The Effect of Automotive Seat Cushion Stiffness Distribution on the Subjective Comfort

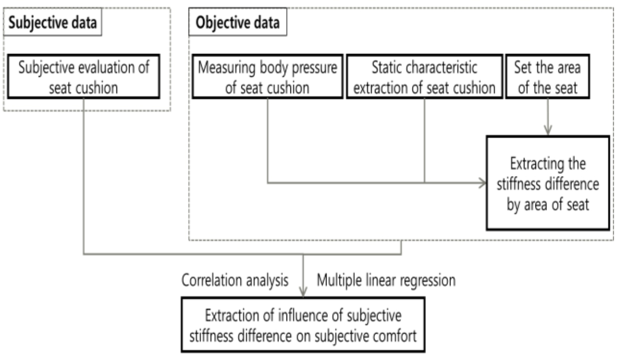
Hyo-Seong Ji, Sung-Yuk Kim, Key-Sun Kim, Yong-Du Jun

Abstract: When body pressures are concentrated, sense of fatigue is increased. To confirm this, correlation analysis between the difference in stiffness of seat and comfort using multiple linear regression analysis has been conducted. For the selected three types of seats which are small-, mid-, and large-size seats, respectively, static tests were con-ducted to measure the distribution of the subject's body pressure on the cushion, through which local stiffness distribution were derived. Also, a subjective comfort evaluation was conducted, and analyzed. According to the present analysis results, the correlation coefficients between stiff-ness of hip area and comfort of hip area were observed to be 0.713 and 0.789, respectively, indicating a strong positive correlation. Thus, the comfort of seat perceived by the driver could be seen to have the largest linear correlation with the stiffness of hip area. Selection of variables for the multiple linear regression analysis was implemented by a backward removal method. Differences of stiffness by areas were selected as independent variables, and subjective comfort evaluation results were selected as dependent variables. According to multiple regression analysis, the comfort of the cushion increased when the left and right balance of the stiffness distribution was maintained even if the body pressure distribution of the hip area was concentrated on one side. According to the analysis results, the stiffness of hip area could be seen to have the greatest linear relationship with the overall satisfaction of comfort, in which comfort is planned to be confirmed by actual production of seats.

Keywords : Comfort, Correlation analysis, Seat, Static Characteristics, Subjective evaluation, Multiple linear regression

I. INTRODUCTION

Among components of a vehicle, seat is the component coming into the most frequent contact with the driver's body. Since the driver is in contact from the moment of getting into a car to the time of getting off, quality of the seat leads directly to the evaluation of the car. While there are various factors for determining the quality of the seat, safety and comfort of the driver are considered as the most important factors. That is why comfortable driving environments should be provided by properly supporting the driver's body and reducing the sense of fatigue while driving so that the driver can safely drive without losing concentrations for a long time. In this way, the importance of automotive seats is being emphasized day by day which leads in an increase of interests in the seat cushion that supports more than 70% of the driver's weight. When the driver is seated, about 75% of the body weight is supported by the hip, while about 35% of the body weight is concentrated in the ischial tuberosity part.[1] If the body pressure is concentrated, blood flow may be hindered causing pain, paralysis, and diseases, even causing pressure sore.[2] Thus, the seat cushion should play the roles of ideally distributing pressures on the part in con-tact with the body and of attenuating impact and vibration.[3] However, most of the seat cushions currently produced in the market are produced in one or two types of stiffness, failing to uniformly distribute the body pressure in the current reality.[4] Therefore, the existing studies of the present study team have been implemented in improvement of the seat's comfort by using cushions with different stiffness per area to realize a uniform distribution of body pressures.[5.6] In the present study, confirmation of the factors for the comfort perceived by the driver has been attempted by the analysis of correlations between the driver's subjective evaluation and the difference in stiffness per area of the seat.[7] First, subjective evaluation for the seat cushion was conducted, and body pressures were measured. Then characteristics tests for seat cushion were conducted for derivation of static characteristics, and seating area was set by considering human body characteristics.[8] By using the set seating area for the seat and objective data, differences in stiffness per area of the seat were derived through correlation analysis be-tween the derived data and comfort of the seat cushion as well as multiple linear regression analysis, the effects of stiffness difference per area on subjective comfort have been derived. Figure 1 shows the flow chart of the present study.



Flow chart of the present study approach

Revised Manuscript Received on July 22, 2019.

