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

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

[1]Department of Industrial and Management Engineering, Pohang University of Science and Technology, 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;

Regression equations for estimation of a driver's hip location (HL) and eye location (EL) using the driver's anthropometric and posture variables have been developed for US drivers. However, those equations are limited to US drivers and do not include seat adjustment variables (e.g., cushion angle) that may affect a driver's HL and EL. The present study developed statistical models for prediction of a driver's HL and EL using seat configurations including (1) fore-aft seat position, (2) seat height, (3) seat back recline angle, and (4) seat cushion angle. Driving postures of 23 Korean drivers (10 females and 13 males) were measured in a seating buck after adjusting seat configurations according to their preferences. The seat configurations, HLs, ELs, and joint angles of the participants were collected by a motion capture system. HL and EL prediction models based on the seat configurations and driving postures were developed by stepwise regression. The proposed models showed high accuracy (adj. $R^2$ = .83 ± .13, RMSE = 19.1 ± 4.2 mm) in prediction of HL and EL. The performance difference between the seat configuration- and posture-based models was not statistically significant. The proposed seat configuration-based models can be used for accurate estimation of a driver's HL and EL for occupant packaging layout design.

## INTRODUCTION

The hip location (HL) and eye location (EL) of a driver are important design reference variables to provide good accommodation, visibility, clearance, comfort, and safety for the driver. The distribution of HLs collected from drivers in an occupant packaging layout (OPL) is used to determine the neutral positions and adjustment ranges of components (such as seat) in the OPL (Parkinson et al., 2005; Philippart et al., 1984). The neutral positions and adjustment ranges determined should provide good exterior vision, clearance to interior components, and comfort for drivers. The distribution of ELs is used to design a vehicle's architecture to ensure a sufficient visual field for a driver (Bhise, 2011; Parkinson et al., 2007). Accurate estimation of HL and EL for a driver is critical to avoid inappropriate OPL design that may result in an uncomfortable driving posture and a decreased driving safety.

Statistical models have been developed to predict a driver's HL and EL. Society of Automotive Engineers (SAE) J4004 provides driver seat position prediction models which estimate preferred fore/aft seat position within the seat track travel path for various sizes (2.5$^{th}$, 5$^{th}$, 10$^{th}$, 50$^{th}$, 90$^{th}$, 95$^{th}$, and 97.5$^{th}$ %ile in stature) of US drivers. SAE J941 uses the seating reference point location (SgRP), seat-track travel (L23), design seatback angle (L40), seat height, steering-wheel position, and seat-track rise as inputs to an eyellipse model to estimate EL.

The SAE models are not enough for accurate estimation of HL and EL due to their limitations. Although the SAE models are useful for OPL design, their predication performances are not provided and the models are limited to US drivers. Furthermore, the data for formulating the SAE models were collected from a fixed fore-aft seat position, seatback angle, and seat cushion angle. Recent vehicles are designed to provide a highly adjustable OPL, such as seat position, cushion length, cushion angle, seatback angle, and headrest position.

The objective of the present study was to develop accurate statistical models for predicting a driver's HL and EL using the driver's anthropometric and seat configurations data. Seat configurations, HLs, ELs, and joint angles of the participants were collected by a motion capture system in a driving simulation experiment using a seating buck. Two groups of statistical models based on seat configurations and driving postures were developed for estimation of a driver's HL and EL by multiple regression analysis. Stepwise regression was performed to identify important variables that significantly affect HL and EL among seat configurations and driving postures.

## MATERIALS AND METHODS

### Participants

23 Korean drivers (10 females and 13 males; mean age = 29.3 ± 7.3 years; mean mass = 63.0 ± 12.7 kg; mean height = 1.66 ± 0.09 m) volunteered to participate in the present study. All participants had valid driving licenses and those having a history of musculoskeletal injuries, surgery, or any current symptom of pain or injuries were excluded from the study. The present study was approved by the institutional review boards at Pohang University of Science and Technology. After a signed informed consent was obtained from a participant,

