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EFFECTS OF DRIVER PERSONAL VARIABLES ON PREFERRED VEHICLE INTERIOR COMPONENTS SETTING

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This study identified and characterized the relationship between driver personal variables and preferred vehicle interior components setting. A two-phase modeling approach was employed to characterize the temporal, logical process involved in the driver selection of a preferred vehicle interior components setting. The modified Bayesian multivariate adaptive regression splines (BMARS) modeling method was employed to identify nonlinear and interactive relationships. Forty-two male and forty-four female drivers with a wide range of ages, stature, and BMI participated in the data collection. A highly adjustable vehicle mock-up was used to empirically obtain each participant's preferred vehicle interior components setting. The study results indicated substantial non-anthropometric variability in the driver-selected seat horizontal positions and identified various interpretable nonlinearities and interactions. The study findings improve the understanding of the relationship between driver personal variables and preferred vehicle interior configuration and further inform the vehicle interior package design for driver accommodation.

Keywords: Driver Accommodation; Occupant Packaging; Vehicle Ergonomics.

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1. INTRODUCTION

When designing a vehicle interior package, adjustment ranges of vehicle interior components need to be determined to accommodate the majority of the individuals within the target driver population (Gragg *et al*., 2012; Gragg *et al*., 2011; Jeong and Park, 2017; Kikumoto *et al*., 2021; Ozsoy *et al*., 2015; Park *et al*., 2018; Parkinson and Reed, 2006; Reed and Flannagan, 2000; Vogt *et al*., 2005). Such design for driver accommodation is essential for ensuring driver comfort (Gragg *et al*., 2011; Kikumoto *et al*., 2021; Luque *et al*., 2022; Park *et al*., 2000; Park *et al*., 2018) and safety (Gragg *et al*., 2011; Kikumoto *et al*., 2021; Luque *et al*., 2022; Park *et al*., 2018; Parkinson and Reed, 2006; Reed *et al*., 2001; Roe, 1993).

To support the vehicle interior package design for driver accommodation, multiple research studies have examined the impacts of driver personal variables (age, gender, stature, and body mass index [BMI]) on preferred vehicle interior components setting (Gou *et al*., 2021; Hanson *et al*., 2006; Jeong and Park, 2017; Jonsson *et al*., 2008; Lee *et al*., 2022;

McFadden *et al*., 2000; Obeidat *et al*., 2022; Park *et al*., 2000; Parkin *et al*., 1995; Porter and Gyi, 1998). Some of the major findings from these studies were as follows:

- Older drivers, on average, had a shorter driver-steering wheel distance than younger drivers (McFadden *et al*., 2000; Parkin *et al*., 1995),
- Female drivers were found to have a more forward and upward seat displacement and a more upright seatback angle than male drivers (Gou *et al*., 2021; Hanson *et al*., 2006; Jonsson *et al*., 2008; Lee *et al*., 2022; McFadden *et al*., 2000; Obeidat *et al*., 2022; Park *et al*., 2000; Parkin *et al*., 1995; Porter and Gyi, 1998),
- Taller drivers, on average, had a longer driver-steering wheel distance and a more reclined seatback angle (Hanson *et al*., 2006; Mcfadden *et al*., 2000; Obeidat *et al*., 2022; Park *et al*., 2000; Porter and Gyi, 1998), and
- Extremely obese (BMI $\geq$ 40 kg/m^2) drivers had a greater rearward seat displacement, a more upright steering wheel angle, a smaller steering wheel column displacement, and a more upright seatback angle than non-obese drivers (Jeong and Park, 2017).

The research studies above improved the understanding of the relationship between driver personal variables and preferred vehicle interior components setting and contributed to the vehicle interior package design for driver accommodation. Nonetheless, the current body of knowledge on understanding driver preferences in vehicle interior components setting is insufficient. First, the previous studies in vehicle ergonomics employed general linear models, such as analysis of variance, t-test, and linear regression, for statistical analyses. These analysis methods are known to be less effective than available alternatives in detecting and representing nonlinearities and interactive relationships (Friedman, 1991; Karaca-Mandic *et al*., 2012). In fact, few studies have reported interactions between driver personal variables on vehicle interior components setting - this may be due to the characteristics of the statistical analysis methods employed rather than the nature of the relationship. Second, the previous studies did not consider the time sequence of driver tasks during the adjustments of the vehicle interior components. Drivers typically adjust the seat's horizontal position first, and the result logically affects the subsequent adjustments of the other variables (Jeong and Park, 2017). The time order is thought to play a fundamental role in giving rise to the relationship under study, and elucidating its reflection during the adjustments of the interior components would facilitate the understanding of the relationship and the associated human behaviors.

In an effort to address the above knowledge gaps and, thereby, further contribute to the vehicle interior package design, the aim of the current study was to identify and characterize the relationship between driver personal variables (age, gender, stature, and BMI) and preferred vehicle interior components setting (seat horizontal position, seat vertical position, seatpan angle, seatback angle, steering wheel tilt angle, and steering wheel column displacement). A modified version of the Bayesian multivariate adaptive regression splines (BMARS) modeling method proposed by Francom *et al*. (2018) was employed to characterize the relationship between driver personal variables and preferred vehicle interior components setting - the modified BMARS modeling method is known to well characterize nonlinearities and interactions as well as prevent overfitting (Dension *et al*., 1998a,b; Francom *et al*., 2017; Francom *et al*., 2018; Friedman, 1991).

