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Patterns of correlation between vehicle occupant seat pressure and anthropometry

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Abstract. Seat pressure is known as a major factor of seat comfort in vehicles. In passenger vehicles, there is lacking research into the seat comfort of rear seat occupants. As accurate seat pressure measurement requires significant effort, simulation of seat pressure is evolving as a preferred method. However, analytic methods are based on complex finite element modeling and therefore are time consuming and involve high investment. Based on accurate anthropometric measurements of 64 male subjects and outboard rear seat pressure measurements in three different passenger vehicles, this study investigates if a set of parameters derived from seat pressure mapping are sensitive enough to differentiate between different seats and whether they correlate with anthropometry in linear models. In addition to the pressure map analysis, H-Points were measured with a coordinate measurement system based on palpated body landmarks and the range of H-Point locations in the three seats is provided. It was found that for the cushion, cushion contact area and cushion front area/force could be modeled by subject anthropometry, while only seatback contact area could be modeled based on anthropometry for all three vehicles. Major differences were found between the vehicles for other parameters.

Keywords: Seat Comfort, Seat Posture, Rear Occupant, Pressure Mapping, Vehicle Package Design

1. Introduction

Vehicle occupant seat pressure is well known to contribute to the overall perception of seat comfort [1,2], as pressure in general is a factor in comfort perception [3]. However, physical seat pressure measurements require a high effort and careful control of study parameters. In order to support the virtual product design process and avoid extensive physical pressure measurements [4], simulating occupant seat pressure up to now requires complex finite element models of driver and seat [5], which are sensitive to seat variation, time consuming and expensive to develop. A simplified method to predict occupant seat pressure from easily accessible anthropometric data is therefore desirable. As rear seat occupant comfort becomes increasingly important for the global automotive market [6], the aim of this study was to determine whether rear seat occupant pressure parameters can be estimated based on anthropometric variables, specifically for typical outboard second row seats of passenger vehicles. No studies were found that investigated this research focus. The relationship between anthropometry and posture however has been explored extensively [7,8].

2. Methods

Production type passenger vehicles from three manufacturers were used for the study, featuring similar measured seating heights (H70-2), but different cushion angles (A27-2) and seatback angles (A40-2) of the second row outboard occupant seats [9]:

– Vehicle A:
  H70-2 = 312 mm; A27-2 = 16°; A40-2 = 24°
– Vehicle B:
  H70-2 = 308 mm; A27-2 = 10.5°; A40-2 = 30.5°
– Vehicle C:
  H70-2 = 335 mm; A27-2 = 17°; A40-2 = 26.5°

Seat pressure was mapped for 64 male subjects, representative of a vehicle customer population (age = 38 ± 6 yrs; stature = 1730 ± 55 mm; body mass =

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75.9 ± 11.7 kg) in a real-type environment. The vehicles were masked for a blinded study. All subjects were randomly allocated to one vehicle and measured on one seat only. 20 subjects were measured in vehicle A, 24 subjects in vehicle B and 20 subjects in vehicle C. Pressure mats were centered on the seat and aligned with the cushion rear and seatback upper borders. Location of four points on the pressure mats, as well as selected palpated body landmarks were recorded with a Faro Fusion arm coordinate measurement system (FARO Technologies Inc., Lake Mary FL, USA) to calculate H-Points and posture.

While Vehicle A and B were equipped with production level seats, vehicle C had a prototype seat installed, which was built close to production level.

Anthropometry was measured using the ANSUR protocol [10], averaged over two or three measurements, depending on difference between first and second measurement, and box corrected.

Seat pressure was measured using a Tekscan Conformat 5330 type sensor system (Tekscan Inc., South Boston MA, USA) using two soft sensor mats for seatback and cushion. Pressure mats were pressure equilibrated and force calibrated using custom designed equilibration and calibration equipment. The sensor mats provide 1024 sensels, which allow for $1x2cm^2$ spatial resolution over a 471x471 mm sensor area. The sensor mat thickness is 1.78 mm. A most comfortable natural posture was assumed by subjects and measured over 15 seconds. The pressure recording was then averaged over the recording time, disregarding the first and last rows of the pressure map.

