

Original Article

## Development of a statistical model for predicting seat pressure felt level in simulated condition based on direct and anthropometric measurement

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**Abstract.** [Purpose] The purpose of this study was to investigate the effects of seat pressure distribution measurements based on a specific posture to predict the pressure felt level when seated. [Subjects and Methods] To examine the relationship between body pressure data and the driver's perception, eleven subjects were selected to participate in a simulated driving experiment using a pressure mat as a direct measurement method to measure the seat pan's pressure distribution. The buttock-popliteal length was measured using an anthropometer, and the pressure felt ratings evaluated after the body pressure measurements were recorded. Accordingly, this was then followed by performing statistical analysis using seat pressure measurements, and the buttock-popliteal length as independent variables along with subjective ratings selected of the pressure felt by the drivers' as dependent variables. [Results] The findings of this study suggest that the direct measurements and anthropometric body data are positively correlated with the predictive model thereby confirming the validity of the model with an  $R^2$  value of 0.952. [Conclusion] The proposed model is expected to provide a useful reference value for new vehicle drivers by providing the pressure felt level based on direct and body measurements in a specific posture.

**Key words:** Pressure, Seat, Anthropometric measurement

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### INTRODUCTION

Sitting comfort can be defined as a combination of appreciating states from the physiological, psychological and physical perspectives between the sitter and the environment<sup>1, 2)</sup>. Meanwhile, discomfort can be defined as the unpleasant state between the sitter's body and its environment<sup>3)</sup>. The driver's comfort, which is influenced by everyday driving practices and activities associated with driving, is extremely subjective. For example, drivers can adjust the position of their seat, steering wheel height and position according to their preference and level of comfort needed to attain a comfortable driving position. Driving in a comfortable and safe position can help to prevent road accidents, improve road safety, and enhance the overall driving experience. However, comfort is also reliant on the duration of travel, time, (i.e. night vs. day) and changing road conditions<sup>4)</sup>.

An extended position coupled with a near static seated position and posture while driving can impose restrictions on the driver which may potentially lead to musculoskeletal disorders such as low back pain, neck pain and shoulder pain<sup>5-7)</sup>. Notably, this is due to the driver's body weight exerting significant pressure, which is forced directly on the muscle areas of the body which are presently functioning in an anaerobic manner. Due to the compressive force imposed on the driver's body and the seat interface, the blood flowing through large vascular blood vessels to the lower part of the anatomy will be obstructed. Consequently, this will lead to insufficient oxygen supply to the body, resulting in discomfort, fatigue and the longer term, will convert into severe pain and possible injury if untreated<sup>8-14)</sup>.

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Many studies have been conducted to measure sitting discomfort. Previous studies have identified two types of measuring methods that are used, namely the subjective and objective methods. The subjective methods are used primarily for indirect evaluation due to the subjective perceptions regarding comfort or discomfort<sup>15</sup>. Conversely, objective methods require the use of specific equipment to measure the comfort condition. Nevertheless, the objective methods produced more advantages compared to subjective methods. Furthermore, the objective methods require less time for observation and in testing subjects and are attributed to less bias and measurement errors, producing fast, relevant information for the design process<sup>16–18</sup>. Accordingly, the objective methods provide a value associated with the condition, by measuring and collecting data mostly numerically. Furthermore, the objective methods are beneficial when integrated with the subjective methods, if there is a relationship between the two methods<sup>19</sup>. Helander et al.<sup>20</sup> cited the causes of sitting discomfort mainly influenced by biomechanical causes.

Many studies in the literature focus on areas associated with seat improvement. For instance, Grandjean<sup>21</sup>, Hubbard et al.<sup>22</sup>, Coelho et al.<sup>23</sup> and Wu et al.<sup>24</sup> concentrated on the seat design parameters and features by considering the postural angle, design, and materials of the seat. Several other studies combined the subjective assessment tools, such as the comfort rating with the pressure distribution data. Prior studies have shown that there is a positive correlation between the pressure distribution data and the seat comfort rating. Ng et al.<sup>12</sup> conducted a study using the same approach by developing an intelligent seat system based on pressure data of an adjustable seat. In this study, subjective comfort ratings (from 1=very poor to 10=very good) and anthropometric measurements were carried out on 20 participants simulating driving positions in a seating buck. Thakurta et al.<sup>25</sup> compared the subjective assessment of short and long-term driving periods along a 129-kilometre highway. Thirty-six respondents using five small cars were assessed using assessment questionnaires relating to 'comfort', where pressure distribution was mapped both before and after driving. Limited studies at this stage have examined the pressure distribution pattern in a fixed driving sitting position with a complete vehicle setup (construct) to observe the effects on the driver. However, there are three studies previously undertaken which are closely associated with this area. Andreoni et al.<sup>26</sup> recorded posture and pressure distribution when the subject put their foot on the car pedal, but this study did not use a fixed position for the pedal. Porter et al.<sup>27</sup> requested the subject to drive the car, but no specific posture was used. In a separate study by Na et al.<sup>28</sup> they set the seat back angle at 1150 based on the posture associated with an average Korean person. However, no assessment regarding the relationship between the measurement and anthropometric body data was performed.