The main hypotheses of this study were as follows: (1) driver personal variables (age, gender, stature, and BMI) affect preferred vehicle interior components setting (seat horizontal position, seat vertical position, seatpan angle, seatback angle, steering wheel tilt angle, and steering wheel column displacement), (2) there are nonlinear and interactive relationships between driver personal variables and preferred vehicle interior components setting, (3) driver's preference on the seat horizontal position affects subsequent adjustment of other vehicle interior components.

2. METHOD

2.1 Participants

A group of male and female drivers with a wide range of ages, stature, and BMI participated in this study. The participants were forty-two male and forty-four female drivers ranging in age from 20 to 74 years. Their stature ranged from 149 to 193 cm, and their body mass ranged from 57.6 to 177.4 kg. Their BMI ranged from 22.5 to 54.6 kg/m^2 – BMI categories (World Health Organization, 2020): normal-weight (18.5 kg/m^2 $\leq$ BMI < 25 kg/m^2), pre-obesity (25 kg/m^2 $\leq$ BMI < 30 kg/m^2), obesity class I (30 kg/m^2 $\leq$ BMI < 35 kg/m^2), obesity class II (35 kg/m^2 $\leq$ BMI < 40 kg/m^2), and obesity class III (BMI $\geq$ 40 kg/m^2). The participants' age, stature, body mass, and BMI data are summarized in Table 1. All of the participants had a valid driver's license, normal or corrected-to-normal vision in both eyes, and no self-reported current musculoskeletal disorders.

2.2 Adjustable Vehicle Mock-up

An adjustable vehicle mock-up was used to empirically collect each participant's preferred vehicle interior components setting. The mock-up was composed of gas and brake pedals, a seat, and a steering wheel (Figure 1). Other typical vehicle elements, such as a roof and an instrument panel, were not included in the mock-up – the absence of the roof and instrument panel geometries was to help identify driver preferences purely from the postural standpoint (Jeong and park, 2017). The seat and steering wheel were highly adjustable – the ranges of adjustment were at least twice larger than those offered by existing vehicles of various types and classes. These large adjustment ranges were capable of emulating various types of vehicle interior configurations; therefore, they could help well identify the most preferred interior components setting. The mock-up configuration was similar to that used in other studies (Hanson *et al*., 2006; Jeong and Park, 2017).

The seat had four variables representing its setting: seat horizontal position (SeatX), seat vertical position (SeatZ), seatpan angle (SeatPA), and seatback angle (SeatBA). SeatX was defined as the horizontal distance (mm) from the ball of foot (BoF) reference point to the seat hinge joint center. SeatZ was defined as the vertical distance (mm) from the BoF to the seat hinge joint center. SeatPA was defined as the horizontal tilt angle (°) of the seatpan surface. SeatBA was defined as the angle (°) between the vertical line and the long axis of the backrest. The steering wheel had two variables: steering wheel tilt angle (SWTA) and steering wheel column displacement (SWCD). SWTA was defined as the angle (°) between the horizontal line and the long axis of the steering wheel column. SWCD was defined as the distance (mm) between the steering wheel column hinge joint center and the steering wheel center. The six variables are visually illustrated in Figure 1. They had been employed by Jeong and Park (2017).

Table 1. Summary of the age, stature, body mass, and BMI data for the participants

Dimensions	Total (n=86)			Male (n=42)			Female (n=44)		
	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)
Age (years)	20.0	74.0	38.8 (±14.5)	21.0	74.0	37.8 (±16.8)	20.0	69.0	39.7 (±12.0)
Stature (cm)	149.0	193.0	168.9 (±1.4)	161.0	193.0	176.4 (±7.6)	149.0	178.5	161.8 (±7.2)
Body mass (kg)	57.6	177.4	105.2 (±26.6)	64.9	177.4	113.1 (±28.8)	57.6	141.5	97.7 (±22.1)
BMI (kg/m^2)	22.5	54.6	36.8 (±8.1)	22.5	54.6	36.3 (±8.7)	22.8	52.0	37.2 (±7.5)

Note: "Min", "Max", and "SD" denote minimum, maximum, and standard deviation, respectively.

