포항공과대학교
산업경영공학과

Ergonomic Design
Technology Lab

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

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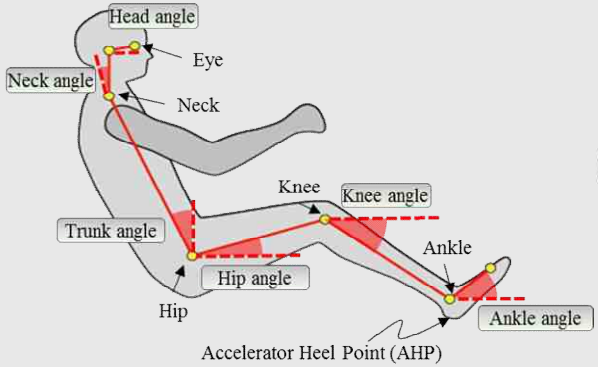
POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY

INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

Ergonomic Design Technology Lab



HYUNDAI | NEW THINKING. NEW POSSIBILITIES.

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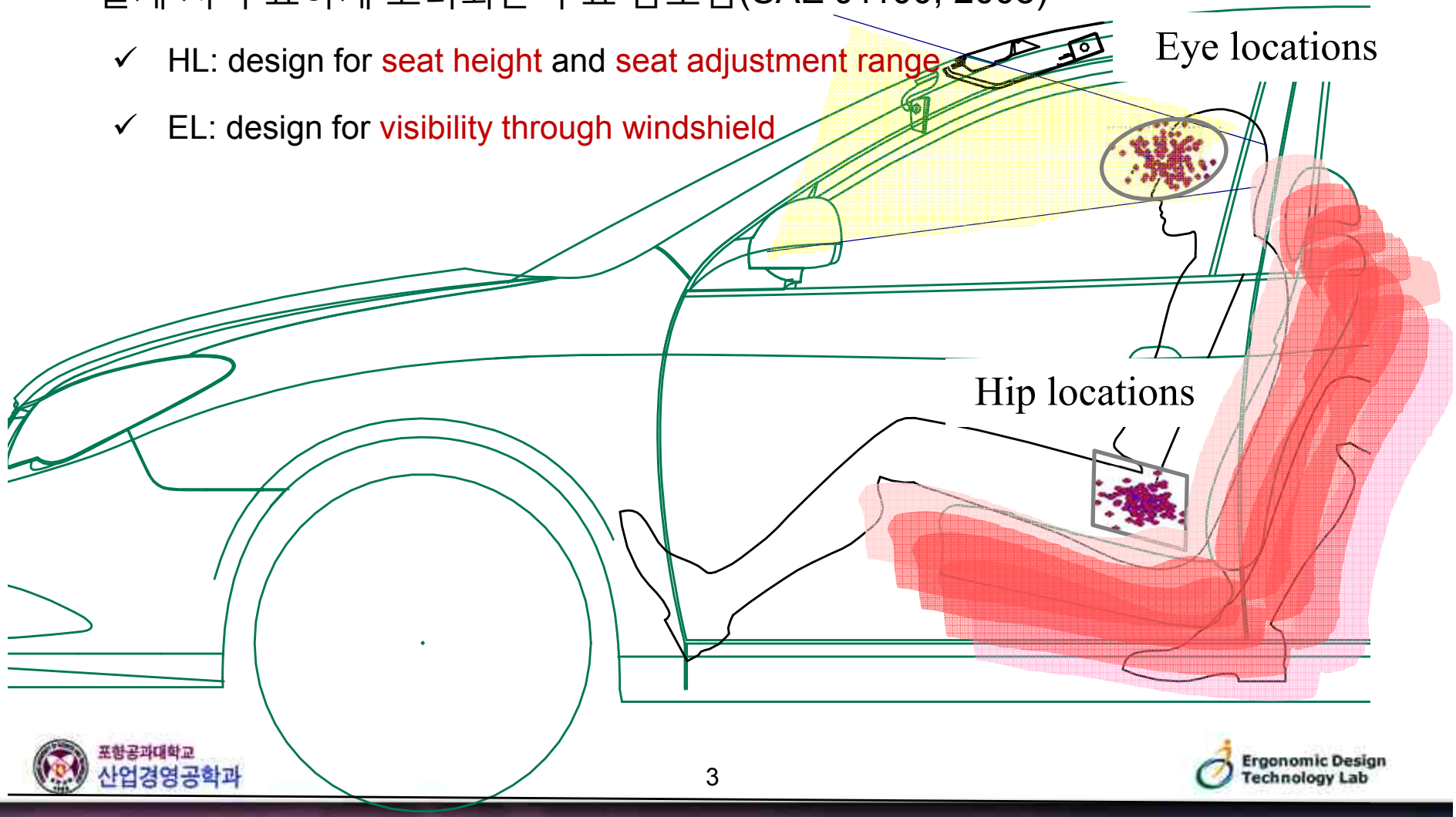
Global Contributor to Eco-Techno-Humanopia

Agenda

- 연구 배경 및 필요성
- 연구 목적
- 연구 방법
  - ✓ Hip & eye locations 측정 protocol
  - ✓ Statistical geometric model (SGM) 개발
- 연구 방법
  - ✓ Posture-based model
  - ✓ Seat configuration-based model
  - ✓ Model evaluation
- Discussion

Drivers' Hip & Eye Locations (HL & EL)

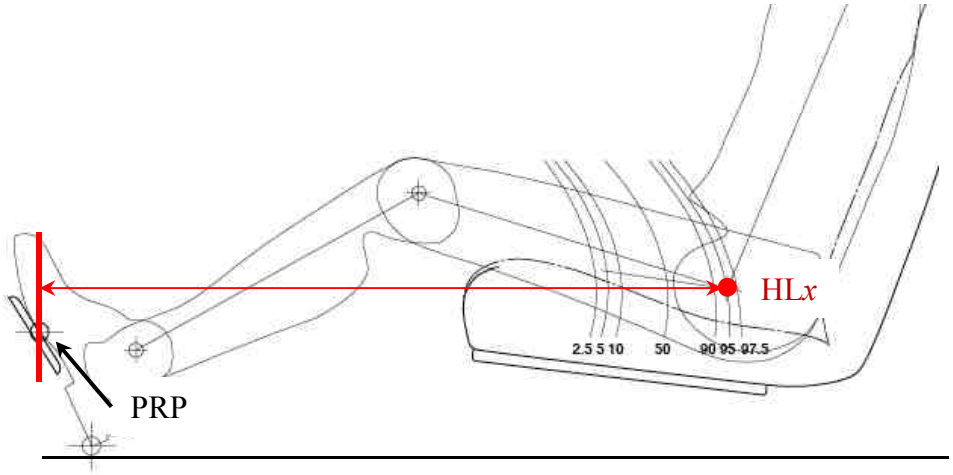
- Hip location (HL)과 eye location (EL)은 occupant package layout (OPL) 설계 시 주요하게 고려되는 주요 참조점(SAE J1100, 2005)
  - ✓ HL: design for seat height and seat adjustment range
  - ✓ EL: design for visibility through windshield



Statistical Model: H-point Prediction Models

- SAE J1517 (2011)은 seat 조절 범위를 설계하기 위해 95%의 운전자를 수용하는 H-point prediction model 개발

(Unit: mm)



$$HLx_{2.5} = 687.1 + 0.895 \times H30 - 0.0021 \times H30^2$$

$$HLx_{97.5} = 936.6 + 0.614 \times H30 - 0.0019 \times H30^2$$

where: $HLx_{2.5}$= horizontal reference location of the 2.5th %ile H-point aft of the pedal reference point (PRP)

$HLx_{97.5}$ = location of the 97.5th %ile H-point aft of the PRP

H30 = seat height

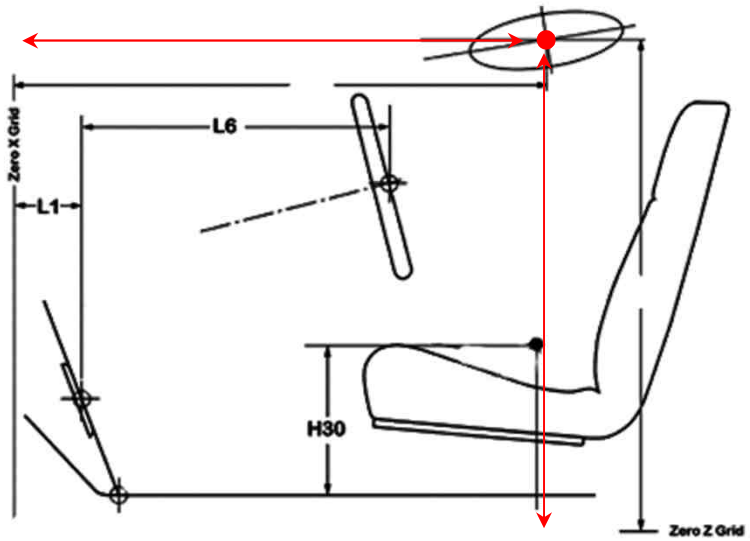
Limitations

1) 개발된 추정식에 대한 성능을 제시하지 않음(e.g., adj. R^2, *RMSE*)
2) Human variables (e.g., body segment lengths, driving postures) 고려하지 않음
3) 다양한 seat 조절 변수(e.g., seatback angle, cushion angle) 고려하지 않음

Statistical Model: EL Prediction Models

- SAE J941 (2010)은 occupant package layout (OPL) 변수를 사용하여 EL을 추정하는 모델을 개발함

(Unit: mm)



$$EL_x = L1 + 664 + 0.587 \times L6 - 0.176 \times H30 - 12.5 \times t$$

$$EL_{y\text{-left}} = W20 - 32.5$$

$$EL_{y\text{-right}} = W20 + 32.5$$

$$EL_z = H8 + 638 + H30$$

where:

PRP = pedal reference point,

AHP = accelerator heel point,

L1 = PRP*x* coordinate,

L6 = steering wheel center to PRP,

H30 = seat height (*z* coordinate of the SgRP, measured vertically from AHP),

t = transmission type (0 = without clutch pedal; 1 = with clutch pedal),

W20 = SgRP *y* coordinate,

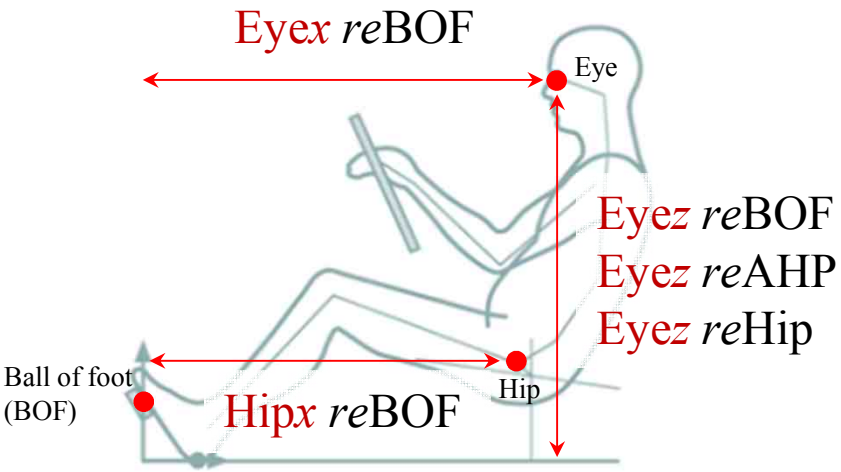
H8 = AHP *z* coordinate

Limitations

1) 개발된 추정식에 대한 성능을 제시하지 않음(e.g., adj. R^2, *RMSE*)
2) Human variables (e.g., body segment lengths, driving postures) 고려하지 않음
3) 다양한 seat 조절 변수(e.g., seatback angle, cushion angle) 고려하지 않음

Statistical Model: HL and EL Prediction Models

- Reed et al.(2002)은 anthropometric 변수(stature, sitting height/stature), OPL 변수(H30, SW to BOFx, cushion angle), design reference points (HL, EL)의 linear relationship을 사용하여 HL과 EL의 추정식 개발



	Anthro. vars.			OPL vars.				
Variable (mm or °)	Intercept	Stature (mm)	Sitting Height/ Stature	Seat Height (H30; mm)	SW to BOFx (L6; mm)	Cushion Angle (L27; °)	R^2_{adj}	RMSE
Hipx reBOF	84.8	0.4659	−430.1	−0.1732	0.4479	−1.04	.78	35.9
Hip-to-eye angle	−72.7	0.00642	115.7	—	0.0147	0.11	.20	3.9
Eyex reBOF	−836.6	0.5842	916.6	−0.1559	0.6101	—	.71	50.9
Eyez reAHP	−267.1	0.3122	679.9	1.0319	0.0292	—	.89	21.8
Eyex reHip	−916.0	0.1187	1347.2	—	0.1563	1.15	.23	41.7
Eyez reHip	−261.5	0.3336	675.8	—	−0.0544	—	.72	22.9

Limitations

1) Body segment의 lengths와 driving posture를 고려하지 않음
2) Cushion angle 외 seat 조절 변수(e.g., seatback angle, seat height) 고려하지 않음

연구 목적

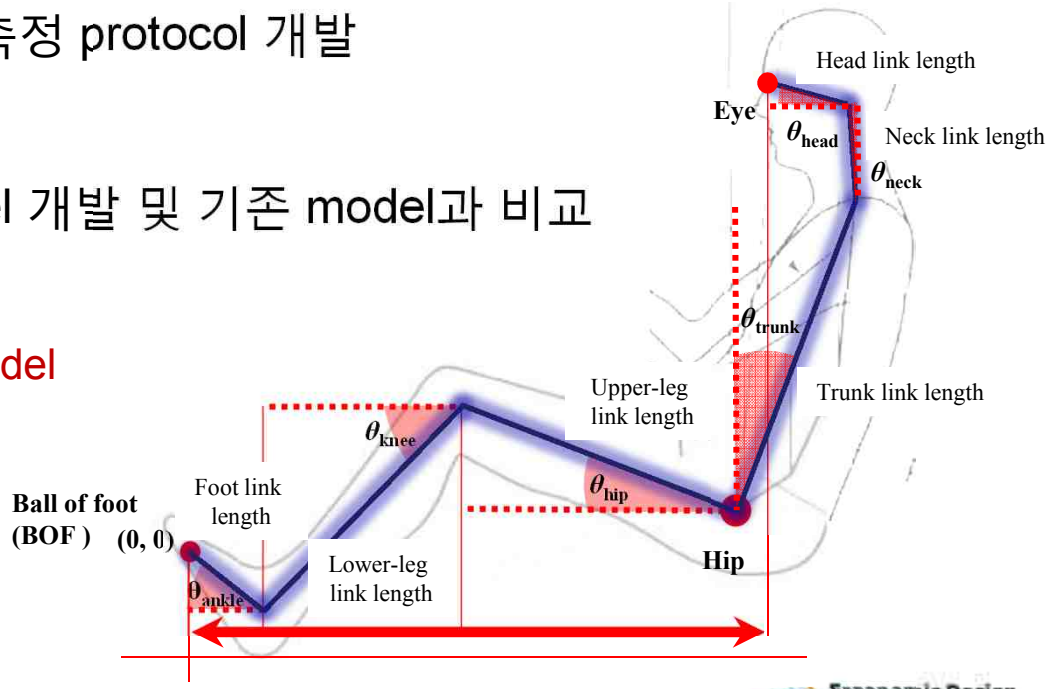
Development of Statistical Models

for Predicting a Driver's Hip and Eye Locations

1) 운전자의 hip & eye location 측정 protocol 개발

2) Hip & eye location 추정 model 개발 및 기존 model과 비교

- Driving posture based model
- Seat configuration based model



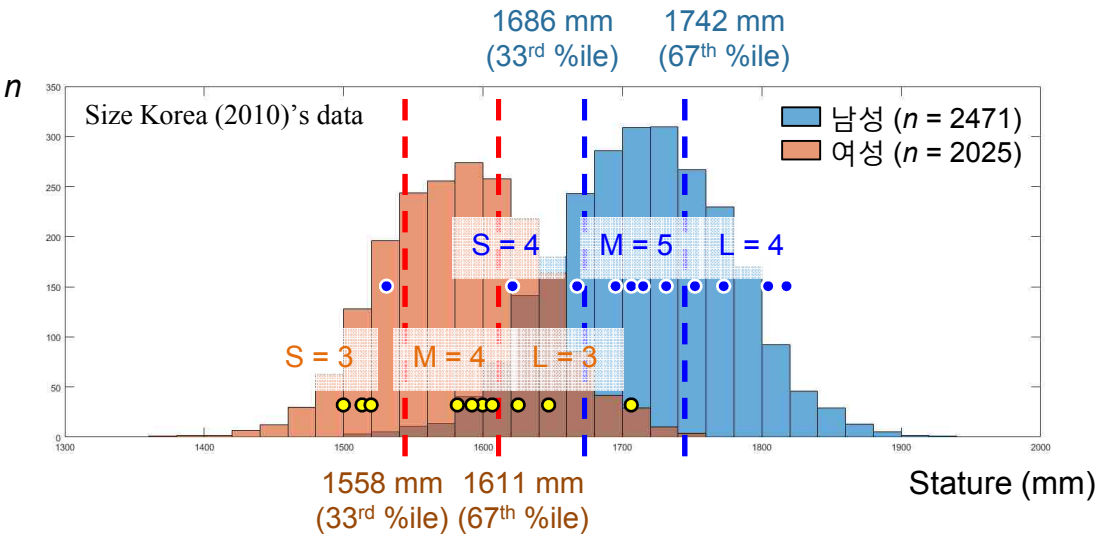
실험 참여자

- n = 23명(남성: 13명, 여성: 10명)
- 연령: M = 29.2, SD = 7.3, R = 24 ~ 51세
- 실험 참여자의 신장은 Size Korea (2010) 한국인 평균 인체크기와 유사

  ⇒ 통계적으로 적합하게 한국인 모집단을 대표

	남		여	
	Size Korea	본 실험	Size Korea	본 실험
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	

*Size Korea (2010) 6차 인체측정자료



실험 Protocol

S1. 실험 설명 및 동의서 작성 (10 min)

S2. 인체 측정 및 marker 부착 (10 min)

- 인체 측정 항목: stature, body weight
- Reflective marker: 19개

S3. 선호 운전 자세 조절 (10 min)

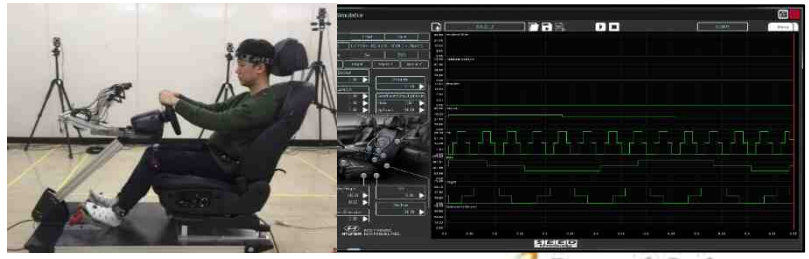
S4. Seat 조절 Profile 생성 (5 min)