In general, the adaptation of body posture while performing a task depends mostly on the adjustability of the seat and anthropometry of the driver<sup>29</sup>. Past studies have shown that there is often a positive relationship between pressure distribution, the subjective rating and body measurement<sup>12, 19, 30</sup>. For instance, Ng et al.<sup>12</sup> evaluated the modern design of a seating system (setup) using the subjective rating and pressure map where seated anthropometric data were collected from 20 subjects. A joint angle was used, such as the ankle angle and knee angle plus the anthropometric measurements, such as buttock-popliteal length and knee height, and was collected when the subject stretched their arms out to reach the steering wheel. Goonetilleke et al.<sup>31</sup> and Shen et al.<sup>32</sup> also identified that the buttock-popliteal length was a primary parameter to determine the sitting pattern, which showed a good relationship with the other measurements. In the study conducted by Goonetilleke et al.<sup>31</sup>, the buttock-popliteal length showed a linear correlation with the seat depth of a chair with 99.98% R-square. Notably, the buttock-popliteal length can be defined as the determinant factor to the cushion length. Based on a study by Reed et al.<sup>33</sup>, a cushion that is too long will lead to localised discomfort due to significant pressure under the person's thigh area, thereby restricting blood flow to the leg.

## SUBJECTS AND METHODS

Eleven subjects (mean age=28 ± 4.83 years of age, a mean height=161 ± 6.38 cm, mean weight=56 ± 7.16 kg) were chosen from the staff and student population at Universiti Kebangsaan Malaysia to participate in this study based on meeting certain criteria. All subjects needed hold a full Malaysia driving license, have a minimum of three years driving experience, aged between 21 to 35 years old. Also, each subject reporting no risk of nausea (motion sickness) while travelling in a car as the driver. The constraint associated with age was proposed to reduce any potential variations in the results due to the subject's age. Notably, even as part of the normal ageing process, people will exhibit slight perceptive and reflex variations that could have a direct effect on their attitude towards driving<sup>34</sup>. A letter of approval relating to Ethical Practice was also required from the Ethical Committee at Universiti Kebangsaan Malaysia with reference number UKM PPI/111/8/JEP-2016-200. Next, the buttock-popliteal length (mean length=47.4 ± 1.8 cm) was measured using an anthropometer. All subjects were able to adapt to the car simulator setup and the task of driving before starting the actual experiment. The experiment commenced five minutes after each subject had been seated in the driving position, which enabled each subject to adapt to the seat and materials (i.e. fabric). All subjects understood and complied with oral and written instructions presented by the researcher for the experiment. Relevant information regarding simulator driving procedures and assessment methods were presented, which was followed by each subject signing a consent form acknowledging that they understood and complied with all information and experimental procedures.

Figure 1 illustrates the driving simulator used for the experiment. The simulator's design and seat parameters are like a Malaysian small car. The simulator consisted of an adjustable driver's seat (adjustable backrest, headrest and seat), steering wheel, clutch, accelerator pedal and brake pedal, handbrake and manual gear shift. The screen was positioned in front and



**Fig. 1.** Simulator setup.



**Fig. 2.** Driving posture.

in full view of the driver along with a virtual dashboard and simulated engine noise. Furthermore, the screen displays the simulated road scene and conditions, driving speed and gear positions using the virtual dashboard.

Figure 2 shows the driving posture. The driving posture required the subject to be seated at the closest comfortable distance to the controls. During the pressure distribution recording, the test subjects were required to locate their left and right hands at the positions of 10 and 2 o'clock, as illustrated in Fig. 2. Furthermore, the subjects needed to ensure that their right leg was located on the car pedal, and able to use either the brake or accelerator pedals, while the left leg was situated on the floor near to the clutch pedal. Accordingly, each subject was required to be seated close to the steering wheel with their knees flexed at an angle less than  $110^\circ$  and be comfortably seated while leaning back against the seat's backrest. Figure 1 displays the steering wheel actions required to be performed by each subject.