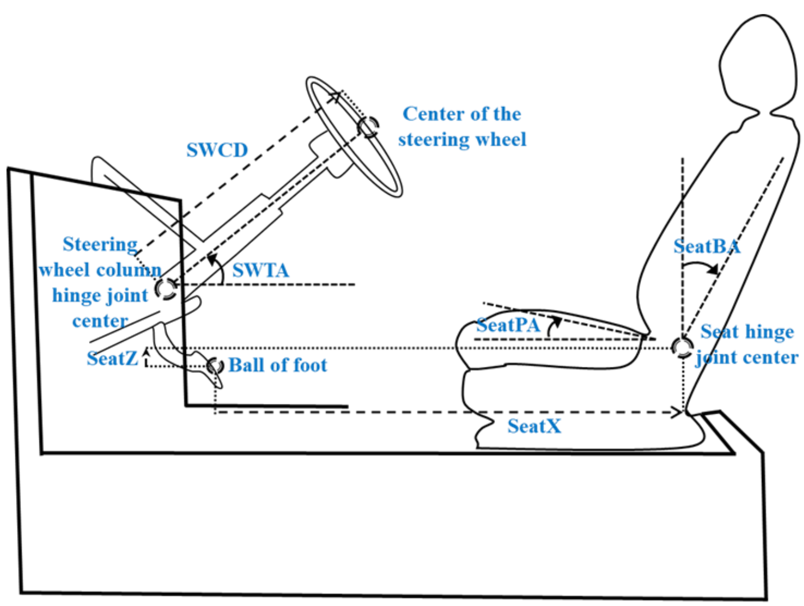

Figure 1. Variables representing the vehicle interior components setting

2.3 Experimental Procedure

Before the data collection trials, the study objective and procedure were fully explained to the participants. The research protocol was approved by the Auburn University Institutional Review Board. Each participant signed a written consent and changed into a sleeveless shirt, short pants, and athletic shoes. The body mass and stature were measured, and the BMI was calculated.

The participants performed a 20 min long data collection trial in the adjustable vehicle mock-up. Before each data collection trial, the initial seat and steering wheel positions (SeatX, SeatZ, SeatBA, SeatPA, SWTA, and SWCD) were set to random values. Throughout the data collection trial, the participants were instructed to freely adjust the seat (SeatX, SeatZ, SeatBA, and SeatPA) and the steering wheel (SWTA and SWCD) to find the most preferred interior components setting. Also, they were told to use a standardized driving posture (both hands on the steering wheel and the right foot on the gas pedal), and a dynamic road scene was presented to them. There were no other instructions/directions because the objective of the study was to investigate preferred vehicle interior components settings, which reflect individuals' different driving habits and different requirements for the seat and steering wheel. During each trial, they were allowed to adjust the interior components setting whenever they felt necessary. At the completion of the data collection trial, the six variables (SeatX, SeatZ, SeatBA, SeatPA, SWTA, and SWCD) representing the most preferred setting of the interior components were measured. The experimental procedure is summarized in Figure 2.

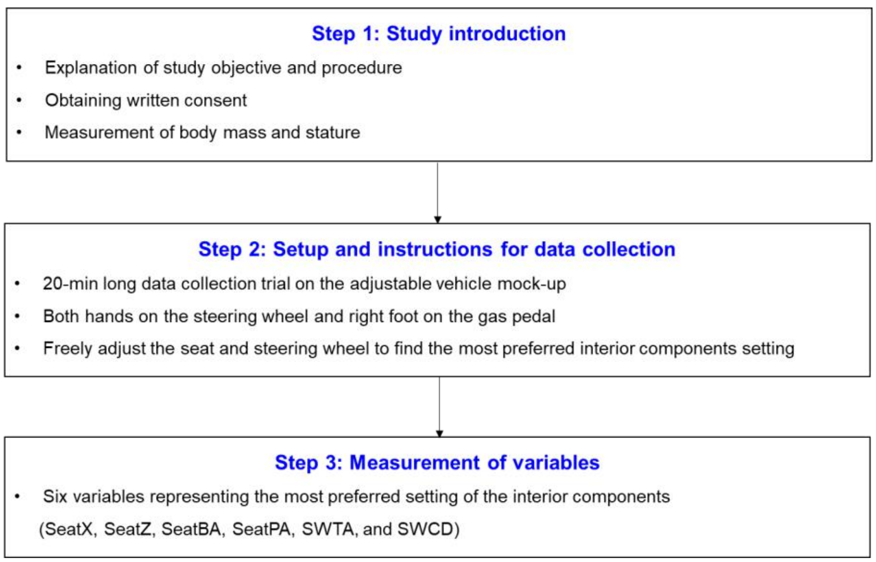

Figure 2. Experimental procedure in data collection trial

2.4 Statistical Analysis

A modified version of the Bayesian multivariate adaptive regression splines (BMARS) modeling method proposed by Francom *et al*. (2018) was used to examine the relationship between the driver personal variables and the six variables representing the preferred setting of the vehicle interior components. The modified BMARS modeling method is known to well characterize nonlinearities and interactions as well as prevent overfitting (Dension *et al*., 1998a,b; Francom *et al*., 2017; Francom *et al*., 2018; Friedman, 1991). The modified BMARS modeling method applies parallel tempering in the Markov Chain Monte Carlo (MCMC) sampling for more efficient posterior sampling and better posterior exploration than BMARS. A detailed description of the modified BMARS model is provided below:

$$y_i = f(x_i) + \epsilon_i, \ \ \epsilon_i \sim N(0, \sigma^2) \ , \tag{1}$$

where $f(\cdot)$ is a mean function to be estimated from the data. $y = (y_1, \cdots, y_{86})$ is a vector of observations of dependent variables (SeatX, SeatZ, SeatBA, SeatPA, SWTA, and SWCD), and X is an $86 \times p$ matrix where the i^{th} row $x_i = (x_{i1}, \cdots, x_{ip})$ is an observation of p independent variables (age, gender, stature, BMI, and SXP).

