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Original scientific paper

Influence of Body Mass Index on Comfort and Parametric Optimization Design of Seat

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Abstract: The influence of body mass index (BMI) on seat comfort was studied. 50 subjects were tested for body pressure distribution experiment about seat factors and BMI, and 118 subjects were tested for comfort survey experiment about the factors combination of seat height, backrest angle, and different body type on the perception of comfort. The experimental results revealed that there was positive correlation between the perception of comfort of foot and shin, foot and front of thigh, foot and back, foot and shoulder, foot and waist, with Pearson's correlation coefficients of 0,608; 0,584: 0,672 and 0,620 ($p < 0{,}05$) and 0,853 ($p < 0{,}01$) respectively. Besides, there was negative correlation between body type and maximum pressure, body type and average pressure gradient, body type and maximum pressure gradient, with Pearson's correlation coefficients of −0,673; −0,589 and −0,635 ($p < 0{,}05$) respectively. This study found that there was negative correlation between body type and shin, contact area and front of thigh, average pressure and front of thigh, average pressure and shoulder, with Pearson's correlation coefficients of −0,769 ($p < 0{,}01$); −0,636; −0,682 and −0,605 ($p < 0{,}05$) respectively. In addition, this study also found positive correlations between maximum pressure and shin, average pressure gradient and front of thigh, maximum pressure gradient and front of thigh, average pressure gradient and shin, maximum pressure gradient and shin, with Pearson's correlation coefficients of 0,681; 0,638; 0,694 ($p < 0{,}05$); 0,765 and 0,785 ($p < 0{,}01$) respectively. Moreover, when the seat height was set as knee height, and backrest angle was set as 120°, the subjective evaluation scores of three body types' subjects were the highest. This study provided additional evidence that seat parameters may be a design approach for improving different body type user's experience.

Keywords: body pressure measurement; comfort survey; ergonomics; perception of comfort; seat

1 INTRODUCTION

The investigation of the influence of seat and ergonomic evaluation on human comfort and physical risk in different sitting postures and multi-purpose work places becomes more important as humans spend an increasing amount of time in daily life [1].

Therefore, it is of great significance to study the comfort of sitting. At present, there are two kinds of comfort evaluation methods, which are subjective evaluation method and objective evaluation method. Subjective evaluation method process usually consists of the following steps: set up the relevant subjective evaluation scale, select appropriate subjects, then evaluate and describe the subjective feeling degree [2, 3]. Some studies have shown that the subjective evaluation results are predictable [4]. In addition, some physical and physiological indexes are the basis for objective evaluation, such as body pressure distribution, brain wave activity level, muscle tension, temperature, etc. The perception of comfort of subjects can be reflected by these indexes [5]. Especially, there is a significant relationship between body pressure distribution and subjective evaluation, which is an important evaluation index in comfort research [6]. The experimental method combining subjective and objective evaluation has become the main method to study seat design evaluation on the perception of comfort [5, 6].

Regarding the research on topics of seat, most of the research literature focuses on seat design evaluation, structural optimization of seat design, and seat design improvement based on ergonomics [7-9]. Furniture for students in school is one studying focus in the research topics of furniture [10-13]. Additionally, a few of the published researches discuss the relationship between the human physical structure parameters and the perception of comfort [14-17].

Hu measured the sitting pressure gradients, the high-pressure areas, and the seat pressure distribution for three type subjects seated on six kinds of sofa cushion with different stiffness. The results showed that the pressure gradient is lowest and the high-pressure area is smallest during the normal subject seated; the obese subject has the lowest seat pressure distribution [18]. Some studies have found that under the same external conditions, the more obese a person was, the smaller the linear pressure gradient, the smaller the judgment value of subjective feeling would be, which could affect the user's feeling [19, 20]. Besides, due to the different gender and physiological structure, the contact surface between the body and furniture would differ from one to another, which could affect the distribution of body pressure [21]. From the technical realization angle, other studies have attempted to establish a measurement tool that could be described and tested to evaluate the characteristics of different elements of a seat, which recorded the comfort relevant seat parameters pressure and elongation while loading a seat [22]. In addition, thermal research and the combined methods were usually used to find out the evaluate comfort levels, including subjective comfort rating, interface pressure measurement, and muscle activity measurement [23].