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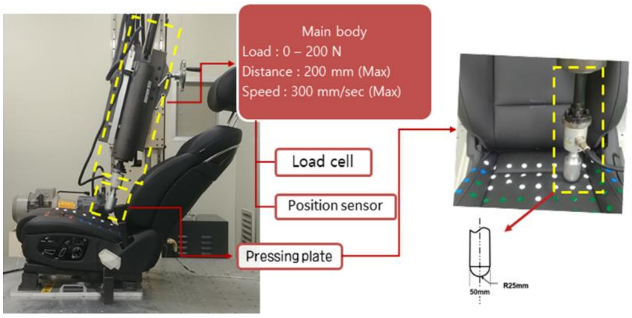
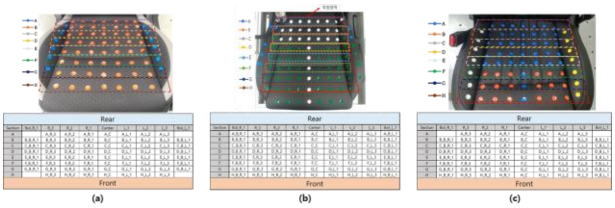
II. MATERIALS AND METHODS

A. Static load characteristic test

Static load characteristic tests were conducted to derive stiffness difference per area. Seats used in the tests were selected as the seats in commercial use, and seats of small-size, mid-size and large-size vehicles were used. Test apparatus is shown in Figure 2, with the diameter of the indenter compressing the seat being 50mm. Here, the speed is 200mm/min, and the compressing force is 200N. Tests were conducted based on Hardness Profile test method in SAE J 2896 posted as the evaluation method for comfort of the seat.[9] Hardness Profile is the test of compressing with each movement by 50mm around the Hip-Point at the center, where the compressed positions are as shown in Figure 3. When the load cell compresses the local position, deflection can be measured upon ap-plication of the force, and stiffness can be derived based on the above data.



Static load characteristic test system



Pressure position of each seat (a) Seat A (b) Seat B (c) Seat C

B. Measurement of body pressure distribution

Measurement of body pressure distribution was conducted to secure the subject's seating posture and pressure distribution for 3 types of seat. A total of 49 subject people was recruited, with selection of those without discomfort in carrying out daily life while having driving experience. For the same seating of the subject people, a line was displayed in the center of the seat, and the acceleration pedal was realized to allow taking of actual driving posture. The subject was made to be able to freely control seat positions after being seated. For measuring device of body pressure distribution, PX100 model of Sensor Technology Corporation has been employed. The relevant model allows measurement of local pressures by using pressure mat with embedding of 2,304 cells of 1.27cm x1.27cm. Figure 4 shows the appearance of how subject's body pressures are measured

Appearance of how subject's body pressures are measured

C. Subjective evaluation

First, , to select subjective evaluation categories, articles and literature related to the seat were surveyed. The categories collected through this effort were 38 types in total, which could be largely classified in terms of back, cushion, and material.[10-12] Among these, only the categories related to the seat cushion were extracted, consisting of 7 types in total which included stiffness of hip area, stiffness of thigh area, sense of support of thigh side, sense of support of hip side, comfort of hip area, comfort of seat cushion bolster, and overall satisfaction of com-fort. Subjective evaluation categories derive are shown in Figure 5. The subject was selected as the same person as for measurement of body pressure distribution and was given enough time to allow free seating on 3 types of seat for evaluation. The derived results of subjective evaluation were standardized to allow satisfaction of a normal distribution.

No.	Large scale	Medium scale	Small scale
1	Seat Back	Lumbar Support	Adequacy of height
2			Adequacy of shape
3			Adjustable front and rear
4			Comfort of the lumber support
5		Headrest	Appropriateness of support and head distance
6			Adjustable up and down
7			Adjustable front and rear
8			Adequacy of shape
9			Hardness
10			Comfort of the headrest
11		Back Support	Adequacy of height
12			Adequacy of shape
13			Adjustable front and rear
14			Comfort of the tailbone support
15			Comfort of the support above back
16			Preventing from slipping during rotation
17			Elasticity of the back
18			Comfort of the back side support
19			Solidity of the back
20			Comfort of the back support

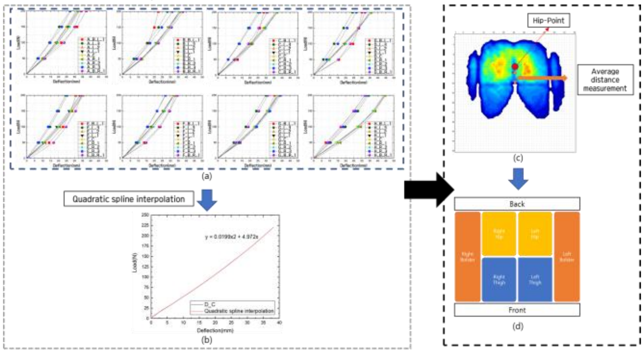
No.	Large scale	Medium scale	Small scale
21	Seat Cushion	Shape	Adequacy of width
22			Adequacy of length
23			Adequacy of height
24			The angle of the cushion (from the horizontal plane)
25			Foreign object of a cushion
26		Function	Preventing from slipping during rotation
27			Hip sliding feeling
28			Hardness
29		Support	Hip side support
30			Thigh side support
31		Comfort	Comfort of the hip area
32			Comfort of the bolster
33			Comfort of the seat cushion
34	Material	Design	Adequacy of seat color and pattern
35			Luxury of the material
36		Function	Friction level of material
37			Feel of material
38		Comfort	Comfort of the seat material