- Experimental design에 따라 81가지 생성
  - ✓ Factors: recline, tilt, slide, height
  - ✓ Factor level: 3 (선호 위치, 선호 위치 ± α)

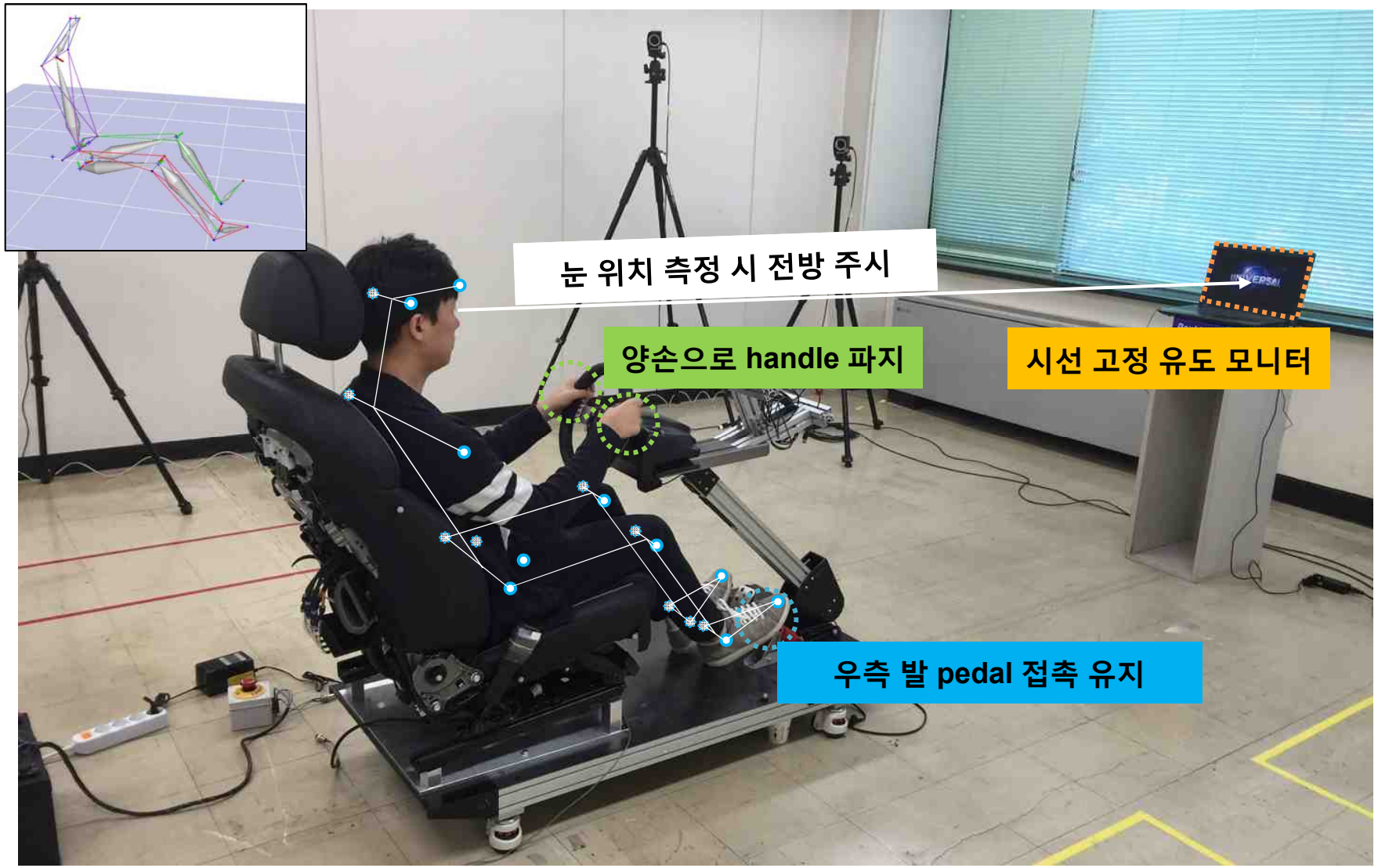
S5. 눈 위치 및 운전 자세 측정(7 min)

2회 반복

총 소요 시간: 약 1시간 / 인



실험 환경



Experimental Design

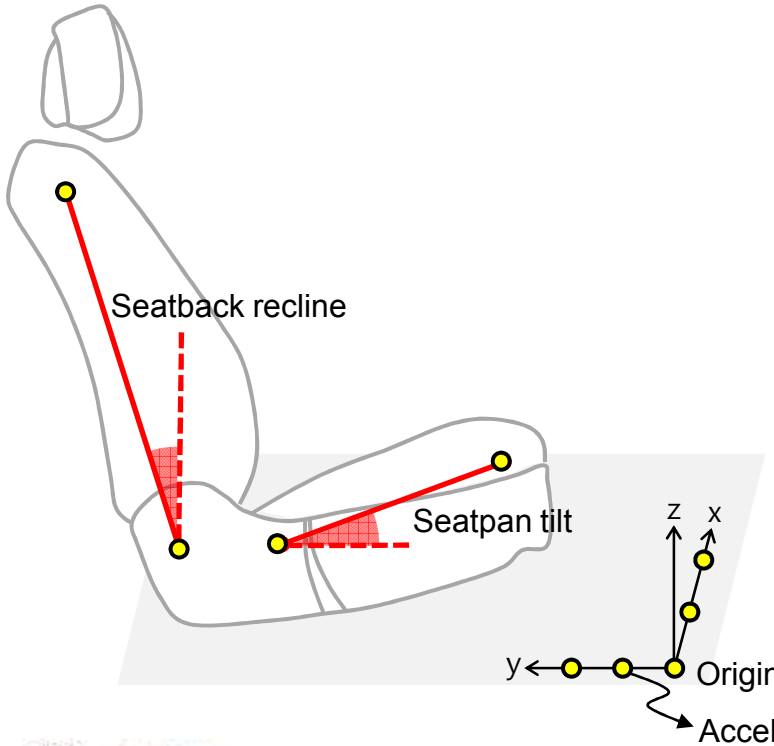
- **인자**: (1) seatback recline, (2) seatpan tilt, (3) seat slide, (4) seat height
- **인자 수준**: 3-level (선호 위치, 선호 위치 ± α)
  - ✓ Setback recline (± 5°), seatpan tilt (± 15 mm)
  - ✓ Seat slide (± 60 mm), seat height (± 25 mm)

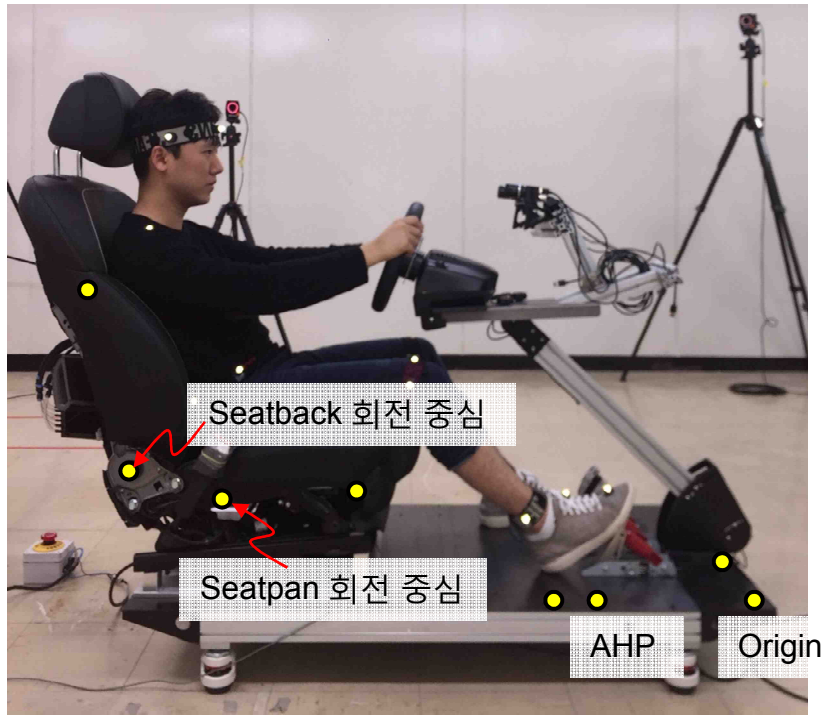
항목	Factor	Factor level		
1	Seatback recline	P – 5°	선호 위치 (Preference, P)	P + 5°
2	Seatpan tilt	P – 15 mm		P + 15 mm
3	Seat slide	P – 60 mm		P + 60 mm
4	Seat height	P – 25 mm		P + 25 mm
실험 조건	**L81(3^4) + 선호 위치 = 총 82 조건**			
실험 소요 시간(명)	7 sec/조건 × 82조건 × 2회 = 약 19분			

