A parametric investigation of preferred pressure distribution on both seat pan and backrest cushions

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ABSTRACT

The present work aimed to investigate the preferred pressure distribution on both seat pan and backrest cushions using a reconfigurable experimental seat and 12 inflatable air cushions. Thirty-seven male and female volunteers participated in the experiment covering a large range of variation in stature (1.51 to 1.9 m) and BMI (18.6 to 43.8 kg/m²). Twelve seating configurations were defined by the combination of 4 back angles (10°; 20°, 30° and 40° from the vertical) and 3 seat pan angles (self-selected from an initial angle of 0°, from an initial angle of 25° and the average of the two previously selected angles). Self-selected pressure distributions were highly dependent on both anthropometric and seat parameters, even for the relative pressure proportion. Results suggest that there is no unique 'ideal' pressure distribution for all sitters and all seats. The parametric models from the present study will be useful for optimising cushion design.

KEYWORDS

Seating, Discomfort, Pressure distribution, Airplane

Introduction

Among objective methods for assessing seating discomfort, the pressure mapping system is the most widely used thanks to its relatively low cost and easy use (Zemp et al., 2015). It is generally recommended that peak pressures on the seat pan should be located under the ischial tuberosities and no other local maxima should be found (Reed et al, 1994). However, quantitative criteria are missing. Mergl et al. (2005) are among very few researchers who proposed criteria based on seat pressure parameters. However, their data were collected only from a sample of 10 young males and 10 young females selected by stature without considering BMI and only for automotive driving tasks. Only six different seat settings defined from two existing seats were tested. It is not clear whether the proposed criteria would be applicable to other seating conditions and populations. The present work aimed to investigate the preferred pressure distribution on both seat pan and backrest cushions using a reconfigurable experimental seat, which allows a sitter to change pressure distribution and seat parameters.

Materials and methods

Thirty-seven volunteers participated in the experiment (18 males, 19 females), aged from 19 to 65. They were recruited based on their body mass index (BMI) (healthy 18.5-25 kg/m², obese >30 kg/m²) and stature (1501-1903 mm). The experimental protocol was approved by the Univ-Effel ethics committee and informed prior consent was obtained for each participant.

The multi-adjustable experimental seat, recently developed at Univ-Eiffel (formerly ISFTTAR, Beurier et al, 2017) was used to simulate different seating configurations and to measure contact forces. A wooden plate was fixed on the seat pan support. Seven inflatable air cushions were attached to the plate using Velco bands, allowing the control of pressure distribution of

- the overall surface (support air cushion);
- the frontal and rear ischial areas. The four ischial cushions were put under the support air cushion and its centre was located at the peak pressure measured by a pressure map. The air pressure of the two frontal cushions was controlled by a same pump, while that of the two rear cushions was controlled by another one.
- the two lateral areas by two lateral air cushions, whose pressure was controlled by a same pump.

Similarly for the backrest, five air cushions were attached to a wooden plate which was fixed on the middle panel, allowing the control of pressure distribution of

- the overall surface (support air cushion);
- the upper and lower lumbar areas by two cushions, whose pressure was controlled separately. The mid point of the two cushions was positioned approximatively at the subject's third lumbar vertebra.
- the two lateral areas by two lateral air cushions, whose pressure was controlled by a same pump. They were positioned symmetrically and self-selected by participants.

Two Xsensor pressure-mapping systems (PX100.48.48.02) covered the cushions and were used to measure the contact pressures at the back and seat pan. They were carefully positioned with respect to the front and up edge respectively for the seat pan and backrest supports. Participants could increase or decrease the air pressure of these cushions using an intuitive user interface, specially developed for this study. Figure 1 shows the location of these inflatable cushions on the seat pan and back supports and an overview of the experimental setup.

Figure 1. Location of the inflatable air cushions on the seat pan and backrest (on the left) and an overview of the experimental set-up with a participant

Twelve seating configurations were defined by the combination of

- 4 seat back angles (A_SB): 10°; 20°, 30° and 40° from the vertical
- 3 seat pan angles (A_SP): self-selected from the initial angle of 0° (PRL) and 25°(PRH) and the average of the two previously selected angles (PRM).

