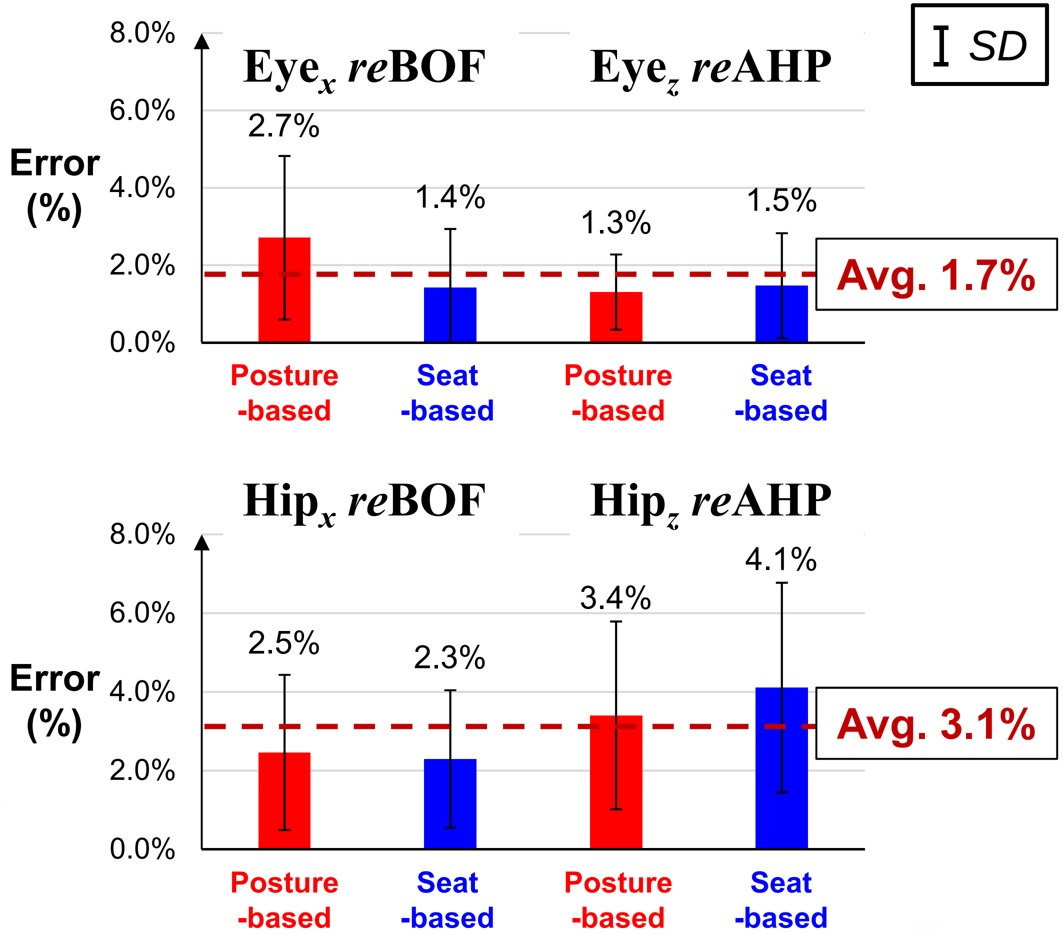
- Horizontal axis models < 1.4 ~ 2.4 × Reed et al.'s models
- Vertical axis models < 1.1 ~ 1.3 × Reed et al.'s models



Model Validation: Prediction Error (%)

- Eye prediction models have on average 1.7% prediction error
- Hip prediction models have on average 3.1% prediction error





Practicality of HL & EL Models

- Two groups of statistical models for prediction of a driver's HL and EL:

  (1) Posture-based model: Geometric relationships of HL and EL with link lengths and joint angles

  (2) Seat configuration-based model: Geometric relationships of HL and EL with fore-aft seat position, seat height, seat back recline angle, and seat cushion angle

  ⇐ The seat configuration-based models are preferred to the posture-based models in terms of practicality because the posture based models require predetermined posture information to predict the driver's HL and EL

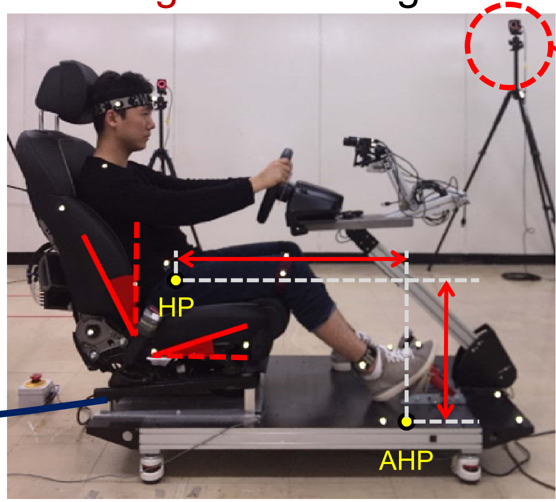
  ⇐ The posture-based models can be used to estimate the driver's HL & EL for an optimal driving posture specified

Known		Model		Results (example)
Predetermined HL & EL	→	**Seat configuration-based**	→	**Design suitability**
Comfortable Driving posture	→	**Posture-based**	→	**HL & EL Appropriateness**