※ 통제 변인: headrest, shoulder, lumbar, bolster 조절량

Reflective Marker: Seat

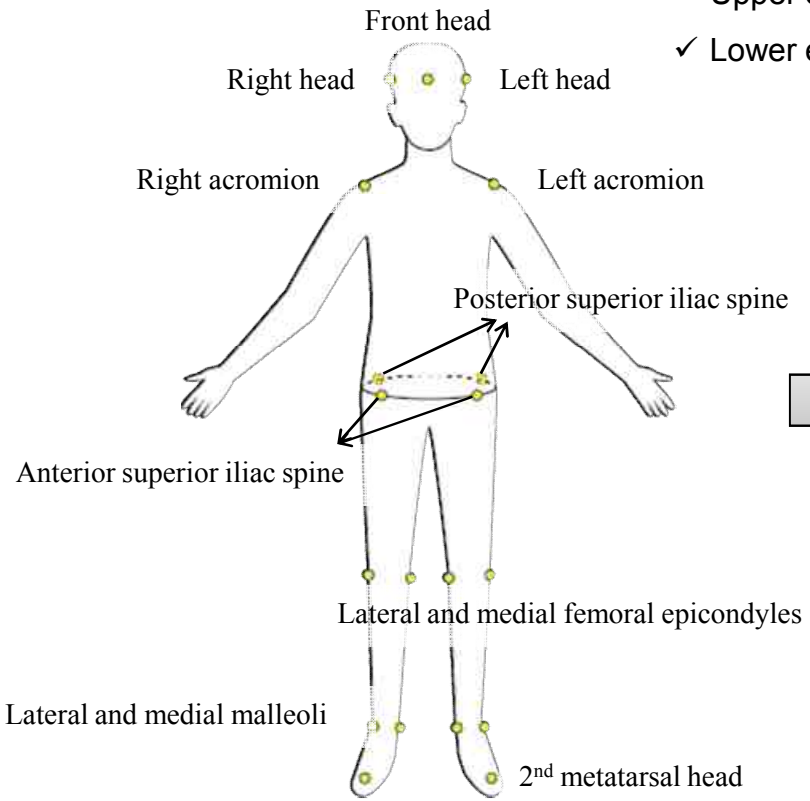
- Seat 조절량(seat 부위별, seat 전반) 측정 marker 부착
- Global coordinate system (origin) 정의를 위한 marker 부착
  - ✓ 기준점(0,0,0)으로부터 서로 수직을 이루는 $\vec{x}, \vec{y}$ 생성(지면과 평행)
  - ✓ $\vec{z} = \vec{x} \times \vec{y}$ (지면과 수직)





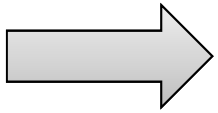
Reflective Marker: Human

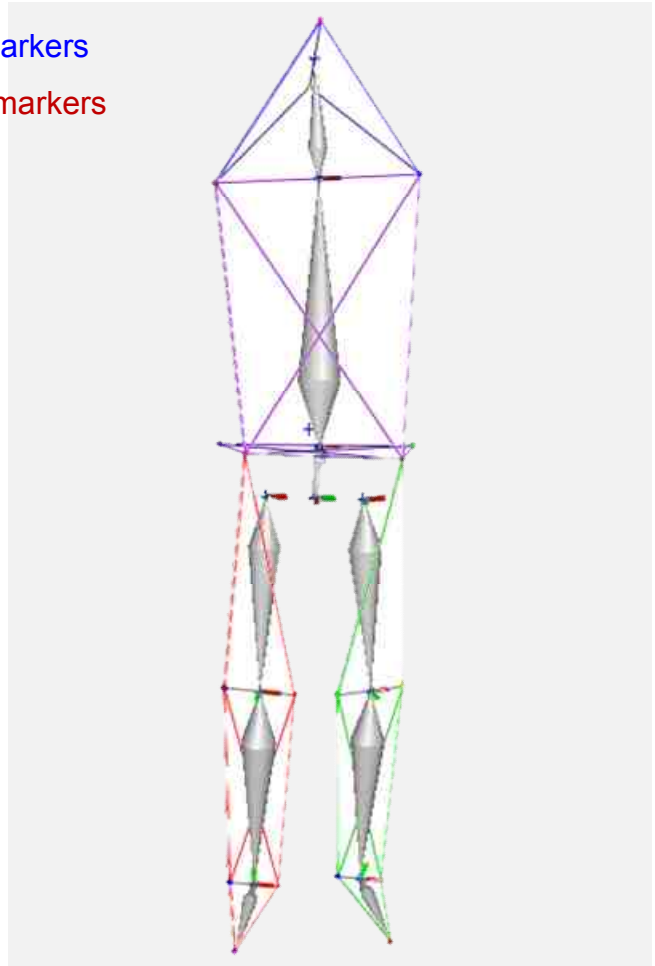
- 19 markers on bony landmark



✓ Upper extremity: 5 markers

✓ Lower extremity: 14 markers

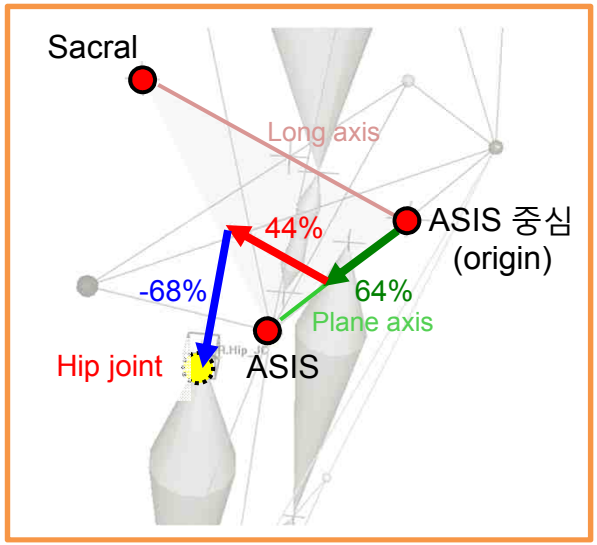


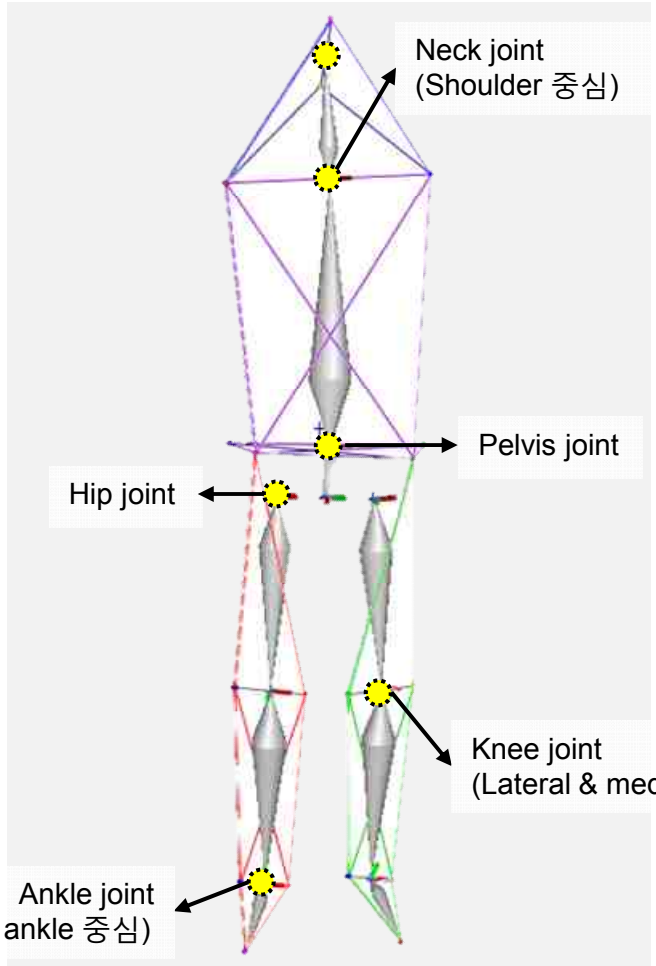


Joint Center

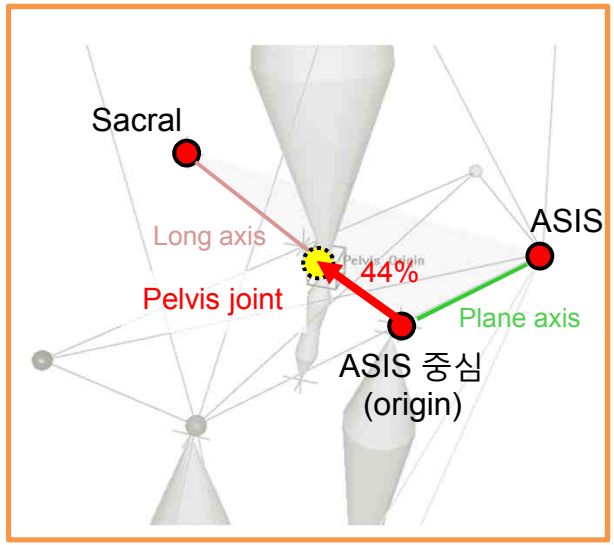
❑ HelenHayes marker set (Vaughan et al., 1999)의 joint center 정의 참고