Prior to test these 12 configurations, a reference pressure distribution was obtained at first at two reference seating configurations, upright seating with A_SP=0° and A_SB=20° for the seat pan and reclined seating with A_SP=14° and A_SB=40° for the backrest. For these two reference seating conditions, participants were instructed to be familiar with experimental facilities and to adjust seat height, seat pan length, and of course the pressure distribution by increasing and decreasing the air pressure of each cushion. As finding a preferred pressure distribution could be a long process (>10 minutes in general), the reference air pressure was saved and used as the initial adjustment for the 12 test conditions. Then for one of four backrest angles randomly selected, three seat pan angles (PRL, PRH and PRM) were tested. For each test configuration, participants were instructed to adjust seat height (and headrest position if used) at first and then air pressure of each cushion to find their preferred pressure distribution on the seat pan and backrest. Once preferred pressure distributions found, participants were instructed to adopt a comfortable position with the buttocks and back being in contact with the backrest and keep still so that the contact forces and pressures were measured.

It happed that some pressure cells failed. The missing pressures were interpolated with the measures of the surrounding cells at first. Then the pressures were smoothed using a moving average filter of 3 by 3. To visualize the main effects of anthropometric and seat parameters, a principal component analysis (PCA) of pressures on both seat pan and back was used to reduce the dimensionality in data. A linear regression was performed between the PC scores explaining 95% of variance and predictors. In the present work, seat pan angle (A_SP), backrest angle (A_SB), stature, BMI and sitting height to height ratio (SHRatio) are chosen as predictors.

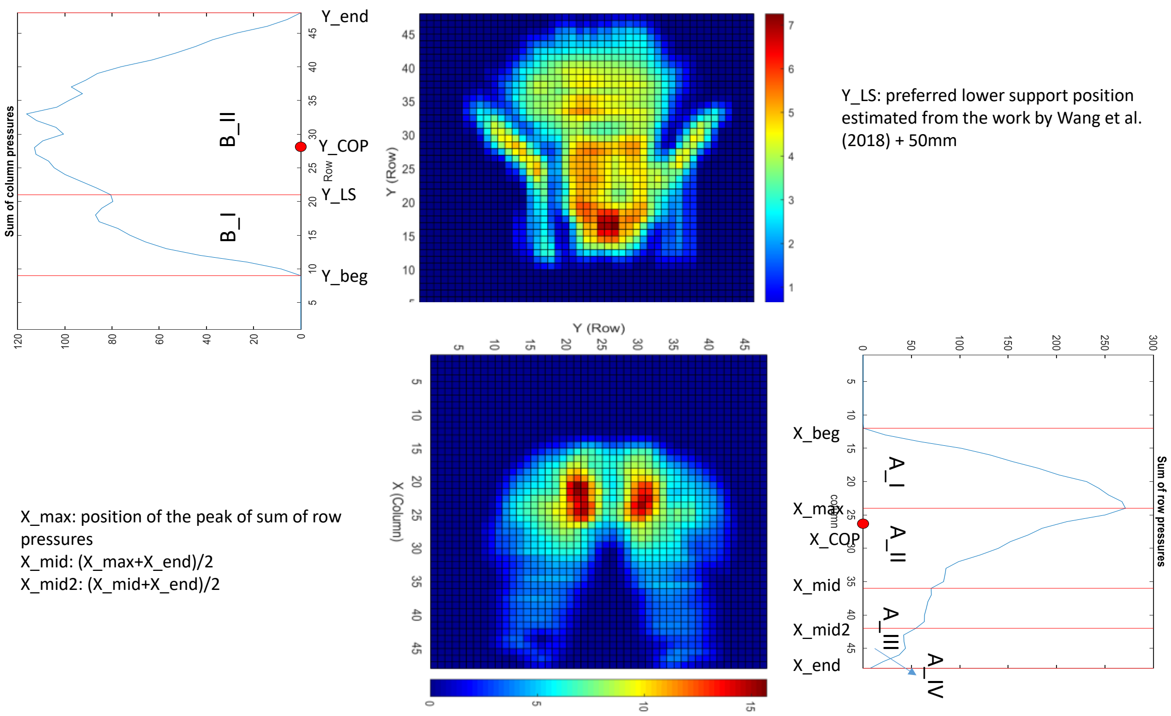


Figure 2. Definition of different contact areas for the seat pan and backrest.