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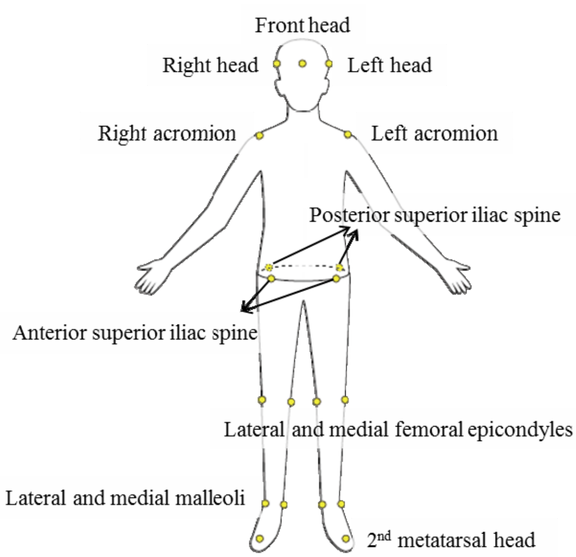
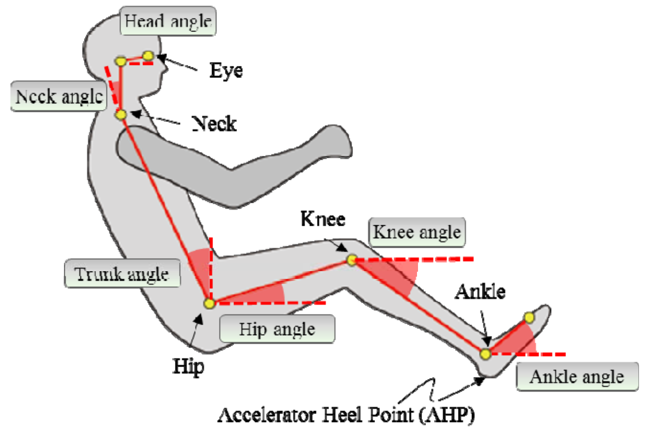
age, mass, and height of the participant were acquired.

### Apparatus

A seating buck consisting of a motorized seat (EQ900 seat, Hyundai-Kia Motors, Korea), and a gaming wheel and pedals (G27, Logitech, Swiss). A PC-based seat control system was developed in the present study and integrated with electronic control unit (ECU) to control fore-aft seat position, seat height, seat back recline angle, and seat cushion angle. Retro-reflective markers ($\phi = 12.5$ mm) attached to a participant (to form a rigid body link model with 6 body segments: head, neck, trunk, thigh, shank, and foot; Figure 1) and the seat (Figure 2) were captured with a motion analysis system consisting of 8 infrared cameras (Osprey, Motion Analysis Corp., Santa Rosa, CA) at a frequency of 60 Hz to obtain driving postures and seat configurations of the participant. Seat H-point was identified based on the relationship between the seat back hinge point marker and seating reference point (the SgRP) according to the manufacturer's seat design guidance. The origin of the 3D coordinate system in the present study was located in the accelerator heel point (AHP). The x-axis ran through the positive rearward direction and z-axis ran through the positive upward direction (SAE J1100, SAE, 2009).




(a) Reflective markers




(b) Geometric variables of driving posture

Figure 1. (a) Attachment of 19 reflective markers to the body for driving posture and (b) related geometric variables: the lengths of foot, lower-leg, upper-leg, trunk, neck, and head links and the angles of ankle, knee, hip, trunk, neck and head.

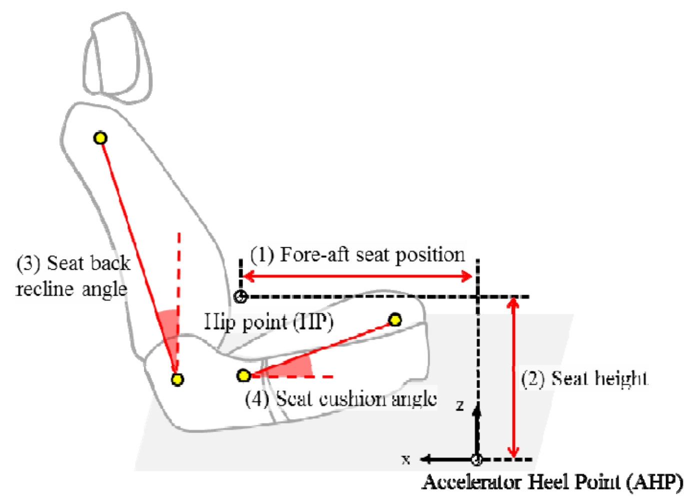



Figure 2. Attachment of 4 reflective markers to the seat (seatback hinge point, cushion hinge point, end of seat back and cushion) to calculate (1) fore-aft seat position, (2) seat height, (3) seat back recline angle, and (4) seat cushion angle