In the modified BMARS approach, $f(x)$ is represented as a linear combination of the Bayesian adaptive splinez surfaces (BASS) basis functions (tensor product of spline functions) $B_m(x)$. $f(x)$ and $B_m(x)$ are defined as follows:

$$f(x) = \beta_0 + \sum_{m=1}^{M} \beta_m B_m(x) \tag{2}$$

$$B_m(x) = \prod_{j=1}^{J_m} \left[h_{jm} \left(x_{r(j,m)} - t_{jm} \right) \right]_+ , \tag{3}$$

where $[\,\cdot\,]_+ = \max(0,\cdot)$, J_m is the degree of interactions modeled by the basis function, h_{jm} is the sign indicators, and $r(j,m)$ produces the index of the independent variable, which is being split on t_{jm}, commonly referred to as the knot points.

In the statistical model, priors such as $\beta_{\text{m}} \sim N(0, \frac{\sigma^2}{\tau(B_m B_m)^{-1}})$, $M \sim Poisson(\lambda)$, and so on are used. The priors have a hierarchical structure, and it is like those in Denison *et al*. (1998a). The posterior distribution on the unknown parameters and the predicted independent variable is very complex, and posterior means and other summary quantities of interest cannot be obtained analytically. Therefore, in this study, R package BASS version 0.2.2 (Francom *et al*., 2017) was used to carry out all statistical analyses. The package applies the reversible jump Markov Chain Monte Carlo (MCMC) method for exploring the posterior distribution.

To identify nonlinear and interactive relationships between driver personal variables and preferred vehicle interior components setting and reflect the typical task sequence during the adjustments of the interior components, the modified BMARS modeling method and a two-phase modeling approach were adopted: 1) the modified BMARS model for SeatX describing the seat horizontal position as a function of the driver personal variables and SeatX preference (SXP) representing the driver's preference on the seat horizontal position relative to the mean position estimated by the model for SeatX was created; and, then, 2) the modified BMARS models for the other five variables (SeatZ, SWTA, SWCD, SeatBA, and SeatPA) were developed, which utilized the driver personal variables (age, gender, stature, and BMI) and the initial choice of the seat horizontal position (SXP) as the predictors (independent variables). The procedure for statistical analyses is summarized in Figure 3. A detailed description of the procedure is provided below:

1. The relationship between personal variables (age, gender, stature, and BMI) and SeatX was characterized as a modified BMARS model for SeatX.
2. For each case in the dataset, the residual in the modified BMARS model for SeatX, that is, the difference between the observed SeatX and the model estimate of SeatX, was computed using the modified BMARS model. This residual was denoted as the SeatX preference (SXP) value as it represents the driver's preference on the seat horizontal position relative to the mean position estimated by the modified BMARS model. A positive SXP value means that the driver placed the seat more rearward than the estimated SeatX. A negative SXP value, on the other hand, indicates that the driver placed the seat more forward compared with the estimated SeatX.
3. The relationship between the independent variables (age, gender, stature, BMI, and SXP) and each of the dependent variables (SeatZ, SeatBA, SeatPA, SWTA, and SWCD) was characterized as modified BMARS models – note that: SXP was included in the independent variables to examine the impacts of the initial choice of seat horizontal position.

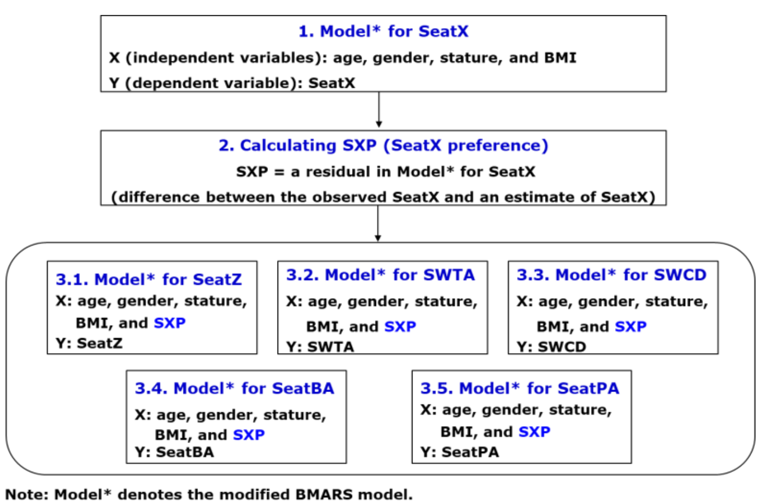

Figure 3. Procedure for statistical analyses

3. RESULTS

As for the modified BMARS model for SeatX (Figure 4), it was found that SeatX generally increased with increasing stature and BMI. The model also identified an interaction between the two variables, along with some nonlinearities. As BMI increased, the stature impact on SeatX became progressively less pronounced, especially for the lower half range of stature (stature ≤ 170 cm) (Figure 4a) – for the non-obese drivers (BMI < 30 kg/m^2), SeatX almost linearly increased with increasing stature at relatively higher rates of increase throughout the entire range of stature; on the other hand, the increase in SeatX associated with increasing stature was less salient for the extremely obese drivers (BMI ≥ 40 kg/m^2), particularly for the lower range of stature. Figure 4b illustrates the interaction between stature and BMI using BMI-SeatX curves. As stature increased, the BMI impact on SeatX became progressively less pronounced (Figure 4b) – for the shorter drivers (stature ≤ 160 cm), SeatX monotonically increased as BMI increased throughout the entire range of BMI; however, for the taller drivers (stature ≥ 180 cm), SeatX remained nearly unchanged with increasing BMI.