The pressure distribution pattern used in this experiment demonstrates and predicts any signs associated with sitting discomfort. Notably, pressure measurement is sensitive to postural changes of various angulations and has a positive correlation with subjective comforts, by determining the maximum pressure, average pressure ratio and maximum pressure gradient<sup>19, 35</sup>. In this study, the Tactilus<sup>®</sup> pressure mapping system supplied from Sensor Products Incorporations (SPI) is used. The system includes  $22 \times 22$  sensor pads calibrated at 0 to 5 pounds per square inch (psi) with a  $32 \times 32$  sensor matrix. The interface pressure uses thin and flexible sensor arrays. Also, by scanning the grid and measuring the electrical resistance at each grid point, the pressure distribution on the sensor's surface can be determined. The electronic scanner is packaged in a handle type assembly that clips onto the sensor's interface tab that provides the electrical connection to each sensor cell.

All subjects were requested to wear suitable attire for driving without bulky seams, buttons or pockets to ensure minimal effect on the pressure readings and to avoid false seat or backrest interface pressure readings. The mats were securely attached to the seat using strips of masking tape and care was exercised to ensure that the mats were placed in a consistent location from the subject, seat and backrest. For the driving position, each subject was required to put both hands on the steering wheel and to look directly ahead. Accordingly, this enabled measurements to be accurately recorded. Next, the mats were removed, and the subject was asked to re-enter the simulator and sit on the seat to complete the survey, thereby negating any interference caused by the mats. The reason for this instruction was because the subjects had trouble rating the appearance of the seat when they sat on it.

For the subjective assessment form, two sections within the form were required to be completed. The information within the first section that was needed related to each subject's demographic background, age, gender, weight, height and driving experience. The second section required each subject to identify their perceptions of the pressure felt level based on driving posture. In this section, the seat component was split into two parts representing the buttocks and thighs. The Visual Analogue Scale (VAS) was used to represent the perception of pressure felt, using a 10-cm continuous horizontal line with each point along the line having a different definition. In this case, 0 was referred to as no pressure felt, and 10 referred to as extreme pressure felt.

Data from the experiment were used to predict and estimate the dependent variable (DV) based on an independent variable (IV) by using the Regression Method. Accordingly, this was used to predict the value of a variable based on the value of another variable. The variable to predict is called the DV, while the variable used to predict the other variable's value is called the IV or otherwise known as the predictor variable. In this study, the DV is based on the subjective assessment, while the IV

is referred to as the objective assessment (pressure distribution map measurement). The highest mean score for each IV was used to develop the model in this section.

Based on this method, the regression coefficient ( $K$ ), regression constant ( $c$ ), multiple correlation coefficients ( $R$ ), coefficients of determination ( $R^2$ ) and significance level ( $p$ ) are determined. The acceptance or rejection of the Null hypothesis ( $H_0$ ) is also determined based on the newly developed model ( $H_0: \beta_1=0$  and  $\beta_2=0: \beta_1 \neq 0$  and  $\beta_2 \neq 0$ ). The  $H_0$  can be rejected if the p-value is low ( $p < 0.05$ ). As a result, it can estimate the drivers' condition based on these integrated assessment methods. In other words, a predictor that has a low p-value is likely to be a significant predictor to the model because the changes in the predictor's value are connected to changes in the response variable. The linear equation to predict the drivers' state is given by Equation 1:

$$y = k_1x_1 + k_2x_2 + c \text{ (Equation 1)}$$

where

$y$ =drivers' state based on subjective assessment (DV),

$k$ =regression coefficient as the contributor factor towards pressure pattern,

$x_1$ =mean pressure at the buttock part (IV<sub>1</sub>)

$x_2$ =buttock-popliteal length (IV<sub>2</sub>)

$c$ =regression constant.

## RESULTS

Table 1 displays the results for the seat pan based on the subjective assessment regarding the pressure felt level and the objective assessment regarding pressure distribution of the seat pan at the buttock and thigh areas. According to Table 1, based on the pressure felt level, the highest pressure felt rate at the buttocks area was higher than the thigh area at the position, 6.52 and 2 respectively. Furthermore, the highest pressure based on the pressure measurement was observed to be in the buttock area at 2.88 pounds per square inch (psi). Meanwhile, the thigh area only demonstrated 0.83 psi for the pressure measurement, as illustrated in the Table 1.

Overall, according to the subjective and objective assessments, the highest-pressure value was observed at the buttock area with the mean pressure scores of 6.52 and 2.88 psi from both assessments respectively. Furthermore, based on the statistical analysis, it confirmed a strong correlation between the pressure distribution at the buttock area and the buttock-popliteal length ( $r=0.804$ ,  $p < 0.05$ ).