### Experiment Procedure

Driving postures and seat configurations of a participant were obtained in two phases, preparation and main experiment phases. In the preparation phase, 19 retro-reflective markers were placed on bony landmarks (front head, right/left head, right/left acromion, right/left anterior superior iliac spine, right/left posterior superior iliac spine, lateral and medial femoral epicondyles, lateral and medial malleoli, and second metatarsal head) according to the modified Helen-Hayes marker set for measuring joint angles of the participant in the sagittal plane. Joint centers of the link model were defined by Seidel et al. (1995)'s method. 4 retro-reflective markers were attached to the seat (seatback hinge point, cushion hinge point, end of seat back and cushion) to calculate (1) fore-aft seat position, (2) seat height, (3) seat back recline angle, and (4) seat cushion angle. Sufficient time was provided to the participant to be familiar with the seat adjustment mechanisms. In the main experiment phase, the participant was allowed to adjust the seat (fore-aft seat position = ± 60 mm, seat height = ± 25 mm, seat back recline angle = ± 5°, seat cushion angle = ± 2.5°) to his/her preferred seat configurations. Then, the participant was asked to hold the steering wheel at 10 and 2 o'clock directions, put the right foot on the accelerator pedal and the left foot on the floor of the seating buck, and look straight ahead. In front of the seating buck, a video clip was displayed on a screen for the participant to keep looking straight ahead. Then driving posture and seat configurations of the participant were captured with the motion analysis system.

## RESULTS

The present study developed two groups (seat configuration-based and posture-based) of statistical models for prediction of a driver's HL and EL by stepwise regression ($p_{in} < .01$ and $p_{out} < .05$) using seat configuration variables and driving posture variables. The horizontal locations (e.g., Hip $_x$ *re*AHP) and vertical locations (e.g., Eye $_z$ *re*AHP) of HL and EL relative to the AHP were estimated from the proposed statistical models.

Performance of the seat configuration-based models (adj. $R^2 = .82 \pm .16$, root mean square error (RMSE) = 18.8 ± 2.1 mm) were not significantly different from the posture-based model (adj. $R^2 = .84 \pm .11$, RMSE = 20.1 ± 5.9 mm) ($t(4) = 0.77$, $p = 0.498$ for adj. $R^2$; $t(4) = 0.52$, $p = 0.637$ for RMSE). Among 6,576 sample data, percentage of %error > 5% (both over and under estimation) for the seat configuration-based models and posture-based models were 13.3% and 14.4%. Adj. $R^2$, RMSE values, and percentage of %error > 5% of the proposed regression equations are summarized in Table 1.

Table 1. Prediction performance (Adj. $R^2$, RMSE, Percentage of %error) for HL and EL

| Predictor | Location | Adj. $R^2$ | RMSE (mm) | Percentage of %error > 5% |
|---|---|---|---|---|
| Seat configuration | Hip $_x$ *re*AHP | 0.92 | 20.67 | 11.3% |
| | Hip $_z$ *re*AHP | 0.59 | 16.08 | 28.1% |
| | Eye $_x$ *re*AHP | 0.96 | 17.72 | 6.0% |
| | Eye $_z$ *re*AHP | 0.83 | 18.93 | 7.7% |
| Driver's posture | Hip $_x$ *re*AHP | 0.89 | 23.26 | 14.2% |
| | Hip $_z$ *re*AHP | 0.68 | 14.17 | 24.0% |
| | Eye $_x$ *re*AHP | 0.91 | 26.60 | 16.5% |
| | Eye $_z$ *re*AHP | 0.88 | 15.71 | 2.9% |

Note: RMSE = root mean square error, HL = hip location, EL = eye location; AHP = accelerator heel point

The seat configuration-based models were summarized as follows:

$$\text{Hip}_x\ re\text{AHP} = -373 + \{104 \times S\} + \{0.969 \times HP_x\} - \{0.236 \times HP_z\} - \{37.2 \times \cos(\theta_{seatback})\} + \{311 \times \sin(\theta_{seatback})\} \quad (1)$$

$$\text{Hip}_z\ re\text{AHP} = 81.8 + \{7.87 \times S\} + \{0.993 \times HP_z\} - \{74.6 \times \cos(\theta_{seatback})\} + \{205 \times \sin(\theta_{seatback})\} - \{355 \times \cos(\theta_{seatpan})\} \quad (2)$$

$$\text{Eye}_x\ re\text{AHP} = 277 - \{87.1 \times S\} + \{1.04 \times HP_x\} - \{683 \times \cos(\theta_{seatback})\} - \{136 \times \sin(\theta_{seatpan})\} \quad (3)$$