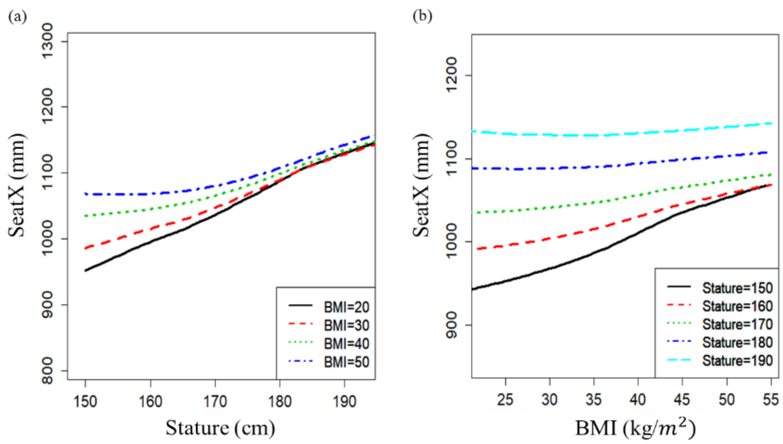

Figure 4. The modified BMARS model for SeatX

SeatX preference (SXP) was obtained for each participant using the modified BMARS model – the descriptive statistics and distribution of SXP are graphically illustrated in Figure 5 using a box whisker plot and a histogram. Regarding the descriptive statistics and distribution of SXP (Figure 5), it was found that there was a wide range of distribution (from -100 to +100 mm) in SXP. This means that there is substantial residual variance in the seat horizontal position (SeatX).

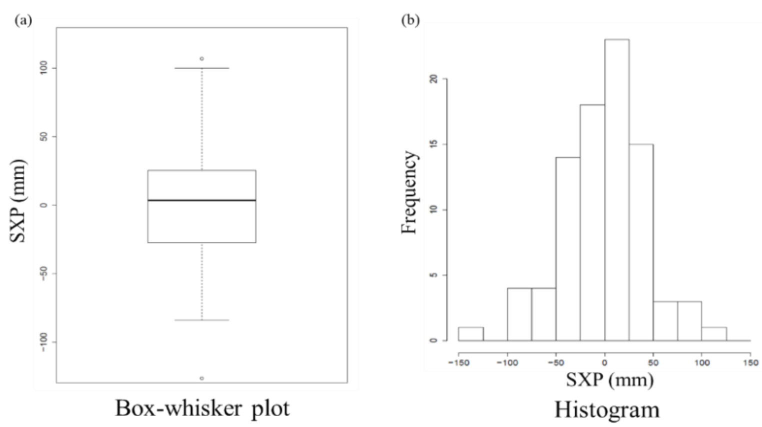

Figure 5. The descriptive statistics and distribution of SXP

The results for the modified BMARS model for SWTA, SWCD, and SeatBA are provided in Figures 6−8; as for the modified BMARS model for SeatZ and SeatPA, no relationship was found between the independent variables and the dependent variables.

Regarding the modified BMARS model for SWTA (Figure 6), it was found that SWTA generally increased with increasing BMI and decreasing SXP in a piecewise linear fashion. Also, an interaction between the two variables was identified. Figure 6a shows how SXP modified the BMI impact – as SXP decreased from positive to negative values, the increase in SWTA associated with increasing BMI became progressively more salient. Figure 6b describes the same interaction between BMI and SXP using SXP-SWTA curves – SWTA remained nearly unchanged throughout the entire range of SXP for the non-obese drivers (BMI < 30 kg/m^2), but, as BMI increased beyond the non-obese range, the impact of SXP became progressively more pronounced.

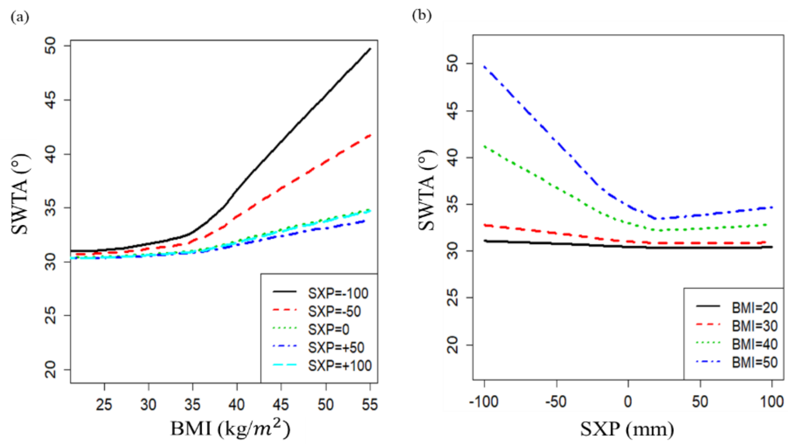

Figure 6. The modified BMARS model for SWTA

The modified BMARS model for SWCD (Figure 7) shows that SWCD generally increased with increasing stature and SXP – note the nonlinearities in the relationship. The model also identified an interaction between the two variables. The stature impact on SWCD was modified by SXP level (Figure 7a) – the stature impact became progressively more pronounced as SXP increased from negative to positive values. Figure 7b illustrates the same interaction between stature and SXP using SXP-SWCD curves. The SXP impact on SWCD was modified by stature level (Figure 7b) – the SXP impact became progressively larger as stature increased; it remained nearly unchanged with increasing SXP for the shorter drivers (stature ≤ 160 cm).