Hip Joint 정의



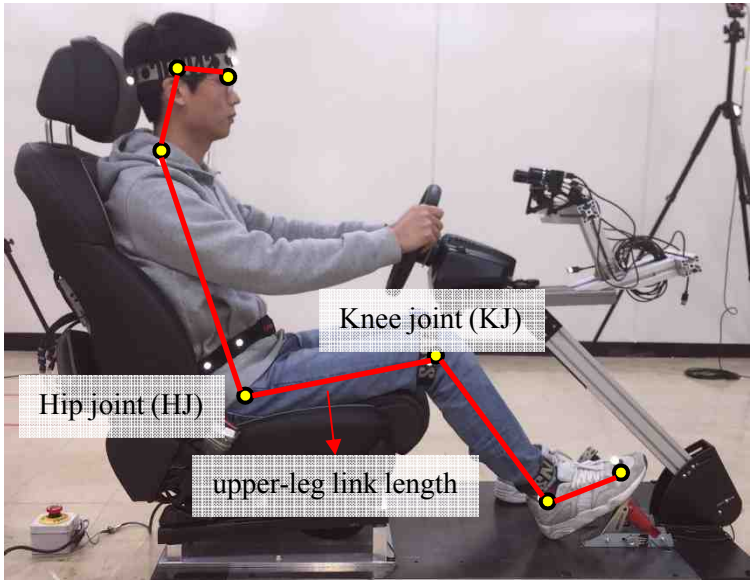


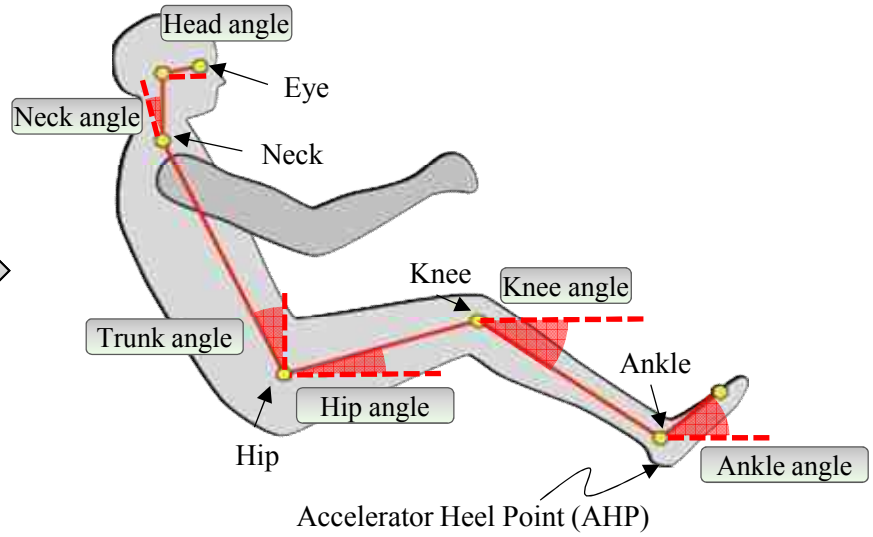
Pelvis joint 정의



Joint Angle & Link Length

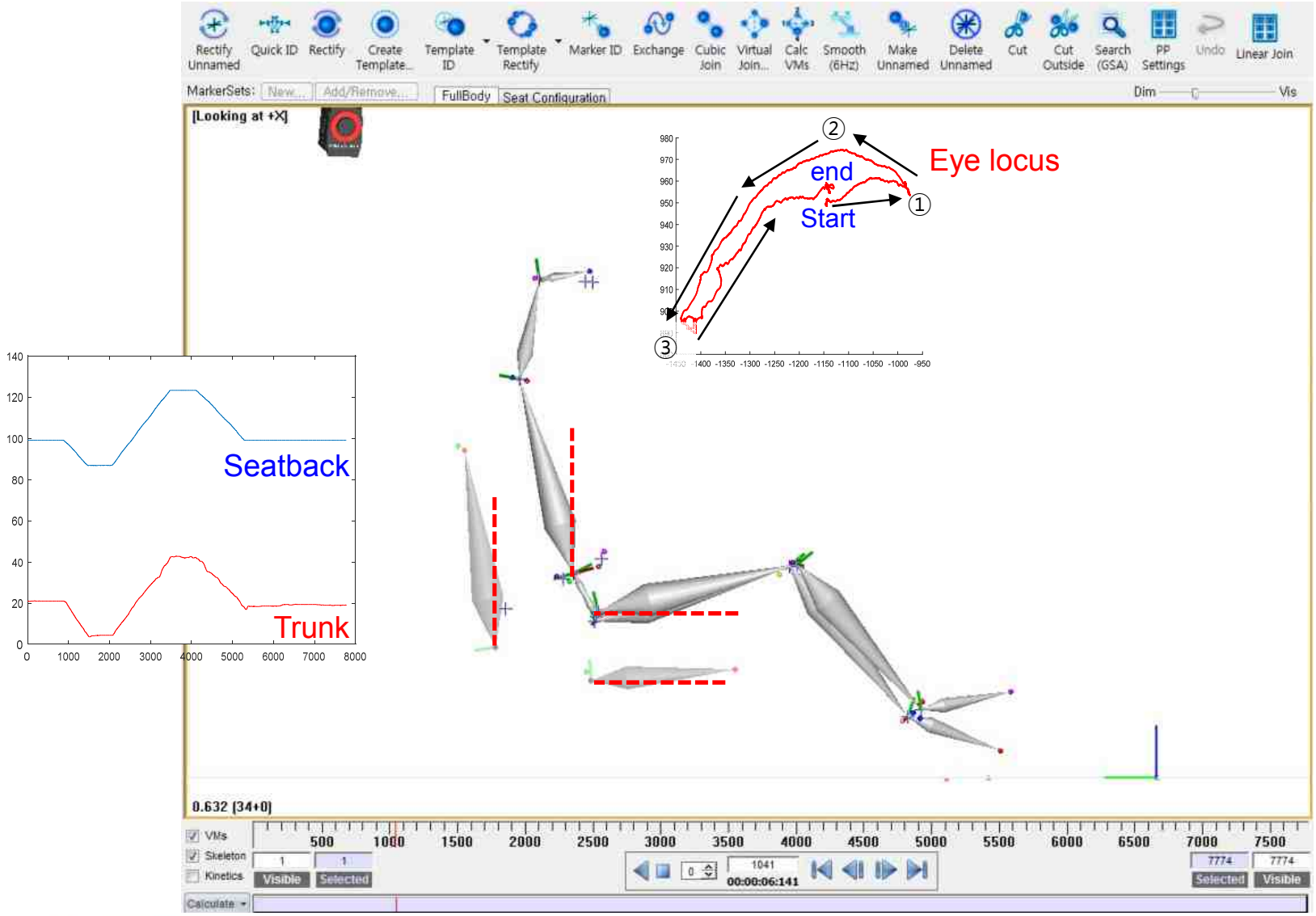
- Flexion/extension angle: sagittal plane에서 linkage 사이 각도
- Link length: Joint center간 Euclidian distance





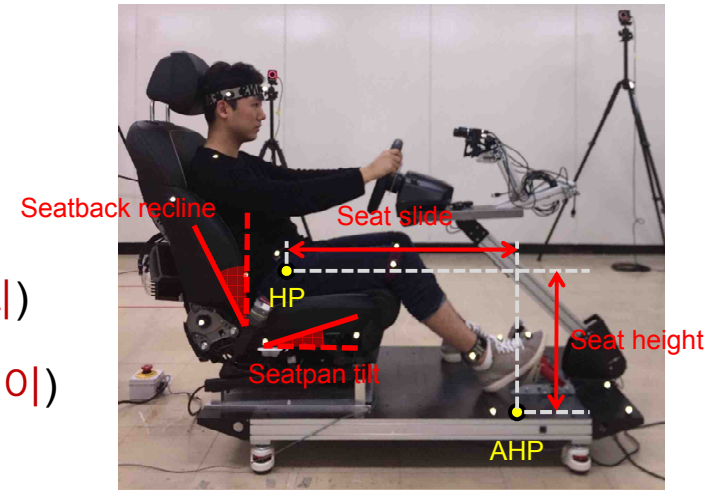
예) upper-leg link length = $\sqrt{(Hj_x - Kj_x)^2 + (Hj_y - Kj_y)^2 + (Hj_z - Kj_z)^2}$

운전 자세 측정 예

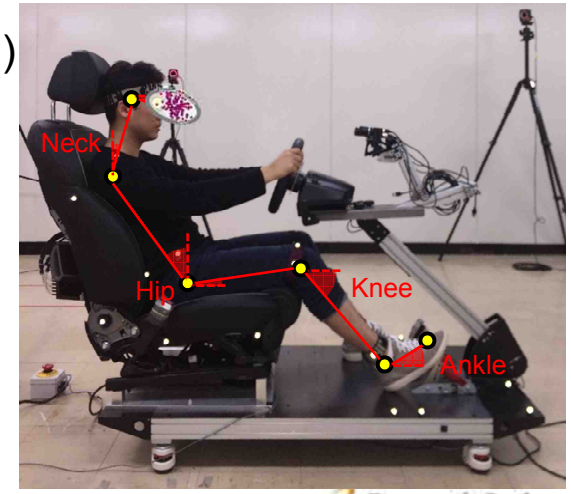

Rectify Unnamed
Quick ID
Rectify
Create Template...
Template ID
Template Rectify
Marker ID
Exchange
Cubic Join
Virtual Join...
Calc VMs
Smooth (6Hz)
Make Unnamed
Delete Unnamed
Cut
Cut Outside
Search (GSA)
PP Settings
Undo
Linear Join
MarkerSets:
New...
Add/Remove...
FullBody
Seat Configuration
Dim
Vis
[Looking at +X]
Eye locus
end
Start
Seatback
Trunk
0.632 [34+0]
VMs
Skeleton
Kinetics
Visible
Selected
00:00:06:141
Calculate

Data Extraction

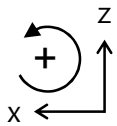
- Seat configuration 관련 변수
  1. Seatback recline
  2. Seatpan tilt
  3. Seat slide: HP_x *re*AHP (Hip point – AHP 수평 거리)
  4. Seat height: HP_z *re*AHP (Hip point – AHP 수직 높이)



- Posture 관련 변수
  1. Joint angle: ankle, knee, hip, trunk, neck, head (6 가지)
  2. Link length: foot, lower-leg, upper-leg, trunk, neck, head (6 가지)