This study has two objectives. The first was to investigate the relationship between body pressure distribution test and main seat parameters under different body types. The second was to determine the relationship between the perception of comfort and different parts of human body under different body types. College students are a specific user group with both young body and long seat-use time, which could lead to office ergonomics and banishing work-related injuries issues. This is what the starting point and the foothold of this study is.

2 MATERIALS AND METHODS

2.1 Subjects Selection

The subjects were recruited in Sichuan Agricultural University. A total of 118 test subjects took part in this study, 50 of them were tested for body pressure distribution experiment. Subjects were instructed to wear comfortable clothing.

Body Mass Index (BMI) is an important index to measure body weight published by the World Health Organization (WHO).

The equation for BMI calculation is as follows:

$$BMI = \frac{m}{h^2} \tag{1}$$

where, *BMI* represents the body mass index and the unit is kg/m^2, *m* is the body weight and the unit is Kilogram, *h* is height (of a person) and the unit is meter.

Because of the physical differences of Asians, the criteria in the Guidelines for Prevention and Control of Overweight and Obesity in Chinese Adults were applied in this study [24], rather than the WHO standard. Moreover, Body Fat Percentage (*BFP*) is the proportion of the body fat mass in the total body mass, and is an important parameter reflecting the amount of fat in human body.

The *BFP* was defined using the Deurenberg equation as follows [25]:

$$BFP = 1,2 \times BMI + 0,23 \times A - 5,4 - 10,8 \times G \tag{2}$$

where, *BFP* represents the body fat percentage, *BMI* represents the body mass index, *A* is the age, *G* is gender, the value of female is 0 and that of male is 1.

All the subjects are students at university and as there was no obesity case found in the subjects, obese option is not separately listed in this study. Then, subjects were divided into three groups: underweight (*UW*, $BMI < 18,5$); normal weight (*NW*, $18,5 \le BMI < 24$) and overweight (*OW*, $BMI \ge 24$, with $BFP \ge 25\%$ for male and $\ge 30\%$ for female), according to integrated reference of *BMI* and *BFP*. Ethical approval was obtained from the Science and Technology Ethical Review Committee of College of Forestry at Sichuan Agricultural University.

2.2 Pressure Measurement

Pressure distribution at the body's interface with the seat cushion are captured using the Body Pressure Measurement System (*BPMS*) developed by Tekscan, consisting of pressure sensing pad, sensor handle, PC interface board and *BPMS* software. The pressure sensing pad is paper thin with a rectangular grid of sensing elements featuring 487,7 by 426,7 mm with 2016 pressure-sensing elements. The sensing pad is placed on top of the seat and the subjects sit on top of the sensing pad. Pressure measurement systems such as this have been used extensively in the past for medical, automotive, and manufacturing pressure evaluations [26-28].

In the process of pressure data acquisition, the computer software *BPMS* which is equipped with the volume pressure measuring instrument can conveniently and effectively observe the contour line of body pressure distribution. In Fig. 1, different pressure values are distinguished by different colour. The colours represented by the values of body pressure from small to large are dark blue, light blue, green and red. At the same time, important relevant data of body pressure distribution could be recorded in the final experimental data as time changes. The instantaneous value of data at a certain time or the average value in a period of time can be obtained from the software. Typical examples of pressure distribution in sitting position are shown in Fig. 1.

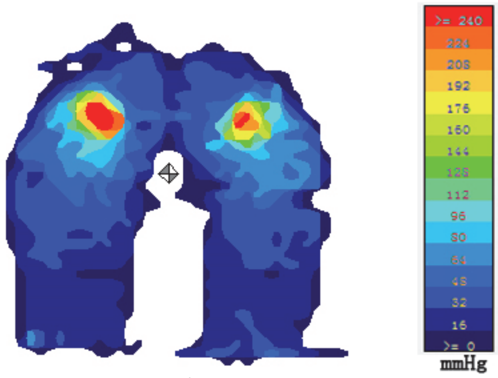

Figure 1 Typical example of body pressure distribution in sitting position

2.3 Comfort Survey

The comfort survey included two parts: the overall physical condition rating (*PCR*) and the local perceived discomfort (*LPD*) for various body parts, such as foot, shin, ischium, caudal vertebrae, front of thigh, back of thigh, back, shoulder and waist. The *PCR* and *LPD* consisted of a 7 - point-Likert-scale ranging from "strongly uncomfortable" corresponding to "1" to "strongly comfortable" corresponding to "7", used to conduct the comfort-level assessment in which responders specify their level of agreement to a statement typically in seven points: (1) strongly uncomfortable; (2) uncomfortable; (3) slightly uncomfortable; (4) neither comfortable nor uncomfortable; (5) slightly comfortable; (6) comfortable; (7) strongly comfortable.