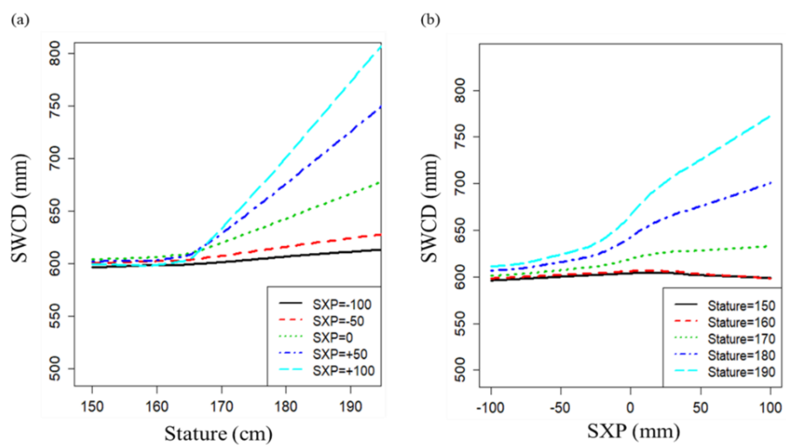

Figure 7. The modified BMARS model for SWCD

The modified BMARS model for SeatBA (Figure 8) identified a three-way interaction (age × BMI × gender). Figures 8a and 8b describe the three-way interaction using age-SeatBA curves – SeatBA generally decreased with increasing age. This age impact was more pronounced for the higher BMI drivers and especially for the higher BMI female drivers (Figures 8a and 8b). Figures 8c and 8d depict the three-way interaction using BMI-SeatBA curves – SeatBA generally deceased with increasing BMI. This BMI impact was more pronounced for the older drivers and especially for the older female drivers.

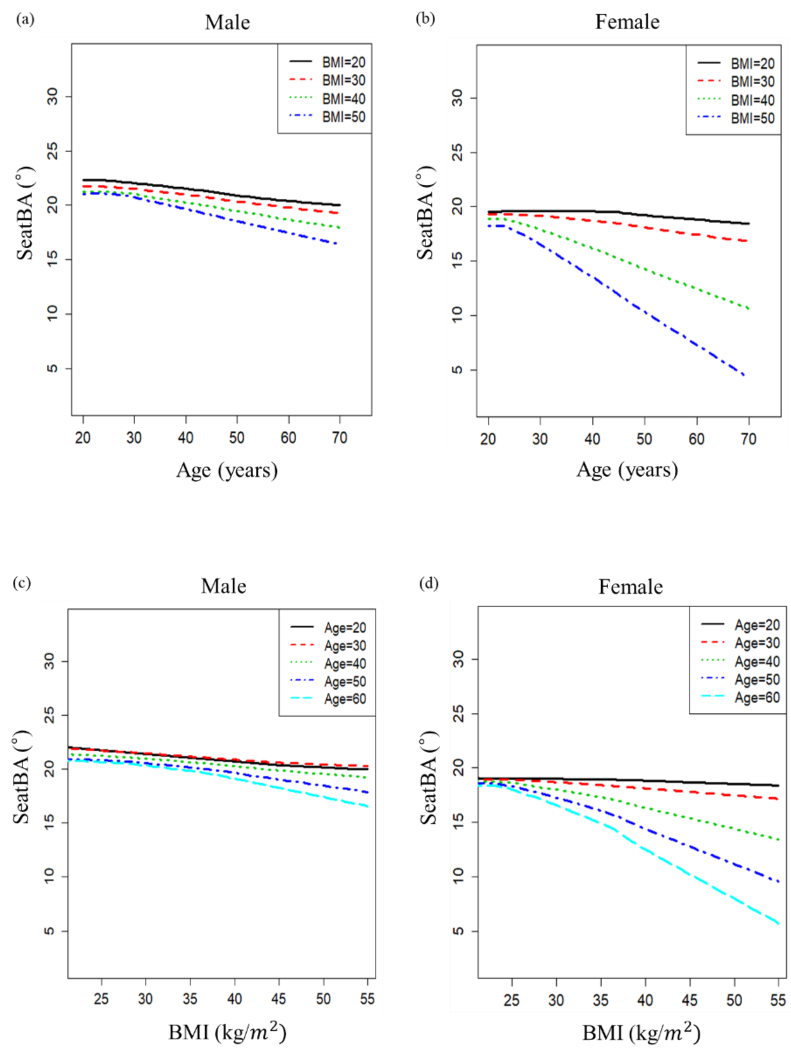

Figure 8. The modified BMARS model for SeatBA

4. DISCUSSION

This study identified and characterized the relationship between driver personal variables and preferred vehicle interior components setting using the modified BMARS modeling method. A group of male and female drivers with a wide range of ages, stature, and BMI participated in this study. A highly adjustable vehicle mock-up was used to empirically collect each participant's preferred vehicle interior components setting.