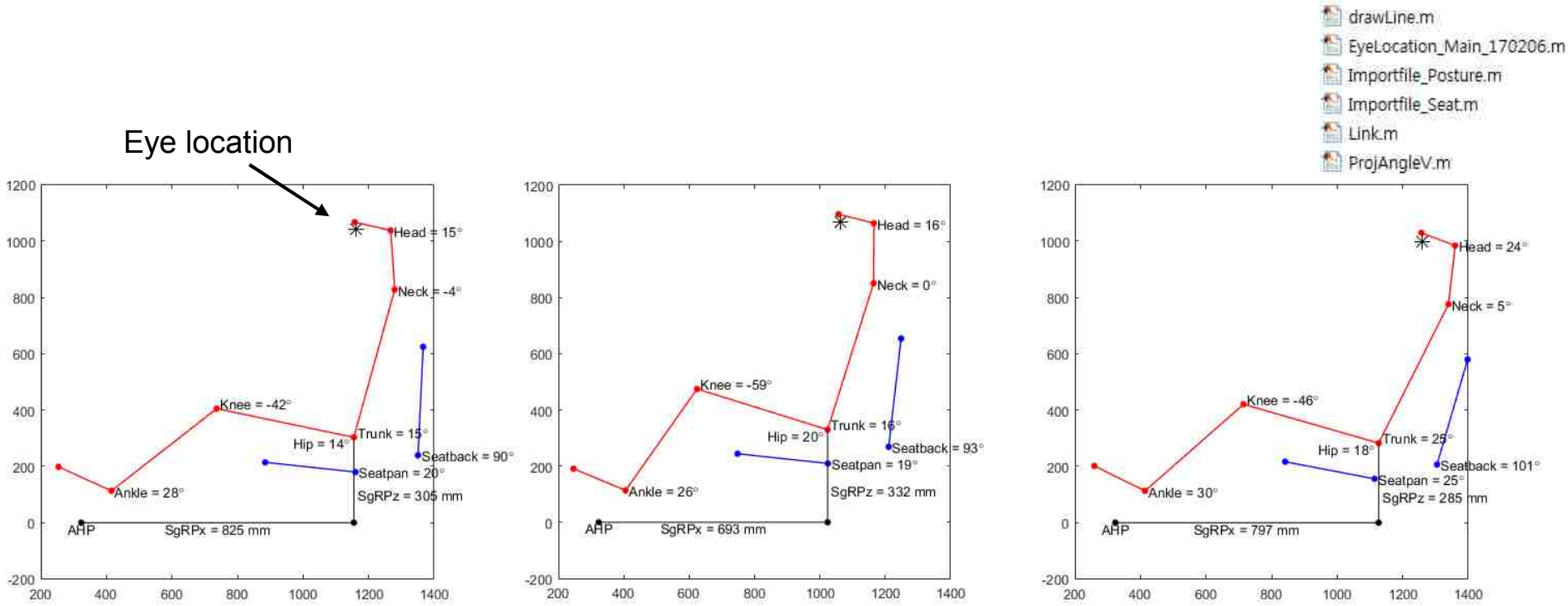


- Hip & eye location



Data Extraction: Code (Matlab)

- Sagittal 평면에서 seat 조절량 및 driving posture 추출

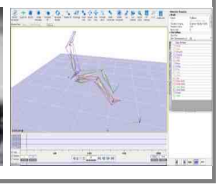


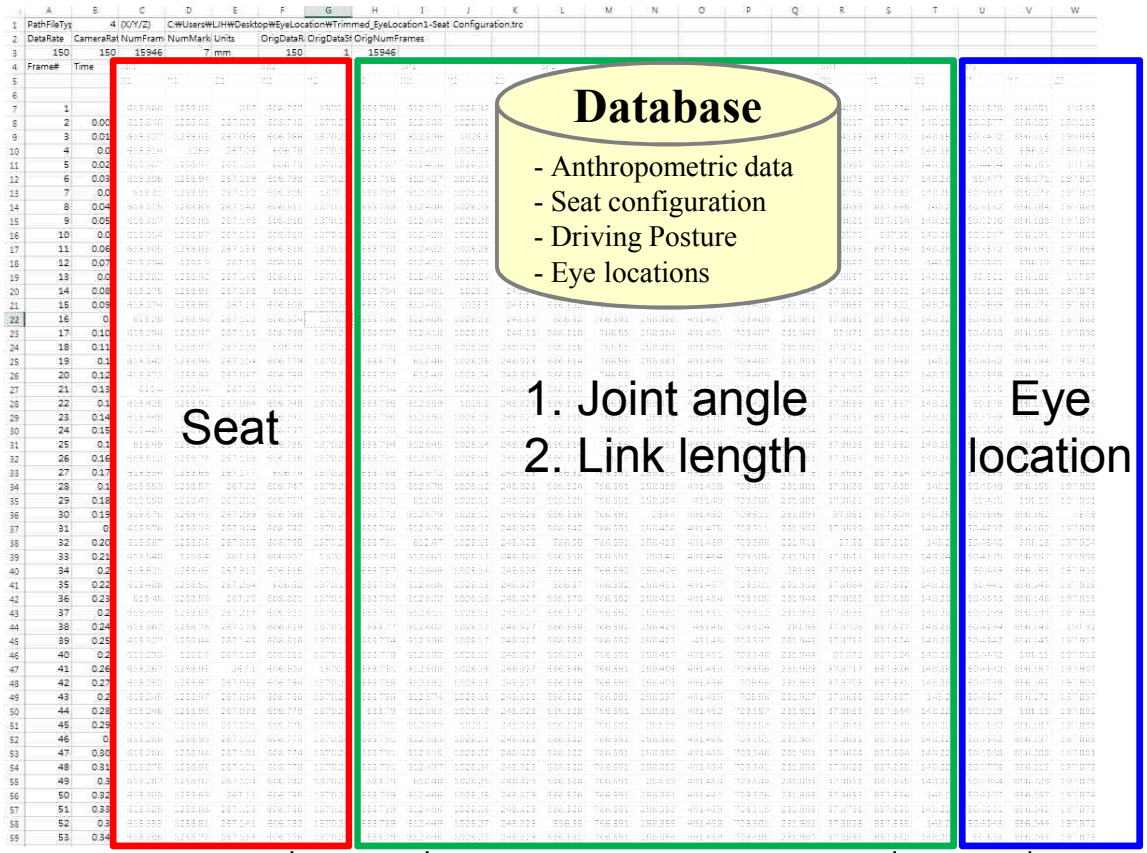
Data 추출 결과 예시

Statistical Geometric Model (SGM): Database

Lab test

- Anthropometric measurement
- Motion capture





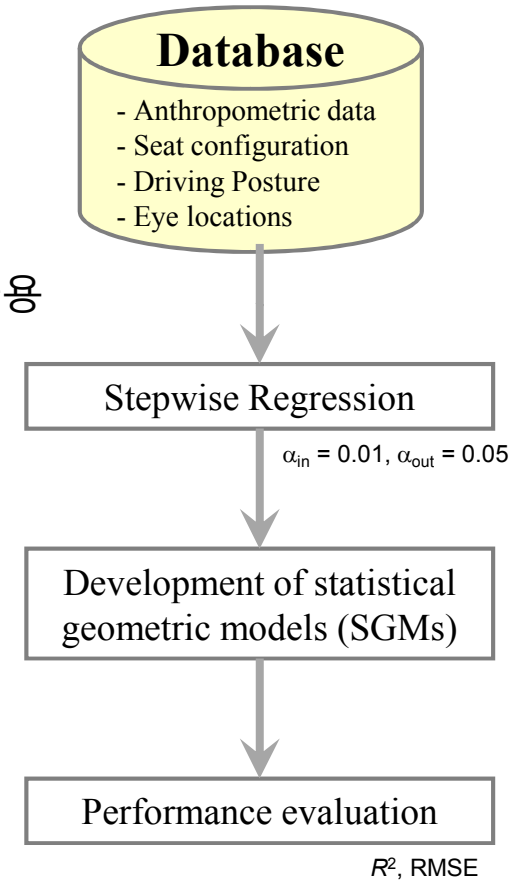
$$Joint\ \ angle = f(seat, stature) \qquad Eye\ location = f(Joint\ \ angle, Link\ \ length)$$

Posture based SGMs $\Rightarrow$ $Eye\ location = f(Joint\ \ angle, Link\ \ length)$

Seat configuration based SGMs $\Rightarrow$ $Eye\ location = f(f(seat), f(stature))$

SGM: Stepwise Regression Analysis

- Stepwise regression을 통해 유의 인자(α_{in} = 0.01, α_{out} = 0.05) 선택 후 회귀 분석
- Predictors
  - ✓ Posture based SGMs: 관절 각도 및 인체 분절 길이 사용
    - Joint angle: θ_{ankle}, θ_{knee}, θ_{hip}, θ_{trunk}, θ_{neck}, θ_{head}
    - link length: foot, lower-leg, upper-leg, trunk, neck, head
  - ✓ Seat configuration based SGMs: 신장 및 seat 조절량 사용
    - Stature
    - Seat configuration: $\theta_{seatback}$, $\theta_{seatpan}$, HP_x *re*AHP, HP_z *re*AHP



Statistical Geometric Model (SGM): Summary

- Posture based: R^2 = 0.90, *RMSE* = 21.2 mm
- Seat configuration based: R^2 = 0.90, *RMSE* = 18.3 mm

	Location	Regression Equation	Adjusted R^2	*RMSE* (mm)
Posture based SGMs	Eye_x *re*AHP			
	Eye_z *re*AHP			
	Hip_x *re*AHP			
	Hip_z *re*AHP			
Seat configuration based SGMs	Eye_x *re*AHP			
	Eye_z *re*AHP			
	Hip_x *re*AHP			
	Hip_z *re*AHP			