The seat used in this experiment is light rest seat. The surface of seat is made of polyvinyl chloride (*PVC*), and the material is compact and hardened which would not produce large area deformation.

2.4 Testing Procedure

50 participants in the objective evaluation were selected to test the comfort of different seat height and backrest angle. After the data of the sensor displayed by the computer is stable, the subjects sit on the seat surface gently, put their hands on knees, and lean their back on the seat backrest. During the test, the subjects can adjust their sitting posture slightly, and if the final data does not affect the test results, it is considered as valid.

According to pre-experiment, the most comfortable seat height and backrest angle have been reached. The most comfortable seat height is *H* mm and *H* - 25 mm, where *H* represents the knee height of the subjects; the most comfortable backrest angles are 105° and 120°. Thus, the independent variable is seat height, which has two groups: *H* mm and *H* - 25 mm. Another independent variable is backrest angle, which has two groups: 105° and 120°.

Firstly, the seat height was adjusted to *H* mm, and the backrest angle was adjusted to 105°. After the data was stable, the experimenter recorded and saved the experimental data as ASCII file. Then the subjects were kept in their original position, and the pressure sensing pad was removed. The subjects fully felt the test seat for 15 minutes and filled in the subjective evaluation form according to their experience. The duration of the test was 15 min for all participants. This time duration was chosen on the basis of the experience of Karimi et al [29].

Secondly, with the seat height unchanged, the backrest angle was adjusted to the next angle of 120° and the experimenter recorded the experimental data and repeated the above experimental steps. Finally, the *H* - 25 mm seat height experiment was about to be carried out, and the above process was repeated.

3 RESULTS AND DISCUSSION

3.1 Measurement Results and Analysis of Body Pressure Distribution

After body pressure distributions tests, all data generated by the body pressure distribution system are exported to ASCII document (CSV) to form corresponding pressure matrix data, and then imported into Microsoft Excel software for data standardization and preliminary analysis. Then, data of pressure gradient are extracted from each frame of pressure matrix and imported into Graphpad prism software for linear regression analysis, so as to obtain the average pressure gradient and maximum pressure gradient values. According to the indexes of body pressure distribution, the pressure data of subjects were selected for analysis, the relationship between different body type and the indexes of body pressure distribution under seat height *H* and *H* - 25 mm are shown from Fig. 2 to Fig. 11.

The testing for normality and descriptive statistics for quantitative data were carried out with SPSS version 19 software (IBM, Chicago, Illinois, USA). Normality tests are for continuous quantitative data, so only the body pressure data were analysed by normality test. The Shapiro-Wilk test was performed to verify the normality of data distribution, all data was found to be normally distributed ($p > 0,05$)

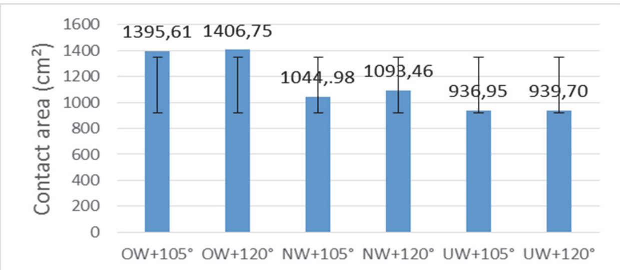

Figure 2 The relationship between different body types and contact area under seat height *H*