Accuracy of HL & EL Models

- The seat configuration- and posture-based models developed in the present study showed high accuracy in prediction of HL (RMSE = 19.8 mm) and EL (RMSE = 18.9 mm)
  - ⇐ Accurate measurement of HL, EL, link length, and joint angles would contribute to the performance of prediction models
  - ⇐ Motion capture system provides more accurate measurement of driving posture
  - ⇐ The PC-based seat control system used in this study can measure driver's natural HL, EL, and driving posture changes according to seat configuration change

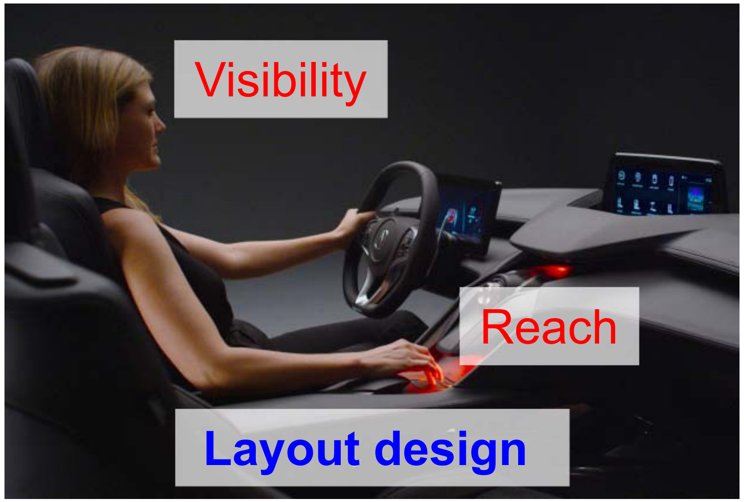
PC-based seat control system



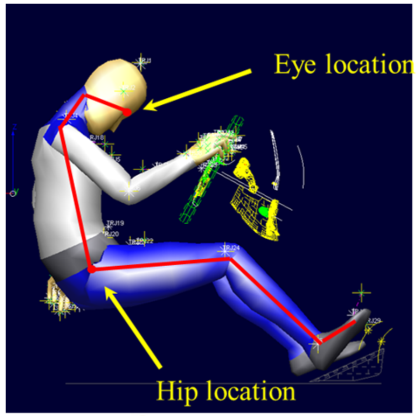
8 Osprey cameras

Application of HL & EL Models

- Drivers' HL & EL prediction models can be used for
  - ✓ intelligent car design which provides driver with convenience such as auto seat adjustment and side mirror control
  - ✓ layout design of in-vehicle interface for various driving assistance systems, infotainment systems, entertainment systems, etc.
  - ✓ evaluation of ergonomic simulation based on digital human model considering various body sizes, sitting postures, and seat configurations

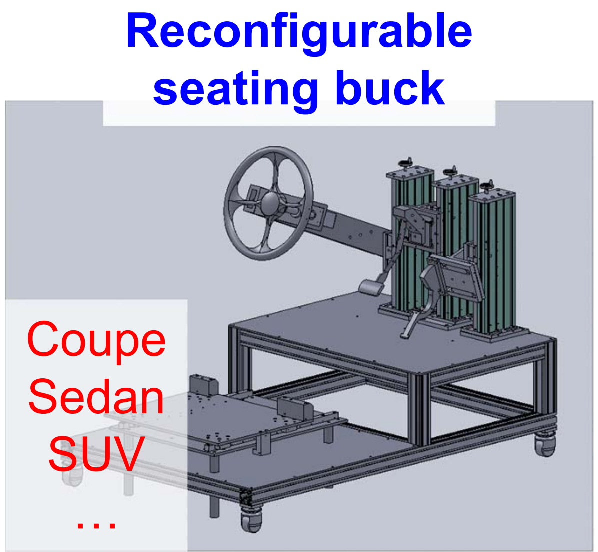


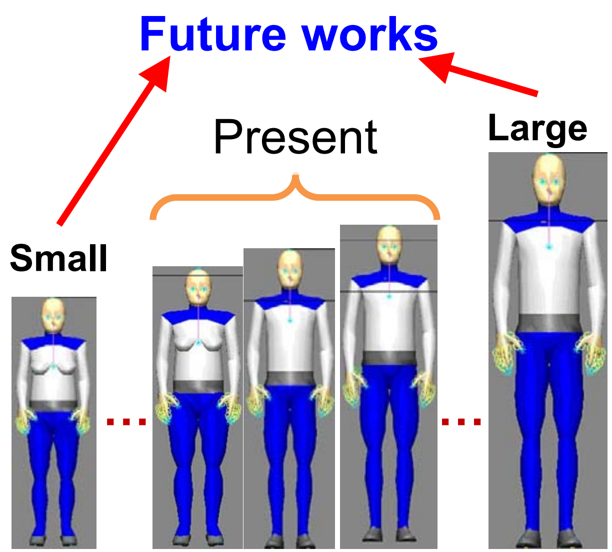
Ergonomic simulation



Future Research

- ❑ Validation of the prediction models in the real car condition
- ❑ Generalization of prediction models by considering various occupants package layout (e.g., coupe, SUV) conditions
  - ⇐ Prediction models developed in this study can be applied only to sedan condition
- ❑ Applicability of prediction models that can be applied to extremely small & large drivers





Q & A

Thank you for your attention…