Regarding the modified BMARS model for SeatX (Figure 4), while SeatX was found to generally increase with increasing stature and BMI, an interaction between the two variables was identified. As shown in Figure 4a, the impact of increased stature became progressively less pronounced as BMI increased. The same interaction is also shown in an alternative form in Figure 4b – the impact of increased BMI became progressively less pronounced as stature increased. This interaction could be logically explained in terms of a mutual masking effect between BMI and stature. An increase in BMI involves increases in the volumes of the abdomen and hip segments (Gyi *et al*., 2019). Also, an increase in stature entails an increase in leg length (Johnson *et al*., 2022; Mandal *et al*., 2022). Each of these anthropometric changes needs to be accommodated by providing the required space. Increasing SeatX can address both needs simultaneously – indeed, both stature and BMI were found to be overall positively correlated with SeatX (Figure 4). It is thought that for obese drivers, the large abdomen and hip segment volumes required an increase in SeatX, and thus, the impact of increased stature and leg length on SeatX became manifest only when it exceeded that of the obesity condition (Figure 4a). Similarly, for taller drivers, it is thought that the large leg length had a masking effect on the impact of increased BMI and body segment volumes on SeatX (Figure 4b).

As for the descriptive statistics and distribution of SXP (Figure 5), SXP was found to have a wide range of distribution (from -100 to +100 mm). This means that there is substantial residual variance in the seat horizontal position (SeatX) – in other words, people who have identical body dimensions (stature and BMI) can choose very different seat horizontal positions. This finding is congruent with those of multiple previous studies (Flannagan *et al*., 1998; Parkinson and Reed, 2006; Porter *et al*., 2004; Reed *et al*., 2000b; Reed *et al*., 2002; Reed and Flannagan, 2000; Reed *et al*., 2000a). The previous studies referred to the observation as "postural variability" or "non-anthropometric variability."

Regarding the modified BMARS model for SWTA (Figure 6), SWTA was found to generally increase with increasing BMI and decreasing SXP – please note the nonlinearities (a piecewise linear relationship) captured by the modified BMARS model. Also, an interaction between the two variables was identified (Figure 6). As shown in Figure 6a, the impact of increased BMI was progressively more pronounced as the seat position shifted forward, that is, as SXP decreased. Figure 6b shows the same interaction in a different form of presentation – the impact of decreased SXP was progressively more pronounced as BMI increased; note that SWTA remained nearly unchanged throughout the entire range of SXP for the non-obese drivers (BMI < 30 kg/m^2). The interaction observed is thought to reflect the increase in the driver space requirement associated with increasing driver BMI – a small SXP value indicates the driver's preference to locate the seat forward; in such a situation, an obese driver would require a larger driver space than a non-obese driver, and, thus, would have to place the steering wheel more upright (larger SWTA) to secure the necessary space.

As for the modified BMARS model for SWCD (Figure 7), SWCD was found to generally increase with increasing stature and SXP – please note the nonlinearities captured by the modified BMARS model. Also, an interaction between the two variables was identified. As shown in Figure 7a, the impact of increased stature was progressively more pronounced as the seat position shifted rearward, that is, as SXP increased. Figure 7b shows the same interaction in a different form of presentation - the impact of increased SXP was progressively more pronounced as stature increased. The interaction observed appears to reflect the nature of the geometric relationship between the driver's hand position in the sagittal plane and the anthropometric (stature) and non-anthropometric (SXP) variables.

The modified BMARS model for SeatBA (Figure 8) revealed that: 1) SeatBA generally decreased with increasing age and BMI, 2) SeatBA was generally smaller for the female drivers than for the male drivers, and 3) age, BMI, and gender interacted with one another to influence SeatBA. The interactions are characterized as follows:

- The impact of increased age on SeatBA was progressively more pronounced as BMI increased (Figures 8a and 8b), and vice versa (Figures 8c and 8d),
- The impact of the age × BMI interaction on SeatBA was more pronounced for the female drivers than the male drivers (Figures 8a–8d), and
- The two- and three-way interactions described in Figure 8 indicate that the impacts of the three variables combined in a way that was more multiplicative than additive.

The observed age impact on SeatBA may be understood on the basis of the muscular strength characteristics associated with old age. The decline in the upper extremity muscular strength associated with old age (Baumgartner *et al*., 1998; Greenlund and Nair, 2003; Lauretani *et al*., 2003; Voorbij and Steenbekkers, 2001) would necessitate the elderly drivers to maintain biomechanically advantageous muscle lengths in the upper extremities, which may result in a shorter distance between the torso and the steering wheel, and, thus, a smaller SeatBA value for the elderly drivers than for the young drivers. Also, the deterioration of eyesight and spatial perception associated with old age (Andersen and Ni, 2008; Asano *et al*., 2007; Bertone *et al*., 2011; Oteir *et al*., 2016) may be related to the observed age impact on SeatBA.

Similar to the age impact, the gender difference in SeatBA may be attributed to the muscular strength characteristics of the female population. On average, the upper extremity muscular strength is lower for females than for males (Cid *et al*., 2020; Chow and Dickerson, 2009; Sinaki *et al*., 2001; Lafortuna *et al*., 2005; Danneskiold-Samsøe *et al*., 2009; Maleki-Ghahfarokhi *et al*., 2019). Also, the arm length and sitting height are, on average shorter for the females than for the males (Allison *et al*., 1983; Hennessey *et al*., 1994; Masanovic *et al*., 2020; Mervaala *et al*., 1988; Park *et al*., 2013; Popovic, 2019; Won *et al*., 2009). Therefore, female drivers would be needed to move their upper body toward to the steering wheel to obtain enough view and hold the steering wheel with both hands. This may also be related to the observed gender difference in SeatBA.