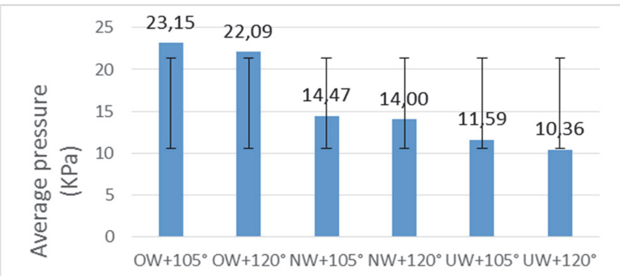

Figure 3 The relationship between different body types and average pressure under seat height *H*

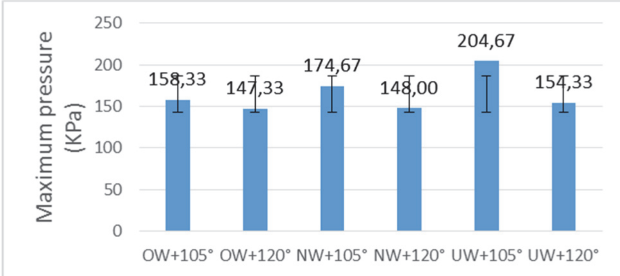

Figure 4 The relationship between different body types and maximum pressure under seat height *H*

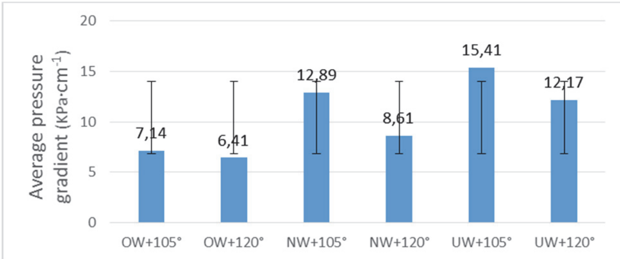

Figure 5 The relationship between different body types and average pressure gradient under seat height *H*

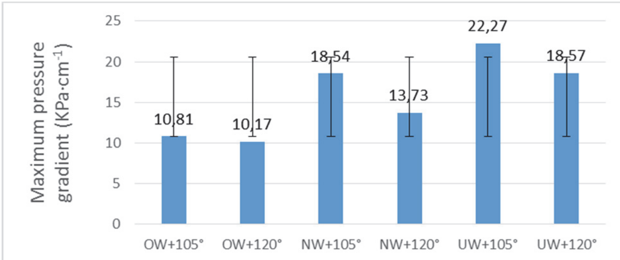

Figure 6 The relationship between different body types and maximum pressure gradient under seat height *H*

The relationship between different body types and indexes of body pressure distribution with the increase of backrest angle at *H* height was compared.

From Fig. 2, the contact area changes with the increase of backrest angle. The contact area of subjects with three body types increased slightly with the increase of backrest angle. Under the same angle, the larger the *BMI*, the larger the contact area, that is, the contact area of overweight body type is larger than normal weight, and that of normal weight is larger than underweight.

From Fig. 3, with the increase of backrest angle, the average pressure of subjects with three body types decreases. However, under the same angle, the average pressure decreases with the decrease of *BMI*, that is, the average pressure of overweight body type is larger than that of normal weight, and that of normal weight is larger than underweight.

From Fig. 4, with the increase of backrest angle, the maximum pressure of three body types decreases. Under the same angle, the maximum pressure increases with the decrease of *BMI*, that is, the maximum pressure of overweight body type is less than that of normal weight, and the maximum pressure of normal weight body type is less than that of underweight. It can be found that at 105° backrest angle, the maximum pressure changes significantly with the change of *BMI*, while at 120°, there is little difference among the three body types groups.

From Fig. 5 and Fig. 6, it can be seen that the average pressure gradient and maximum pressure gradient of three body type groups have different degrees of decline with the increase of backrest angle. The average pressure and maximum pressure gradient of overweight body type subjects decreased slightly with the increase of backrest angle, while the average and maximum pressure gradient of normal weight and underweight body type subjects decreased significantly with the increase of backrest angle. At the same angle, the larger the *BMI*, the smaller the average and maximum pressure gradient, namely, the average and maximum pressure gradient of overweight body type subjects is smaller than that of normal weight, and the average and maximum pressure gradient of normal weight body type subjects is smaller than that of underweight ones.