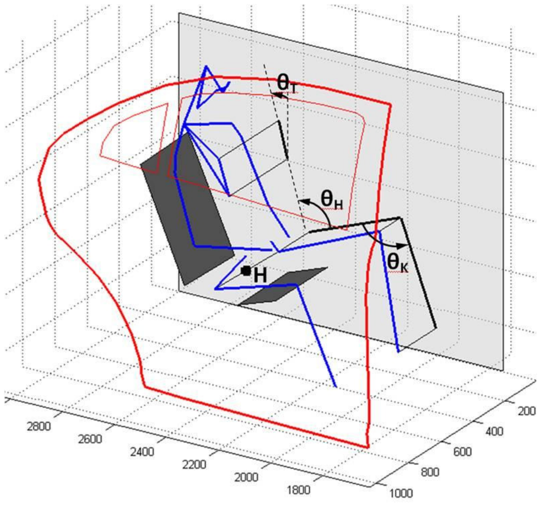

Figure 1: Postural model and definition of H-Point

True H-point location and torso angle were calculated using the body landmarks scanned with the FARO arm. The true H-point (H) was taken as the midpoint between the two greater trochanterion tuberosities (Figure 1).

A small number of independent anthropometric variables were selected based on body contact with seat cushion or seatback (Table 1) and correlated with dependent average pressure parameters derived from the pressure maps of the cushion and seatback (2.1), within the four areas of the pressure maps. Pressure recordings were not normalized for occupant position and posture. The model correlated with cushion pressure was then based on BM, HC, HB, KH and BK, while the model correlated with seatback pressure was based on BM, SH, BB and SA.

Table 1

Selected anthropometric variables

Variable	*Definition*
BM	Body mass
SH	Sitting height
BB	Bideltoid breadth
SA	Sitting acromial height
HC	Hip circumference
HB	Hip breadth feet apart
KH	Sitting knee height
BK	Buttock-to-knee length

2.1. Pressure parameters

Each pressure map was divided into four equal quarters (Figure 2). The two hind side quarters of the seat cushion mat are referred to as "cushion rear", the two seat edge quarters are referred to as "cushion front". Similarly, the seatback pressure mat was divided into four equal quarters, the two upper quarters forming "seatback upper" and the two lower quarters "seatback lower".

Seat pressure parameters were defined for the four areas, based on contact areas and contact forces. Contact forces were calculated in BPMS Research 7.02 (Tekscan Inc., South Boston MA, USA) as the calibrated integral of sensor pressure by contact area (Table 2). Leg take-off point (TOP) was defined as the longitudinal distance between the centre point of the most forward leg seat contact line and the forward edge of the pressure mat, which approximates the seat front edge.

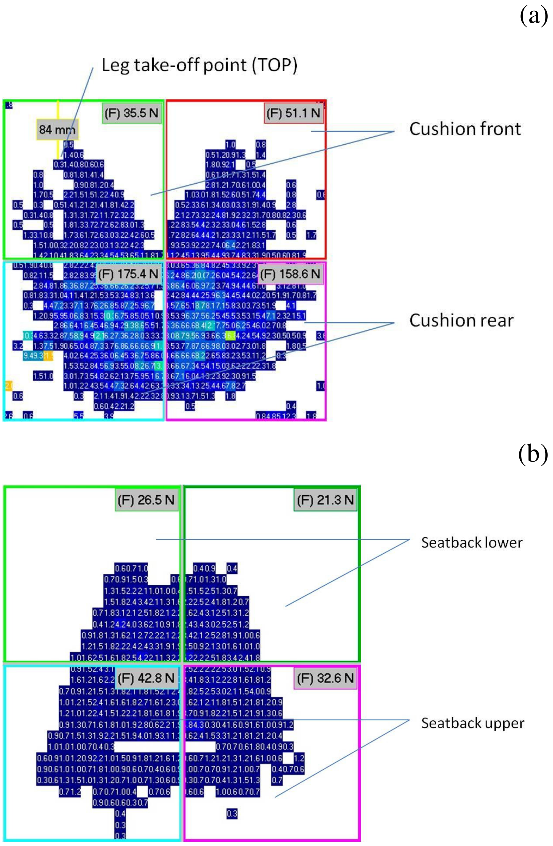

Figure 2: Pressure map divisions. Cushion (a) and seatback (b)

Table 2

Seat pressure parameters

Parameter	*Description*
TOP	Leg take-off point
TAC	Total contact area seat cushion
TAB	Total contact area seatback
TAF	Total contact area rear cushion
TAR	Total contact area front cushion
TAU	Total contact area upper seatback
TAL	Total contact area lower seatback
TFR	Total force rear cushion
TFF	Total force front cushion
TAR/TAF	Total contact area rear cushion by Total contact area front cushion
TAU/TAL	Total contact area upper seatback by Total contact area lower seatback
TAC/TAB	Total contact area seat cushion by Total contact area seatback
TFR/TFF	Total force rear cushion by Total force front cushion
TFU/TFL	Total force upper seatback by Total force lower seatback

2.2. *Hypotheses*

An independent samples t-Test (confidence interval 95%, equal variances assumed, 2-tailed significance) was calculated to compare means of the linear scaled variables between vehicles A-B, vehicles A-C and vehicles B-C. Hence equality of means between anthropometric variables was tested for the subject groups, and equality of means was tested for pressure parameters measured in the different vehicles, to support the basic quality assurance hypotheses that

- H1: subject groups were anthropometrically equal in the three vehicles (null hypothesis) and that
- H2: seat pressure parameters were equal for the production level seats and the prototype seat (null hypothesis).
- H3: seat pressure parameters were equal for the seating postures in vehicles A/C and vehicle B (null hypothesis).