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

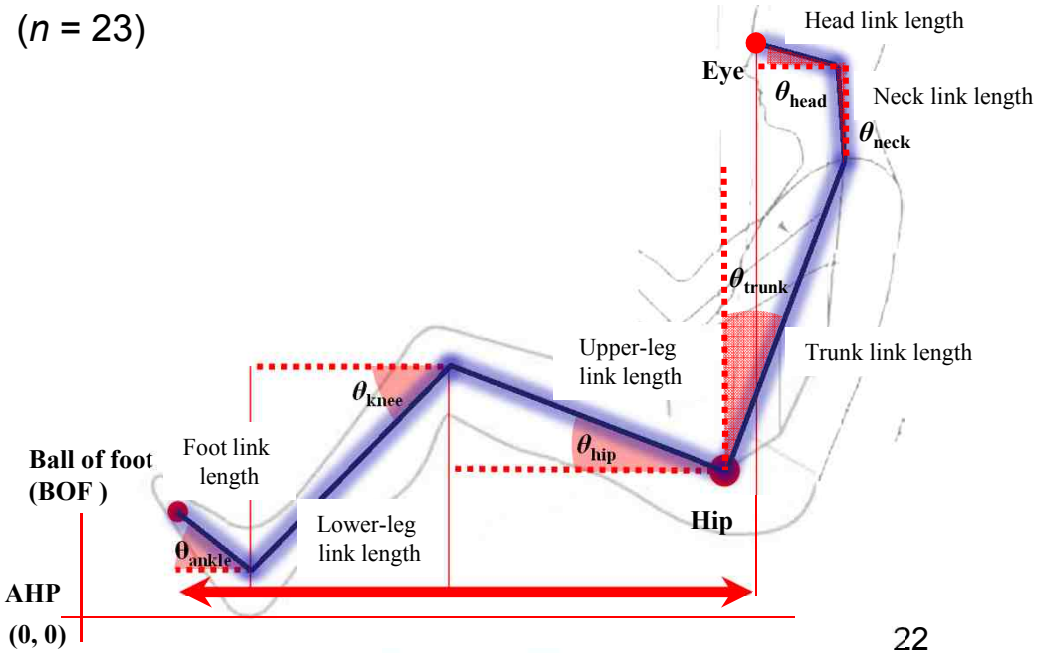
Eye$_x$ *re*AHP =

+ {0.917 :

Eye$_z$ *re*AHP =

+ {0.879 :

(*n* = 23)



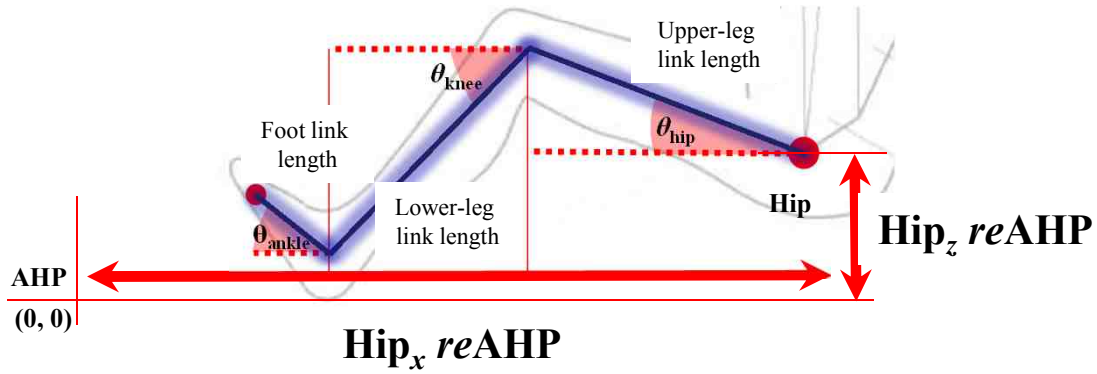
where: BOF = ball of foot,
FL = foot link length,
LL = lower-leg link length,
UL = upper-leg link length,
TL = trunk link length,
NL = neck link length,
HL = head link length,
θ_{hip} = hip angle,
θ_{knee} = knee angle,
θ_{ankle} = ankle angle,
θ_{trunk} = trunk angle,
θ_{neck} = neck angle,
θ_{head}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

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

Hip$_x$ *reAHP* =

Hip$_z$ *re*AHP =

(*n* = 23)



where: 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

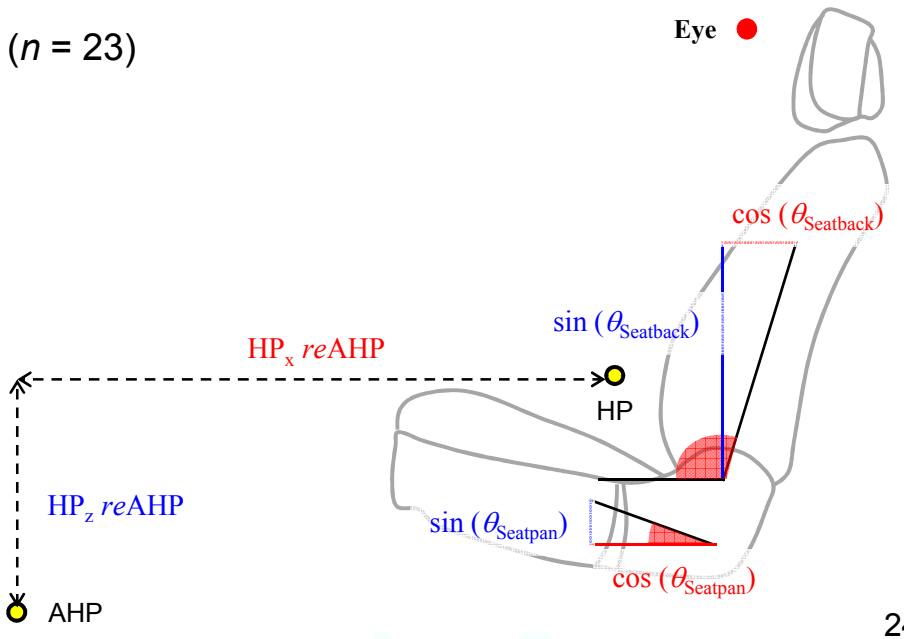
Seat-Based SGMs: Eye$_x$ *re*AHP & Eye$_z$ *re*AHP

Eye$_x$ *re*AHP =

Eye$_z$ *re*AHP =

+ {53.6 ×

(*n* = 23)



where: AHP = Accelerator Heel Point,
HP: Hip point,
HP$_x$ *re*AHP = Horizontal HP-AHP length,
HP$_z$ *re*AHP = Vertical HP-AHP length,
S = Stature
$\theta_{seatback}$ = seatback angle,
$\theta_{seatpan}$ = cushion angle

Seat-Based SGMs: Hip$_x$ *re*AHP & Hip$_z$ *re*AHP

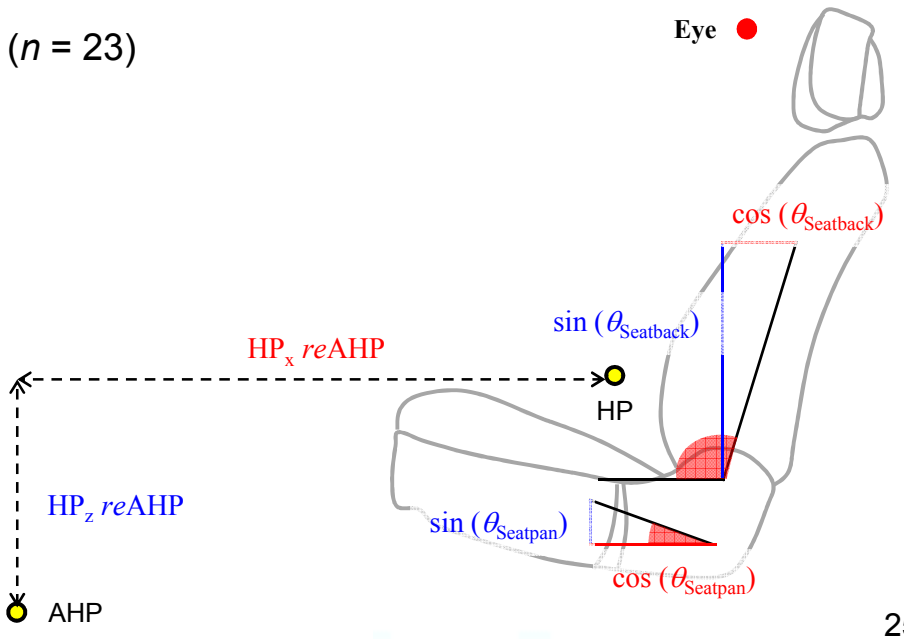
$$\text{Hip}_x\ reAHP = -373 + \{104 \times S\} + \{0.969 \times \text{HP}_x\ reAHP\} - \{0.236 \times \text{HP}_z\ reAHP\} - \{37.2 \times \cos(\theta_{Seatback})\} + \{311 \times \sin(\theta_{Seatback})\}$$

Adj. $R^2 = 0.92$; *RMSE* = 20.7 mm

$$\text{Hip}_z\ reAHP = 81.8 + \{7.87 \times S\} + \{0.993 \times \text{HP}_z\ reAHP\} - \{74.6 \times \cos(\theta_{Seatback})\} + \{205 \times \sin(\theta_{Seatback})\} - \{355 \times \cos(\theta_{Seatpan})\}$$