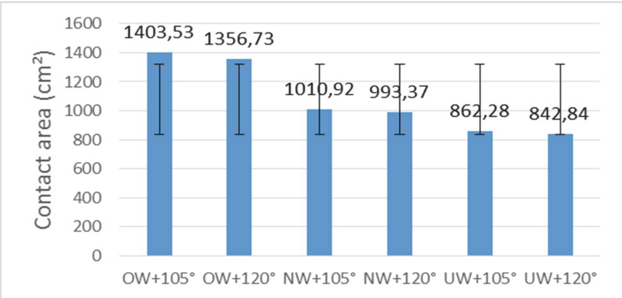

Figure 7 The relationship between different body types and contact area under seat height *H* - 25

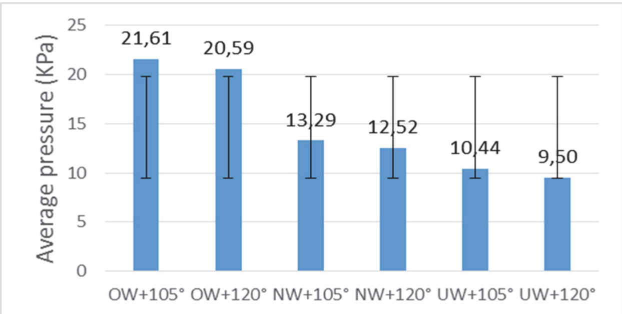

Figure 8 The relationship between different body types and average pressure under seat height *H* - 25

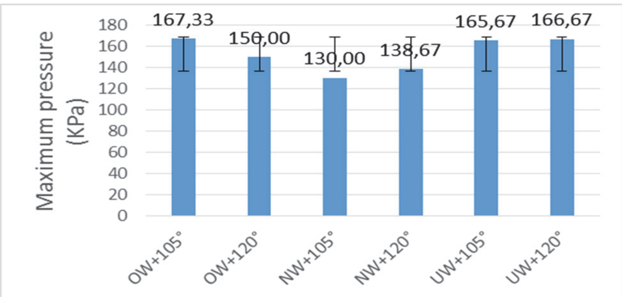

Figure 9 The relationship between different body types and maximum pressure under seat height *H* - 25

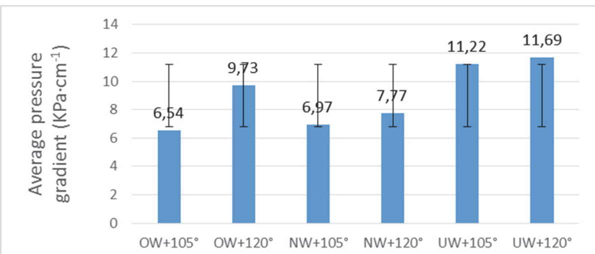

Figure 10 The relationship between different body types and average pressure gradient under seat height *H* - 25

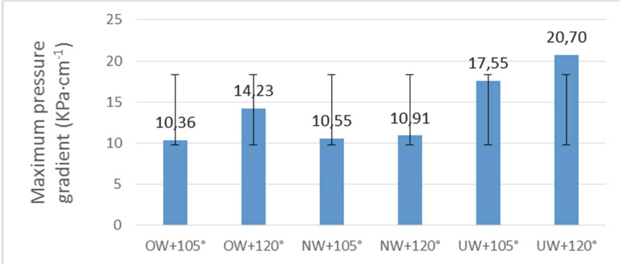

Figure 11 The relationship between different body types and maximum pressure gradient under seat height *H* - 25

The relationship between different body types and indexes of body pressure distribution with the increase of backrest angle at *H* - 25 height was compared.

As can be seen from Fig. 7, the contact area decreases with the decrease of *BMI* under the same backrest angle. Different from *H* height, the contact area of subjects with the same *BMI* decreased with the increase of backrest angle at the height of *H* - 25 mm.

From Fig. 8, under the same backrest angle, the *BMI* decreases, while the average pressure also decreases. Compared within same body type subjects, the average pressure would slightly decrease with the increase of backrest angle.

From Fig. 9, the maximum pressure decreases first and then increases with the decrease of *BMI* under the same backrest angle, and subjects with same body type would show different laws under different backrest angle.