The study followed the primary research hypothesis (H4) that seat pressure parameters can be derived from selected occupant anthropometry variables in linear models. This hypothesis was tested independently for each vehicle using regression analysis (confidence interval 95%) to determine the Pearson correlation coefficient. Significance was estimated at 1% (**) and 5% (*) error levels.

3. Results

3.1. *Subject posture*

The H-Point spread denoted in vehicle coordinates X/Y/Z [9], and measured across all subjects was 277/33/61 mm in vehicle A; 131/46/64 mm in vehicle B and 208/40/103 mm in vehicle C.

3.2. *Equality of subject groups*

It was found that the means for all anthropometric variables were equal ($p > 0.05$) in the three subject groups. Hypothesis H1 was accepted and the quality criterion confirmed.

3.3. *Sensitivity of pressure parameters*

The mean values of TFR/TFF (**), TAR/TAF (**), TAC/TAB (**), TAC (*), TAF (**), TOP (**), TFR (**), TFF (**), TAC/TAB (**), TAB (**), TAL (**) and TAU (**) were significantly different between vehicles with production seat and the vehicle with a prototype seat. H2 was rejected and the quality criterion confirmed for these parameters.

TFR/TFF (*), TAR/TAF (*), TAC (*), TFR (*) and TAB (*) were significantly different between vehicles with different postures, i.e. in vehicles A/C and vehicle B. H3 was rejected and the quality criterion confirmed for these parameters.

Based on the quality criteria, seat pressure parameters were selected for further testing.

3.4. Correlations between seat pressure and anthropometry

Pearson coefficients of correlations between the selected seat pressure parameters and anthropometric variables are shown in Table 3 for the seat cushion and Table 4 for the seatback. The closest fit to a linear model was achieved for TAC, with regression coefficients of R^2= 0.552 (vehicle 2), 0.784 (vehicle 3) and 0.789 (vehicle 1).

Table 3

Correlations between cushion pressure parameters and anthropometry

($^{\#\#}$: quality criterion H2 and H3 confirmed; $^{\#}$: quality criterion H2 or H3 confirmed)

Anthropometric variable	Vehicle	Seat cushion pressure parameters							
		TFR/TFF$^{\#\#}$	TAC/TAB$^{\#}$	TAC$^{\#\#}$	TAF$^{\#}$	TAR/TAF$^{\#\#}$	TFR$^{\#\#}$	TFF$^{\#}$	TOP$^{\#}$
BM	A		-0.379*	0.845**	0.660**		0.605**	0.589**	
	B	-0.366*		0.413*	0.432*	-0.376*	0.452*	0.666**	
	C			0.856**	0.741**		0.492*	0.636**	
HC	A			0.866**	0.592**		0.497*	0.446*	
	B			0.494**	0.580**	-0.512**		0.694**	
	C			0.725**	0.546**		0.501*	0.475*	
HB	A			0.847**	0.638**		0.452*	0.477*	
	B							0.578*	
	C			0.734**	0.640**		0.467*	0.580**	
KH	A	-0.390*	-0.391*	0.498*	0.463*			0.481*	
	B		-0.425*						
	C				0.406*				
BK	A		0.504*	0.533**	0.452*			0.408*	
	B						0.432*		
	C			0.399*					

Table 4

Correlations between seatback pressure parameters and anthropometry

($^{\#\#}$: quality criterion H2 and H3 confirmed; $^{\#}$: quality criterion H2 or H3 confirmed)

Anthropometric variable	Vehicle	Seatback pressure parameters			
		TAC/TAB$^{\#}$	TAB$^{\#\#}$	TAL$^{\#}$	TAU$^{\#}$
BM	A	-0.379*	0.895**	0.832**	0.688**
	B		0.686**		0.440*
	C		0.611**	0.568**	0.552**
SH	A			0.396*	
	B	-0.452*			
	C				
BB	A		0.806**	0.749**	0.621**
	B		0.690**		0.365*
	C		0.536**	0.598**	0.420*
SA	A		0.552**	0.514**	0.424*
	B	-0.491**			
	C				

TAC is shown in relation to BM (Figure 3) for all three vehicles.