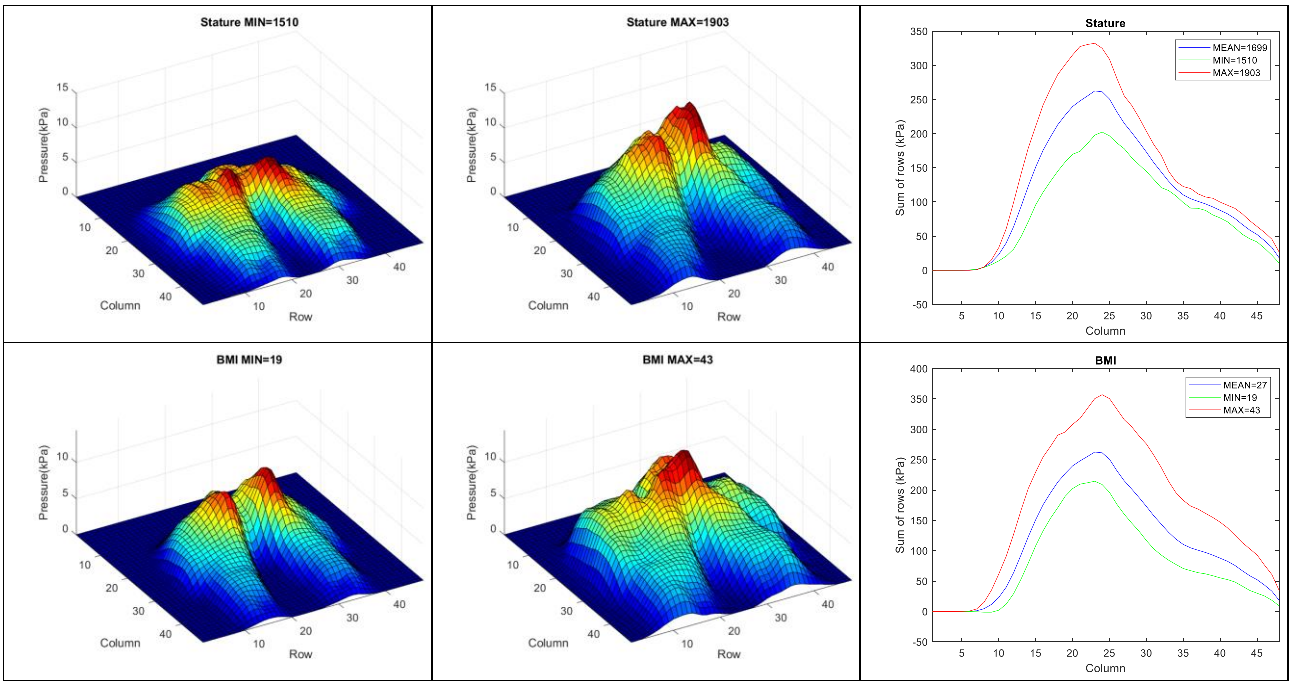
From the pressure profile as illustrated in Figure 2, three contact regions were defined for the seat pan representing buttock, rear and frontal thigh. For comparison purpose, the frontal thigh was further divided into two sub-regions and the one close to the knee was named ‘IV’. For the backrest, two regions were defined representing lower and upper back support areas. They were separated by the line corresponding to the preferred lower support position, estimated using the regression equation from our previous work (Wang et al, 2018) taking into account the participant's height, BMI, seat pan angle and back angle. 50 mm was added to define the separation line considering the half width of the panel used in our previous study. As peak pressure and gradients are more sensitive to raw data noise and data processing, the load proportions applied at these sub-regions were preferred:

- A_I, A_II, A_III and A_IV: ratios of the sum of pressures in the sub-regions I to IV with respect to the total pressure applied on the seat pan contact surface
- B_I, B_II: ratios of the sum of pressures in the sub-regions I and II with respect to the total pressure applied on the backrest contact surface

Multifactor ANOVAs and multiple variable regressions were performed using STATGRAPHICS Centurion 18. Effects of independent variables were considered 'significant' when $p<0.05$.