When backrest angles are 105° and 120°, the maximum pressure of underweight body type is greater than that of overweight, and the maximum pressure of overweight body type is greater than that of normal weight. Compared within the same type of subjects, the maximum pressure changes of the three body types were different with the increase of backrest angle, respectively as follows: the maximum pressure of overweight body type subjects decreased with the increase of backrest angle, the maximum pressure of normal weight body type subjects increased with the increase of backrest angle, but the maximum pressure of subjects with underweight body type did not change with the change of backrest angle.

It can be seen from Fig. 10 and Fig. 11, when backrest angle is 105°, the average and maximum pressure gradients increase with the decrease of *BMI*. When backrest angle is 120°, the average and maximum pressure gradients first decrease, and then increase with the decrease of *BMI*. Compared with different backrest angle and same body type subjects, it is found that the average and maximum pressure gradients of three body type subjects increased with the increase of backrest angle.

3.2 Results and Analysis of Comfort Survey

From Fig. 12, the specific analysis of overweight body type subjects is as follows. The backs of thigh perception of comfort are better at backrest angle 105 ° and seat height *H*. The perception of comfort of foot, back, shin and waist is better at backrest angle 105 ° and seat height *H* - 25. The perception of comfort of shin, ischium, caudal vertebrae and waist is better at backrest angle 120 ° and seat height *H*. The perception of comfort of foot, shin, ischium, back of thigh, back, shoulder and waist is better at backrest angle 120 ° and seat height *H* - 25 mm.

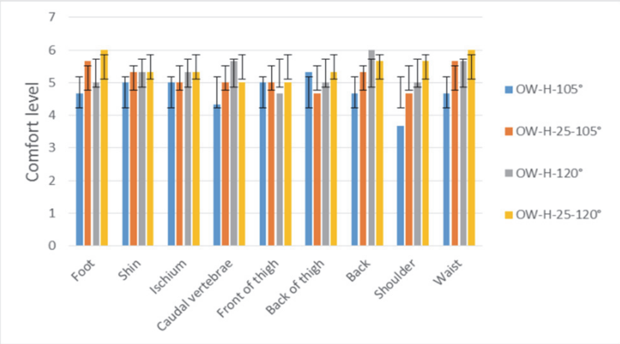

Figure 12 Evaluation results of comfort survey of overweight body type subjects

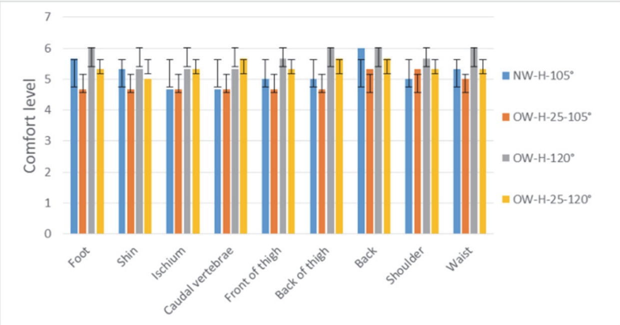

Figure 13 Evaluation results of comfort survey of normal weight body type subjects

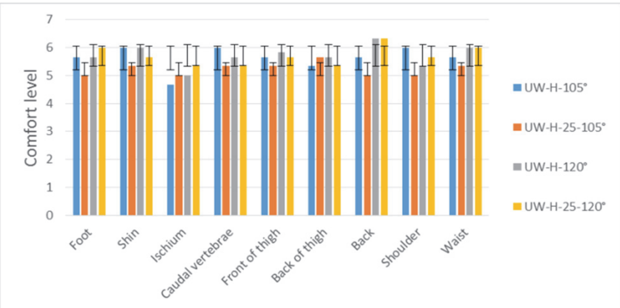

Figure 14 Evaluation results of comfort survey of underweight body type subjects

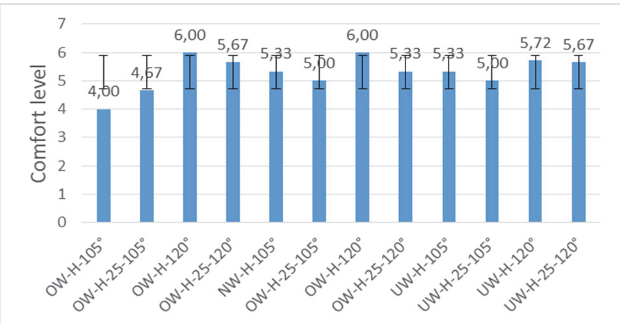

Figure 15 Evaluation results of overall comfort survey of three body types' subjects