$$\text{Eye}_z\ re\text{AHP} = -471 + \{455 \times S\} - \{0.0518 \times HP_x\} + \{0.794 \times HP_z\} + \{53.6 \times \cos(\theta_{seatback})\} + \{185 \times \sin(\theta_{seatback})\} - \{94 \times \cos(\theta_{seatpan})\} + \{48.5 \times \sin(\theta_{seatpan})\} \quad (4)$$

where: AHP = accelerator heel point,

S = stature (m),

$SgRP_x$ = fore-aft seat position (mm),

H30 = seat height (mm),

$\theta_{seatback}$ = seat back recline angle (rad),

$\theta_{cushion}$ = seat cushion angle (rad)

The posture based models were summarized as follows:

$$\text{Hip}_x\ re\text{AHP} = 54.6 + \{0.318 \times FL \times \cos(\theta_{ankle})\} + \{1.01 \times LL \times \cos(\theta_{knee})\} + \{0.993 \times UL \times \cos(\theta_{hip})\} \quad (5)$$

$$\text{Hip}_z\ re\text{AHP} = 220 + \{0.0479 \times FL \times \sin(\theta_{ankle})\} - \{0.504 \times LL \times \sin(\theta_{knee})\} - \{0.620 \times UL \times \sin(\theta_{hip})\} \quad (6)$$

$$\text{Eye}_x\ re\text{AHP} = 31.5 + \{0.262 \times FL \times \cos(\theta_{ankle})\} + \{0.981 \times LL \times \cos(\theta_{knee})\} + \{0.945 \times UL \times \cos(\theta_{hip})\} + \{0.917 \times TL \times \sin(\theta_{trunk})\} + \{1.06 \times NL \times \sin(\theta_{neck})\} - \{0.301 \times HL \times \cos(\theta_{head})\} \quad (7)$$

$$\text{Eye}_x\ re\text{AHP} = -79.9 + \{0.0853 \times FL \times \sin(\theta_{ankle})\} - \{0.479 \times LL \times \sin(\theta_{knee})\} - \{0.337 \times UL \times \sin(\theta_{hip})\} + \{0.879 \times TL \times \cos(\theta_{trunk})\} + \{0.993 \times NL \times \cos(\theta_{neck})\} + \{0.858 \times HL \times \sin(\theta_{head})\} \quad (8)$$

where: FL = foot link length (mm),

LL = lower-leg link length,

UL = upper-leg link length,

TL = trunk link length,

NL = neck link length,

HL = head link length,

$\theta_{ankle}$ = ankle joint angle (rad),

$\theta_{knee}$ = knee joint angle,

$\theta_{hip}$ = hip joint angle,

$\theta_{trunk}$ = trunk joint angle,

$\theta_{neck}$ = neck joint angle,

$\theta_{head}$ = head joint angle

## DISCUSSION

The seat configuration- and posture-based models developed in the present study showed high accuracy (adj. $R^2$ = .83 ± .13, RMSE = 19.1 ± 4.2 mm) in prediction of HL and EL. The performance difference between the seat configuration- and posture-based models was not statistically significant. Moreover, percentage of %error > 5% (over and under estimation) of the seat configuration-based models (13.3%) was similar to that of the posture-based models (14.4%).

The seat configuration-based models are preferred to the posture-based models in terms of generalizability and practicality. The posture-based models depend on body dimensions of the Korean population and therefore their performance decreases if they are applied to a different nation population. Lee et al. (2013) reported that the correlations between stature and body segment lengths can significantly differ among populations. In contrast, the seat configuration-based model can be generally and practically used when stature information of a driver and seat adjustment range data are available.

The posture based models require predetermined posture information to predict the driver's HL and EL. Many studies have been conducted to develop models to predict joint angles or the range of joint angles (Hirao et al., 2006, 2007; Kyung and Nussbaum, 2009; Kyung et al., 2010; Park et al., 2000). Kyung and Nussbaum (2009) identified comfortable driving postures using digital human modeling techniques. Those techniques can be applied to the present study to determine drivers' postures.

Our findings may not be suitable to seniors (> 65 years) because we recruited only young (20s to 50s) participants. Park et al. (2016) reported that elderly drivers tend to sit slightly lower in the seat than younger drivers because the volume of buttock muscle could reduce as age increases. Therefore, the effects of age on a driver's HL and EL need to be considered in a future study.

## ACKNOWLEDGEMENTS

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