Results

Pressure distributions on the seat pan and back were highly dependent on the sitter's anthropometric dimensions and seat parameters, as showed in Figure 3 and Figure 4. As expected, higher BMI and higher stature resulted in a larger contact area, while peak pressure was more sensitive to stature than to BMI. A more reclined backrest led to higher pressure on the back thus reducing the pressure on the seat pan. A more reclined seat pan led to higher pressure under the distal part of the thighs (near to the knees) and also increased the pressure on the back.



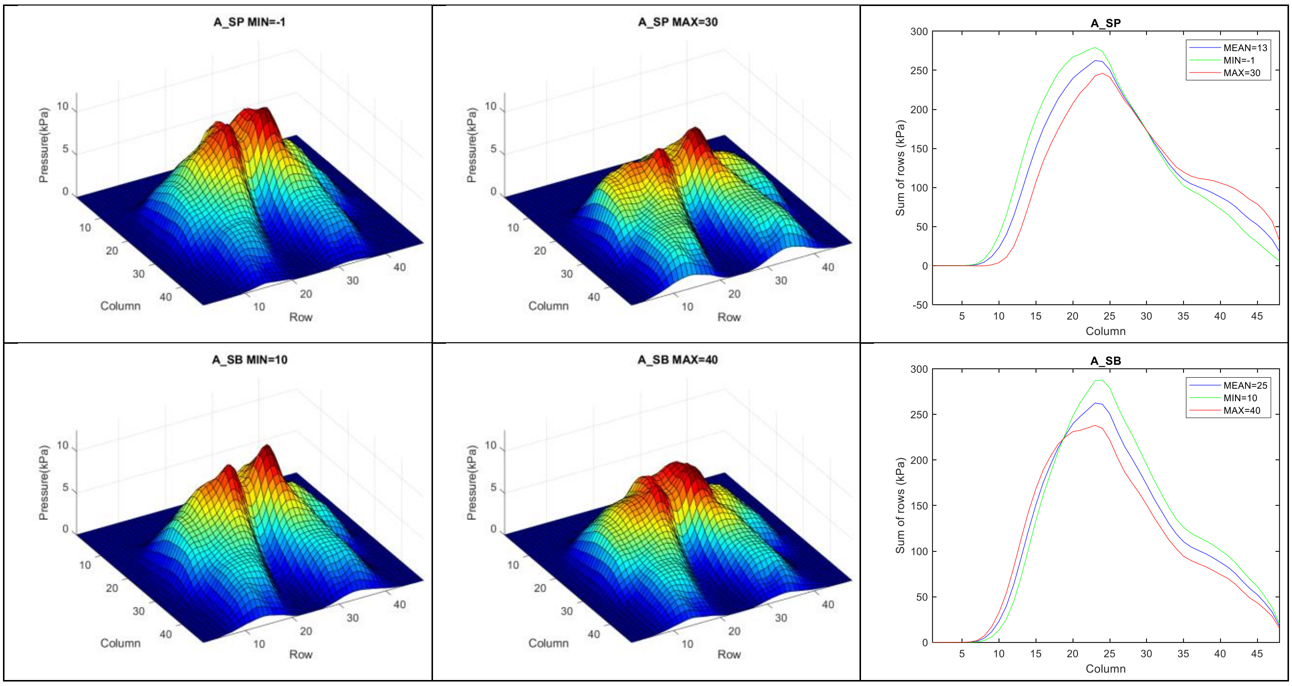
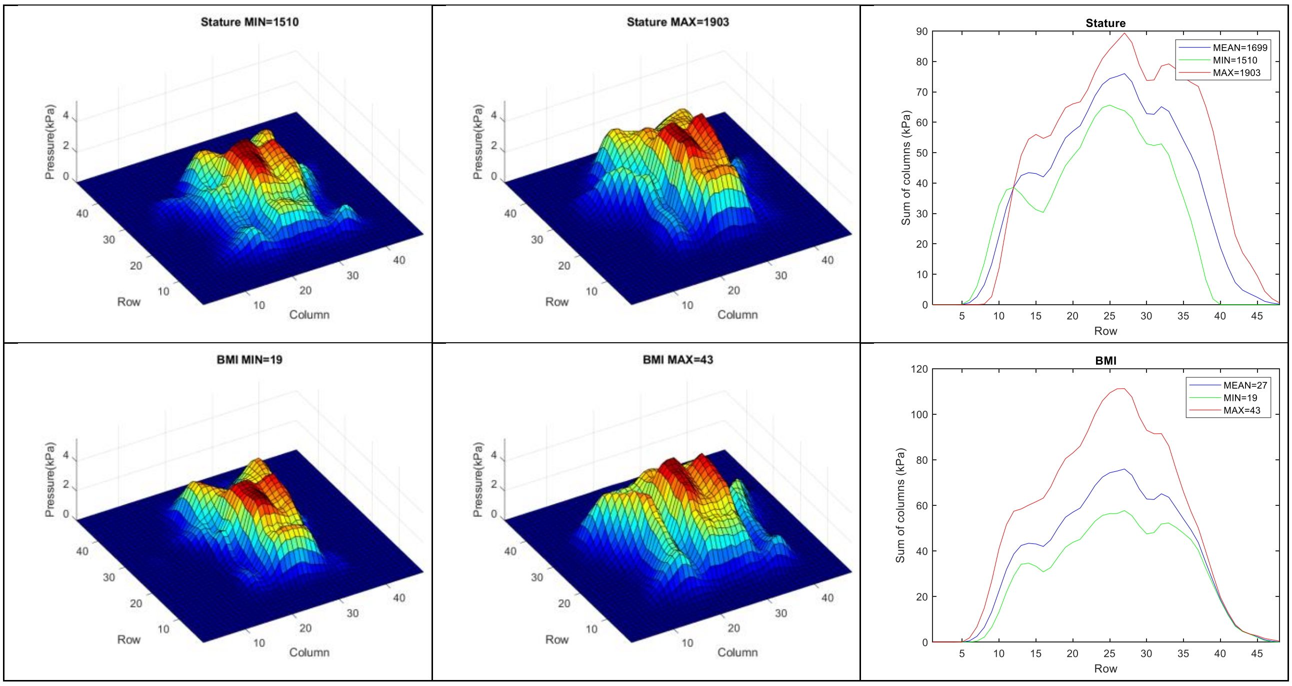