From Fig. 13, the specific analysis of normal weight body type subjects is as follows. The foot, shin, back and waist perception of comfort is better at backrest angle 105°. The perception of comfort of front of thigh, back of thigh, shin, caudal vertebrae and waist is better at backrest angle 120° and seat height H. The perception of comfort of other parts of the body is better at backrest angle 120° and seat height H-25, except for the shin.

From Fig. 14, the specific analysis of underweight body type subjects is as follows. The perception of comfort of other parts of the body is better at backrest angle 105° and seat height H, except for the caudal vertebrae. The perception of comfort of shin, caudal vertebrae, front of thigh, back of thigh and waist is better at backrest angle 105° and seat height H-25. The perception of comfort of other parts of the body is better at backrest angle 120° and seat height H, except for the ischium. The perceptions of comfort of all parts of the body are better at backrest angle 120° and seat height H-25.

It can be seen from Fig. 15, the perception of overall comfort in H-25 mm height is better than that of H at backrest angle 105° only for overweight body type subjects. To other body type subjects, the perception of overall comfort in H height is better than that of H-25 under the same backrest angle.

3.3 Correlation Analysis and Discussion

The correlation analysis method was used to study the correlation among foot, shin, ischium, caudal vertebrae, front of thigh, back of thigh, back, shoulder, waist and overall perception of comfort. Pearson correlation coefficient method was used to express the strength of the correlation. According to the results of correlation analysis, it can be seen in Tab. 1.

There was significant correlation between foot and shin, front of thigh, back, shoulder, waist, with correlation coefficients and it was greater than 0, indicating that there was a positive correlation between them. This shows that when the perception of comfort of foot increases, the perception of comfort of shin, front of thigh, back shoulder and waist will also be improved, and vice versa.

The correlation analysis method was used to study the correlation among different body types, contact area, average pressure, maximum pressure, average pressure gradient and maximum pressure gradient. Pearson correlation coefficient method was used to express the strength of the correlation. According to the results of correlation analysis, it can be seen in Tab. 2.

There was a negative correlation between different body types and maximum pressure, average pressure gradient, maximum pressure gradient with correlation coefficients and it was less than 0.

People with different body mass index will have different body fat ratio. The larger BMI is, the higher BFR will be. Under the same conditions, the higher BFR is, the thicker the hip fat will be. At the most prominent place of hip pressure, the maximum pressure will be smaller of ischial tuberosity, and the pressure on other parts will be more uniform. The average and maximum pressure gradient will be smaller.

The correlation analysis method was used to study the correlation between subjective and objective elements. Pearson correlation coefficient method was used to express the strength of the correlation. The results of correlation analysis can be seen in Tab. 3.

There was a positive correlation between maximum pressure and shin, which indicated that, with the increase of maximum pressure, the perception of comfort of shin would be higher, and the relationship between average pressure gradient and shin, average pressure and front of thigh has the same conclusion.

Table 1 Correlation analysis of subjective evaluation

	Mean value	Standard deviation	Foot	Shin	Ischium	Caudal vertebrae	Front of thigh	Back of thigh	Back	Shoulder	Waist	Overall
Foot	5,446	0,499	1									
Shin	5,36	0,388	0,608*	1								
Ischium	5,055	0,275	0,312	−0,017	1							
Caudal vertebrae	5,223	0,5	0,335	0,642*	0,265	1						
Front of thigh	5,237	0,404	0,584*	0,728**	0,142	0,564	1					
Back of thigh	5,306	0,413	0,306	0,318	0,453	0,422	0,735**	1				
Back	5,667	0,511	0,672*	0,56	0,285	0,516	0,441	0,193	1			
Shoulder	5,195	0,61	0,620*	0,446	0,111	0,640*	0,475	0,263	0,646*	1		
Waist	5,556	0,434	0,853**	0,679*	0,473	0,589*	0,537	0,316	0,771**	0,699*	1	
Overall	5,306	0,577	0,573	0,41	0,453	0,620*	0,314	0,335	0,856**	0,762**	0,794**	1