Adj. $R^2 = 0.59$; *RMSE* = 16.1 mm

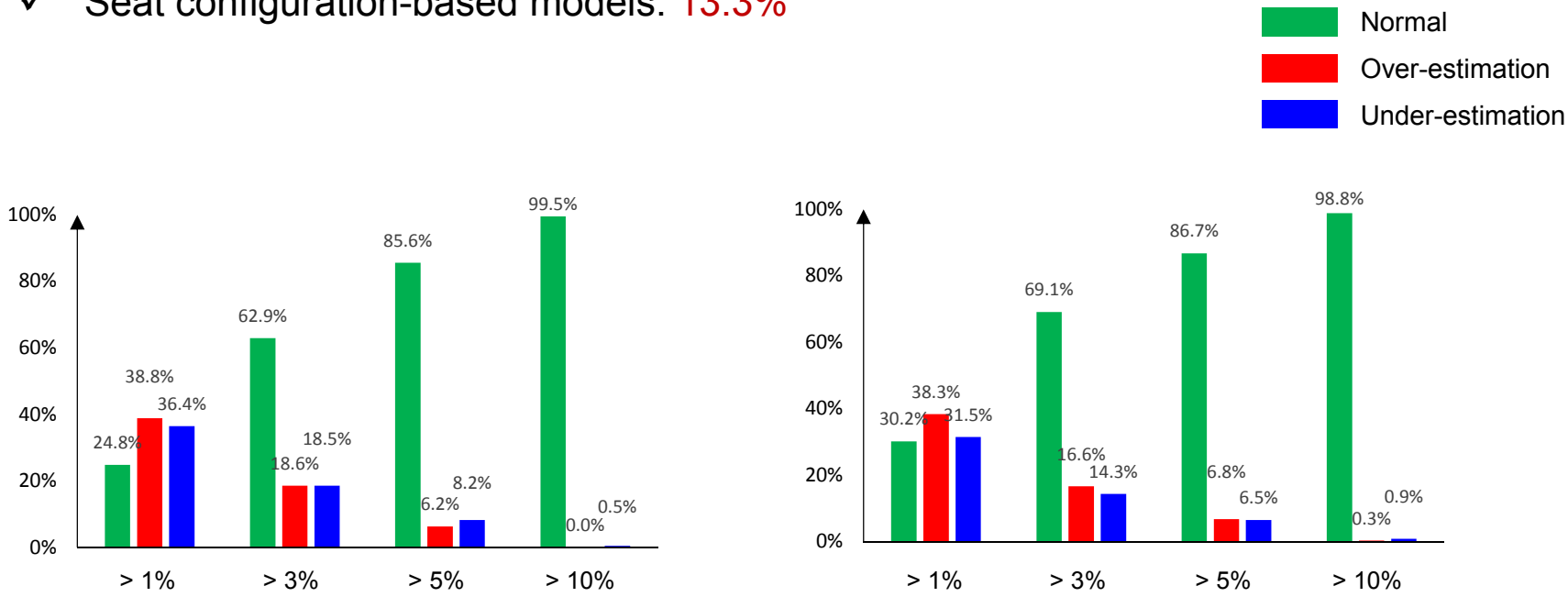
(n = 23)



where: AHP = Accelerator Heel Point,
HP: Hip point,
HP$_x$ *re*AHP = Horizontal HP-AHP length,
HP$_z$ *re*AHP = Vertical HP-AHP length,
S = Stature
$\theta_{seatback}$ = seatback angle,
$\theta_{seatpan}$ = cushion angle

Model Evaluation: Posture *vs.* Seat Configuration

- Sample data (6,576개) 중 percentage of %error > 5% (both over and under estimation)
  - ✓ Posture-based models: 14.4%
  - ✓ Seat configuration-based models: 13.3%

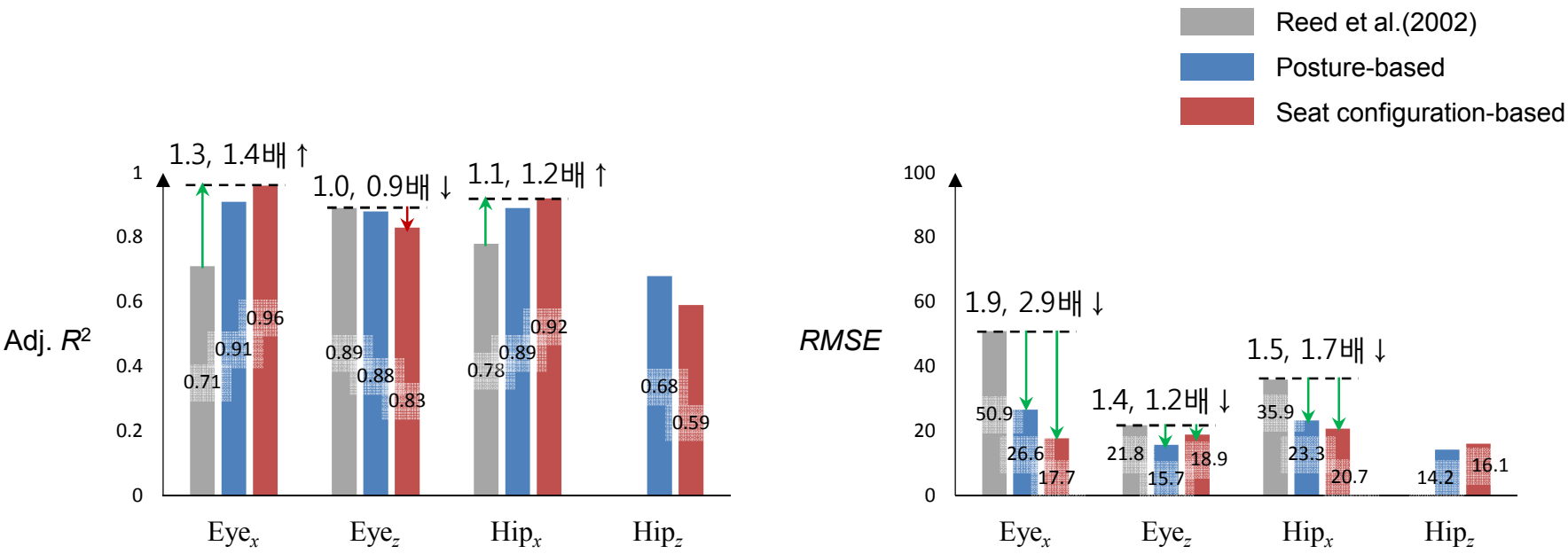


Posture-based models

Seat configuration-based models

Model Evaluation: Reed et al.(2002) *vs.* Current

- Prediction performance and accuracy: SGMs vs. Reed's models
  - ✓ Adj. R^2: SGMs ≥ 0.9 ~ 1.4 × Reed et al.'s models
  - ✓ *RMSE*: SGMs ≤ 1.2 ~ 2.9 × Reed et al.'s models



Discussion

- 본 연구에서 개발된 seat configuration 및 posture-based models은 운전자의 eye location 및 hip location 추정 성능이 우수함(adj. R^2 = .83 ± .13, *RMSE* = 19.1 ± 4.2 mm)

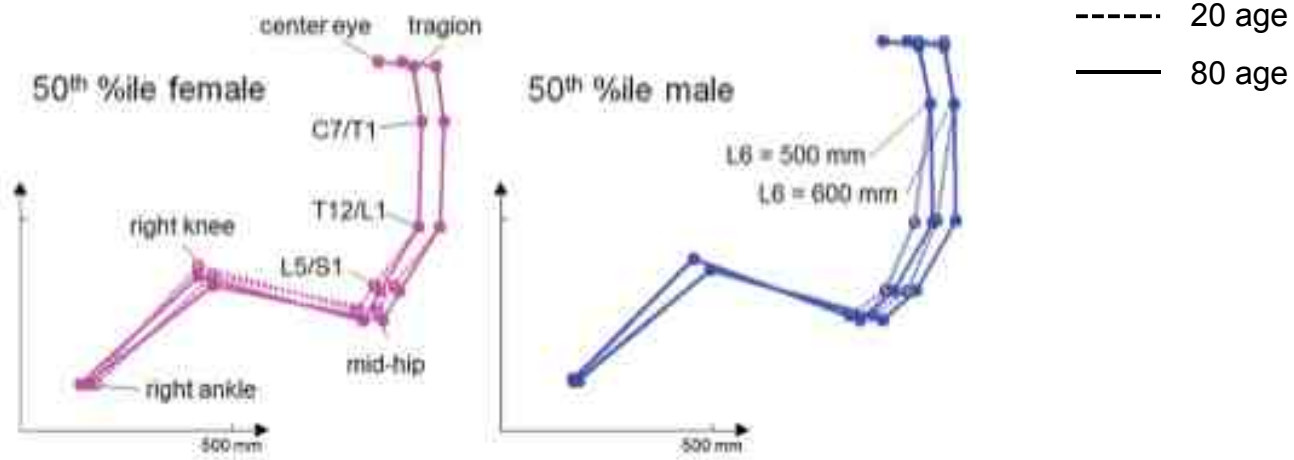
- Seat configuration-based models은 posture-based models 보다 generalizability, practicality 측면에서 선호
  - ⇐ 한국인 실험참여자를 대상으로 개발된 posture-based model은 한국인 외 다른 인종에 대해 추정 성능이 감소할 것으로 사료됨
  - ⇐ Posture-based model은 EL & HL 추정 시 joint angle, link length 정보 필요(seat configuration-based model은 stature 정보 필요)

- 선행연구의 운전자 comfortable driving posture (Hirao et al., 2006, 2007; Kyung and Nussbaum, 2009; Kyung et al., 2010; Park et al., 2000)는 posture-based models을 활용한 EL&HL 추정 시 사용될 수 있음

Discussion

Limitations

- 20 ~ 50 years 실험참여자를 대상으로 개발된 EL & HL 추정식은 age effect를 고려하지 않아 노년층(> 65 years)에 적용 시 추정 성능이 감소될 수 있음
  - ✓ Park et al. (2016)은 나이가 증가함에 따라 buttock muscle이 감소하여 노년층의 EL & HL이 젊은층보다 약간 낮음을 밝힘



Q & A