The observed BMI impact on SeatBA is thought to reflect the change in SeatX associated with increasing BMI. As depicted in Figure 4b, an increase in BMI entails an increase in SeatX. Thus, a high BMI individual would need to reduce SeatBA in order to compensate for the increase in SeatX and decrease the distance between the torso and the steering wheel. Also, it should be noted that body-mass normalized muscular strength is lower for the obese (high BMI) than the non-obese (Cavuoto and Nussbaum, 2013; Koushyar *et al*., 2017; Tomlinson *et al*., 2016). This may also be related to the observed BMI impact on SeatBA.

Overall, the current study identified and characterized describing the relationship between driver personal variables (age, gender, stature, and BMI) and preferred vehicle interior components setting – the study employed the modified BMARS modeling method and a two-phase modeling approach. The modified BMARS modeling method was found to identify the nonlinear and interactive relationship. The two-phase modeling approach enabled characterizing the temporal, logical process involved in the selection of the preferred vehicle interior components setting. The results of the current study indicated that: first, driver personal variables substantially affected preferred vehicle interior components setting – among the driver personal variables, stature and BMI affected seat horizontal position (SeatX); BMI affected steering wheel tilt angle (SWTA); stature affected steering wheel column displacement (SWCD); and age, BMI, and gender affected seatback angle (SeatBA). Second, SXP was found to have a wide range of distribution. This means that people who have identical stature and BMI can choose different seat horizontal positions. Third, the current study identified and characterized the impacts of SXP on the subsequent adjustment of the other variables (SWTA and SWCD) – as SXP increased, SWTA decreased, and SWCD increased. This means that the driver's preference of the seat horizontal position could affect the subsequent adjustment of the steering wheel. Finally, two-way or three-way interactions were identified in SeatX, SWTA, SWCD, and SeatBA.

The findings from this study improve the understanding of the relationship between driver personal variables and preferred vehicle interior components setting – this study well characterized the impacts of driver personal variables and their interactions on the preferred vehicle interior components setting. It is worth noting that the current study provides some useful information for the ergonomics design of vehicle interior packages for accommodating individuals with unique needs or a target population. For example, the study results indicate that short and extremely obese (stature $\leq$ 160 cm and BMI $\geq$ 40 kg/m^2) drivers may experience difficulties driving most of the current vehicles and be very vulnerable in accidents – they have short lower and upper limbs but need a longer horizontal distance from the seat and the gas pedal (larger SeatX) and a more upright steering wheel angle (larger SWTA) than non-obese drivers (Figures 4 and 6); therefore, they may adopt awkward driving postures (e.g., slouching or slumping postures) and have a poor line of sight. Innovative design solutions, such as highly adjustable gas/brake pedals and small and/or non-circular (e.g., butterfly or triangle) steering wheels, may need to be developed for short and extremely obese drivers. Also, the study findings suggest that considering postural variability (non-anthropometric variability) as well as driver personal variables (age, gender, stature, and BMI) in vehicle interior components setting would benefit for achieving a high level of population accommodation in vehicle interior package design. The findings from this study will help designers/manufacturers to accommodate the majority of individuals. Such driver accommodation at both the individual and the population level would ensure driver comfort and safety.

Some limitations of this study are described here along with future research ideas: first, male and female drivers with a wide range of BMI (22.5–54.6 kg/m^2) participated in this study – BMI categories (World Health Organization, 2020) from normal-weight (18.5 kg/m^2 $\leq$ BMI < 25 kg/m^2) to obesity class III (BMI $\geq$ 40 kg/m^2). However, under-weight (BMI < 18.5 kg/m^2) drivers were not recruited. Considering the entire range of BMI would provide complete knowledge for BMI-associated changes in self-selected vehicle interior components setting. Second, this study well identified and characterized the impacts of driver personal variables (age, gender, stature, and BMI), SXP, and their interactions on the preferred vehicle interior components setting. However, this study did not analyze how the factors affect preferred driving posture (a set of body joint angles). Also, this study did not consider other driver personal variables such as upper and lower body length, arm length, driving experience, and race. Future studies are needed to address the research gaps. Finally, although a group of male and female drivers (42 males and 44 females) with a wide range of age, stature, and BMI participated in this study, future studies need to consider extending the current research study by increasing sample size and recruiting more diverse participants in order to improve the generalizability of research findings.

5. CONCLUSION

This study identified and characterized the relationships between driver personal variables and preferred vehicle interior components setting. A two-phase modeling approach and the modified BMARS modeling method were adopted. The former characterized the temporal, logical process involved in the driver selection of the preferred vehicle interior components setting. The latter identified nonlinear and interactive relationships between the predictors and the responses, which were then interpreted on the basis of physical ergonomics concepts. The study findings improve the understanding of the relationship between driver personal variables and preferred vehicle interior components setting, and further inform the vehicle interior package design for driver accommodation at both the individual and the population level.

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