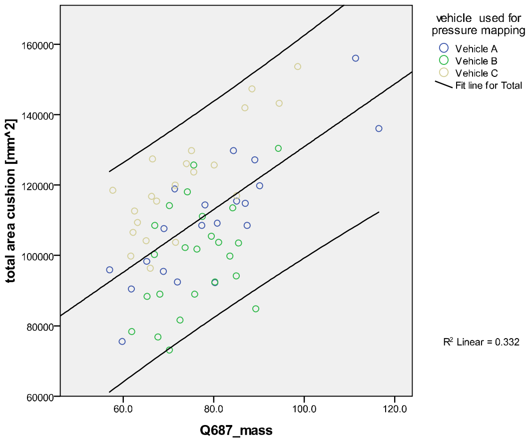

Figure 3: Cushion contact area (TAC) plotted against body mass (BM) [kg] for all vehicles; linear fit with 95% confidence interval

TAF modeled with regression coefficients of R^2= 0.471 (vehicle A), 0.580 (vehicle B) and 0.724 (vehicle C); TFF regression coefficients were R^2= 0.442 (vehicle A), 0.525 (vehicle B) and 0.575 (vehicle C) and TFR regression coefficients (Figure 4) were R^2= 0.570 (vehicle A), 0.452 (vehicle B) and 0.262 (vehicle C).

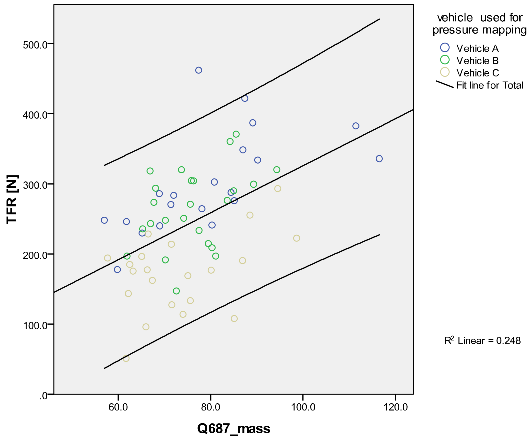

Figure 4: Cushion rear force (TFR) plotted against body mass (BM) [kg] for all vehicles; linear fit with 95% confidence interval

For the seatback, TAB regression coefficients were 0.494 (vehicle C), 0.521 (vehicle B) and 0.828 (vehicle A), see Figure 5.

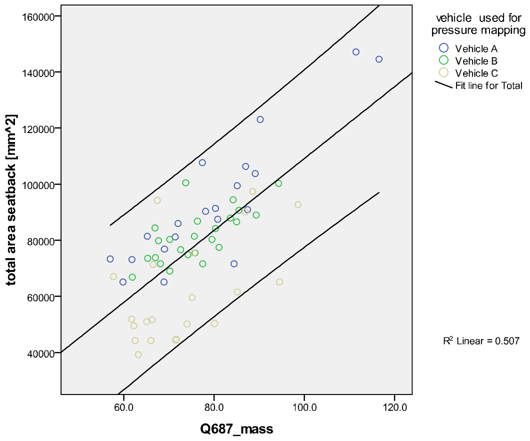

Figure 5: Seatback contact area (TAB) plotted against body mass (BM) [kg] for all vehicles; linear fit with 95% confidence interval

TOP was the only pressure parameter uncorrelated with any of the anthropometric variables in all of the vehicles.

4. Discussion

Body mass and hip circumference were the best indicators for cushion contact area and cushion front contact area. They were also good indicators for cushion front and rear force. Body mass and bideltoid breadth were the best indicators for seatback contact area and seatback upper contact area. Leg take-off point was found to be independent of anthropometry. It was largely consistent across all subjects on each of the seats and therefore needs to be considered a function of seat design in terms of geometry, functional angles, surface shape and foam formulation.

Based on these findings, seat parameters will need to be identified which act as factors in the seat pressure model. The existence of such factors is evident from comparing linear fit curves of the different vehicles, as can be seen for example in Figure 5.

Although congregated seat pressure parameters may prove to be helpful as seat comfort indicators, and could support development of an efficient seat comfort prediction model, they are unhelpful in determining comfort artifacts that stem from design flaws, such as uneven tie downs, leather wrinkles, hard sew lines etc. which cause local pressure peaks. Consequently, and as a matter-of-course, such discomfort cannot be modeled from anthropometry.

As the study was limited to a relatively small range of seat height (H70-2), the results remain to be validated for higher seat heights and more upright postures. The cohort was further on male only, so that the results need to be expanded for female occupants.

5. Conclusion

Further work is needed to investigate if these pressure parameters correlate with subjective comfort perception. This would open a simplified path for seat pressure comfort predictions, based on occupant anthropometry.

Acknowledgement

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