Therefore, for this part, DV represents the data from the subjective assessment of the buttock area, and the IV represents the data from the pressure distribution measurement at the buttock area and buttock-popliteal length measurement. Table 1 shows the findings obtained from the regression method. The table shows R, R<sup>2</sup>, Adjusted R<sup>2</sup>, and the Standard Error of the Estimate (SEE), which is used to determine how well the regression model fits or suits the data. Accordingly, R can be represented as one measure of the quality of the prediction of the DV; in this case, the pressure felt by the subject. A value of 0.963 indicates a reasonable level of prediction. In general, if the R-value is higher than 0.71, it will show a strong correlation between the variables<sup>36</sup>. The R-square column represents the R<sup>2</sup> value, which is the proportion of the variance in the dependent variable as can be seen by the IV (pressure distribution map measurement). Based on Table 2, a value of 0.976 indicates a reasonable level of prediction. The R-square value is 0.952, while the Adjusted R-square was 0.940, smaller than R-square.

Table 3 depicts the coefficient table for the model where the significant level for IVs was less than 0.05. Also, it indicates the possibility to obtain t-value for the constant which was 2.761 and the slope for pressure distribution and buttock-popliteal length were 7.175 and -2.334 respectively.

Based on Table 3, the equation model to predict the pressure felt by the drivers' pressure based on pressure distribution and the buttock-popliteal length can be employed as given by Equation 2:

$$y = 31.518 \times 1 - 0.270 \times 2 + 12.936 \text{ (Equation 2)}$$

According to Equation 2, the Pressure Felt Index (PFI) can be developed. The index scale for each index was developed based on the VAS value, which has been used in the subjective assessment form as described under Subjects and Methods section. The PFI is used to be the reference point to evaluate the driver's pressure felt level with regards to the pressure distribution measurement based on the car seat. The PFI scale are: 0–2.0 (very mild pressure felt); 2.1–4.0 (mild pressure felt); 4.1–6.0 (moderate pressure felt); 6.1–8.0 (extreme pressure felt); 8.1–10.0 (very extreme pressure felt).

**Table 1.** Mean plot for subjective and objective assessment at the buttock and thigh

Body part	Buttock	Thigh
Assessment		
Subjective	6.52	2.00
Objective	2.88 psi	0.83 psi

**Table 2.** Summary of the model for pressure distribution and pressure felt level

Model	R	R Square	Adjusted R Square	SEE
1	0.976	0.952	0.940	0.260

**Table 3.** Coefficient table for the pressure felt prediction model

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	SE	Beta		
1 (Constant)	12.936	4.685		2.761	0.025
Pressure distribution	31.518	4.393	1.365	7.175	0.000
Buttock-popliteal length	-0.270	0.116	-0.444	-2.334	0.048

Dependent variable: Pressure felt on buttock.

**Table 4.** Multiple linear regression validation for the pressure prediction

Assumption	Pressure felt level	Pressure distribution	Buttock-popliteal length
Normality	df(11)=0.410, p>0.05	df(11)=0.888, p>0.05	df(11)=0.079, p>0.05
Linearity	-	r(11)=0.959, p<0.01 Positive (linear)	r(11)=0.804, p<0.01 Positive (linear)
Auto-correlation	-	DW test: 0.66 < 0.707 < 1.60 Run test: Asymp. Sig. (2-tailed)=0.540 >0.05	DW test: 0.66 < 0.707 < 1.60 Run test: Asymp. Sig. (2-tailed)=0.540 >0.05
Heteroscedasticity	-	Beta=1.093, p>0.05	Beta=1.177, p>0.05
Multicollinearity	-	Tolerance (0.164>0.1) & VIF (6.106<10.00)	Tolerance (0.164>0.1) & VIF (6.106<10.00)

The assumptions related to the Classical Linear Regression Method (CLRM) should be used to validate the multiple linear models, and the criteria should be completed for all five tests, namely: normality, linearity, auto-correlation, heteroscedasticity and multicollinearity. Table 4 shows the validation results for the model, and according to these findings, the model fulfilled all the assumptions.

## DISCUSSION

The study proves that the pressure distribution over the seat pan is marginally influenced by the characteristics of the subject's (i.e. sitter's) body area regarding their weight and the buttock-popliteal length as discussed in the analysis relating to the seat pan. Furthermore, the buttock area shows a higher pressure as compared to the thigh area. Also, based on the model, linear regression was employed to predict the pressure felt from the pressure distribution map. Notably, this variable was able to statistically predict the pressure felt. Furthermore, due to the low value of p (p<0.05), the Ho (Ho:  $\beta_1=0$ ) was rejected. Accordingly, the linear model to predict the pressure felt at the buttock was:  $y=31.518 \times 1 -0.270 \times 2 + 12.936$ .

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## Conflict of interest

None.

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