* $p < 0{,}05$ ** $p < 0{,}01$

Table 2 Correlation analysis of objective results

	Mean value	Standard deviation	Different body type	Contact area	Avg. pressure	Max. pressure	Avg.pressure gradient	Max.pressure gradient
Different body type	6,5	3,606	1					
Contact area	1107,26	220,781	0,215	1				
Avg. pressure	15,301	5,091	0,194	0,991**	1			
Max.pressure	158,806	19,349	−0,673*	−0,209	−0,172	1		
Avg. pressure gradient	9,738	2,908	−0,589*	−0,638*	−0,627*	0,768**	1	
Max.pressure gradient	14,866	4,452	−0,635*	−0,693*	−0,682*	0,723**	0,970**	1

* $p < 0{,}05$ ** $p < 0{,}01$.

Table 3 Correlation analysis of subjective and objective elements results

	Different body type	Contact area	Avg. pressure	Max. pressure	Avg. pressure gradient	Max. pressure gradient
Foot	−0,069	−0,165	−0,243	0,333	0,48	0,508
Shin	−0,769**	−0,329	−0,373	0,681*	0,765**	0,785**
Ischium	0,181	0,24	0,187	−0,429	−0,39	−0,278
Caudal vertebrae	−0,368	−0,389	−0,45	0,259	0,386	0,386
Front of thigh	−0,462	−0,636*	−0,682*	0,394	0,638*	0,694*
Back of thigh	−0,15	−0,397	−0,43	−0,015	0,28	0,308
Back	−0,007	−0,537	−0,605*	0,14	0,502	0,519
Shoulder	−0,033	−0,325	−0,405	0,027	0,366	0,433
Waist	−0,215	−0,138	−0,241	0,146	0,338	0,409
Overall	0,064	−0,241	−0,325	−0,118	0,23	0,284

* $p < 0{,}05$ ** $p < 0{,}01$

Under the same conditions, people with different *BMI* have different feelings. The larger the *BMI* is, the thicker the fat will be. For the same stimulation, the sensory sense will be weakened. The harder the seat surface is, the lower the corresponding perception of comfort will be. When the *BMI* increases, the body mass increases, the contact area with the seat surface and the pressure on the leg also increases; eventually the perception of comfort will decrease. The increase of average pressure is caused by the increase of *BMI*, and the pressure on the front of thigh and shoulder is also greater, which leads to the decrease of comfort of these two parts. When the *BMI* decreases, the maximum pressure around ischium increases, the pressure on the leg decreases correspondingly, and the pressure transmitted to shin also decreases, and the perception of comfort increases. When the *BMI* increases, the greater the pressure exerted on the seat surface, the pressure on the front of the thigh and shin will increase, the average pressure gradient will decrease, and the perception of comfort will be reduced.

4 CONCLUSION

When the seat height and backrest angle are the same, the contact area and average pressure between the buttocks and the seat surface would increase with the increase of the *BMI*, but the maximum pressure, average and maximum pressure gradient could decrease with the increase of the *BMI*.

Different combinations of seat height and backrest angle will bring different comfort experience. When the seat height was knee, and backrest angle was 120°, the subjective evaluation scores of the subjects with three body types were the highest among the other combined factors.

There is a certain correlation between the comfort levels of different body parts under certain circumstances. There was a positive correlation between the perception of comfort of foot and shin, front of thigh, back, shoulder, and waist.

Different body pressure distribution data also show different degrees of correlation. There is a negative correlation between body type and maximum pressure, average and maximum pressure gradient.

There are different degrees of correlation between body pressure distribution data and subjective evaluation results. There was a negative correlation between body type and shin, contact area and front of thigh, average pressure and front of thigh, average pressure and shoulder. There was a positive correlation between maximum pressure and shin, average pressure gradient and shin, average pressure and front of thigh.

This work provides valuable design guidelines to seat design and application enterprises recognizing the link between seat function design and ergonomics. The investigation results underline the necessity to analyze and classify the perception of comfort of seat in relation to seat height, backrest angle parameters, and different body types.

Acknowledgements

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