Figure 3. Main effects of stature, BMI, A_SP and A_SB on the pressure distribution on the seat pan. (Column 48, Row 0) represents the frontal right corner. Sum of the pressures by the sensors on the line perpendicular to the seat symmetry axis is on the right.



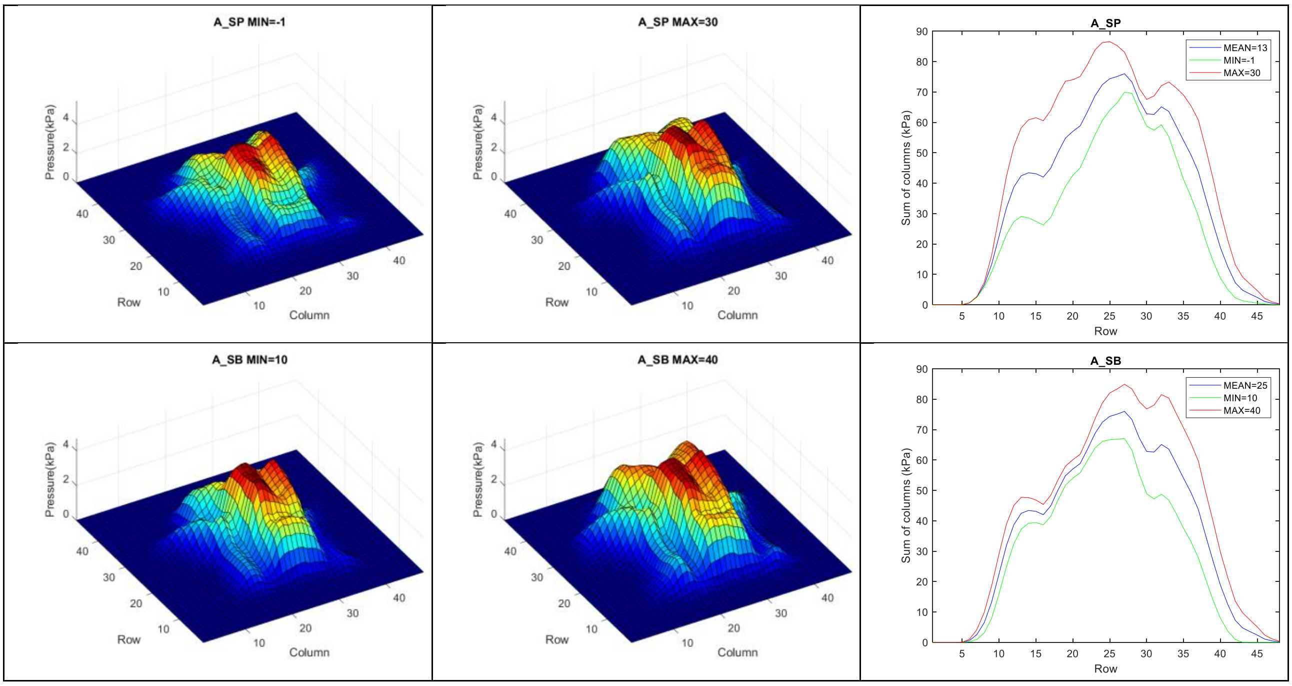


Figure 4. Main effects of stature, BMI, A_SP and A_SB on the pressure distribution on the seatback. (Column 0, Row 0) represents the bottom right corner. Sum of the pressures by the sensors on the line perpendicular to the seat symmetry axis is on the right.

Concerning the relative load proportions defined in Figure 2 (Table 1), BMI affected all of them, while stature only had a slight effect on back pressure distribution (B_I and B_II). A_SP only affected relative pressure proportions (A_I to A_IV) on the seat pan, while A_SB only changed back load proportions B_I and B_II.

Table 1. Regression equations of the load proportions for the sub contact areas defined in Figure 2.

Variable	Constant	A_SP (°)	A_SB (°)	Stature (mm)	BMI (Kg/m²)	SHRatio*	R^2_{adj} (%)	MSE
A_I	0.347	-	-	-	0.0015	-	1.65	0.0047
A_II	0.542	-0.0014	-	-	-0.00276	-	11.07	0.0028
A_III	0.103	0.0018	-	-	0.00133	-	9.85	0.0020
A_IV	-0.023	0.0012	-	0.000026	0.00065	-	13.07	0.0006
B_I	1.60958	-	0.00255	- 0.00021	0.00362	- 2.20169	17.65	0.0085
B_II	=1-B_I							

*SHRatio: ratio between head to seat height in sitting and body height

Discussion and conclusions

In the present work, we experimentally investigated the self-selected pressure distributions on both seat pan and back which using a reconfigurable experimental seat and 12 inflatable cushions. Results show that self-selected pressure distributions were highly dependent on both anthropometric and seat parameters, even for the relative load proportions. Mergl et al (2015) used a scalable grid over the pressure matrix of the seat pan to define different body parts. However, it is difficult to locate these sub contact areas accurately only from pressure distribution. In the present work, we used the peak location on the load profile, corresponding approximately to the position of the ischial tuberosities, to define the sub contact regions on the seat pan. Due to the difference in contact area definition, we cannot compare the load proportions obtained in the present study with those by Mergl et al. However, our results suggest that the 'ideal' pressure distribution depends on body size and seat parameters.

To our knowledge, this study is the first to investigate the self-selected pressure distribution on both seat pan and backrest. The parametric models from the present study will be useful for optimising cushion design.

Acknowledgement

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