No.	Large scale	Medium scale	Small scale
1	Seat Cushion	Function	Hardness of hip
2			Hardness of thigh
3		Support	Hip side support
4			Thigh side support
5		Comfort	Comfort of the hip area
6			Comfort of the bolster
7			Comfort of the seat cushion

Subjective evaluation categories

D. Derivation of stiffness of seat cushion according to human body area

To analyze the effect of seat stiffness on comfort, the stiffness of the seat cushion according to the human body area was derived. First, to obtain the stiffness quadratic spline, the interpolation method was applied to Load-Deflection Curve for derivation of the quadratic curves per compression position. Subsequently, by substitution in the quadratic function after conversion of pressures into forces in the subjects' average body pressure distribution, stiffness data per area was obtained. The derived stiffness data has the area classified for subjective evaluation and correlation analysis. They are largely classified into hip, thigh, and bolster, with the classification method being as follows. In the case of hip, the distance from Hip-Point to crotch was measured, and the hip area and the thigh area were classified based on the measured distance. In the case of bolster, the area was already classified in the seat shape itself for setting based on the shape. Each area was further classified into left and right for final classification into 6 types of area. Figure 6 is a schematic diagram for derivation of stiffness of seat cushion according to human body area.



Schematic diagram for derivation of stiffness of seat cushion according to human body area. (a)Load-Deflection (b) Quadratic spline interpolation (c) Pressure distribution (d) Stiffness pattern

III. RESULTS AND DISCUSSION

A. Correlation analysis of subjective evaluation categories

To identify linear relationships among subjective evaluation categories, Pearson correlation coefficient was obtained, the results of which are given in Table 1.While stiffness of the hip area had a correlation coefficient of 0.758 with comfort of the hip area, indicating a strong positive linear correlation, the former had a correlation co-efficient of 0.287 with comfort of the hip side, indicating a minimum positive linear correlation. Sense of support of the hip side had a correlation coefficient of 0.532 with sense of support of thigh side, indicating a distinct positive linear relationship. Comfort of bolster had correlation coefficients of 0.398 and 0342 for sense of support of hip side and sense of support of thigh side, respectively, indicating a distinct positive linear relationship. Overall satisfaction of comfort had correlation coefficients of 0.713 and 0.789 with stiffness of hip area and comfort of hip area, respectively, indicating a strong positive linear relationship. And stiffness of thigh area, sense of support of thigh side, sense of support of hip side, and comfort of bolster were observed to be 0.387, 0.585, 0.461, and 0.438, respectively, indicating distinct positive linear relationships. Therefore, comfort of seat perceived by the driver could be seen to have the largest linear correlation with stiffness and comfort of hip area.

Table- I: Correlation analysis between subjective evaluation categories

	Stiffness of the hip area	Stiffness of the thigh area	Sense of support of hip side	Sense of support of thigh side	Comfort of hip area	Comfort of bolster	Overall satisfaction of comfort
Stiffness of the hip area	1	0.373	0.287	0.426	0.758	0.321	0.713
Stiffness of the thigh area	0.373	1	0.223	0.255	0.367	0.184	0.387
Sense of support of hip side	0.287	0.223	1	0.532	0.299	0.398	0.461
Sense of support of thigh side	0.426	0.255	0.532	1	0.492	0.342	0.585
Comfort of hip area	0.758	0.367	0.299	0.492	1	0.283	0.789
Comfort of bolster	0.321	0.184	0.398	0.342	0.283	1	0.438
Overall satisfaction of comfort	0.713	0.387	0.461	0.585	0.789	0.438	1

B. Derivation of stiffness difference of seat cushion considering body pressure

A large difference in stiffness means that the body pressures are concentrated in one side and that the dispersion extent of pressures and the solid extent perceived by human body can be displayed differently due to a difference in stiffness even for the same seating posture. Therefore, the effects of stiffness on comfort can be identified only when differences in stiffness are analyzed. For stiffness difference category per human body area, six types in total were selected, including stiffness difference between left and right sides of hip area, stiffness difference between left and right sides of thigh area, stiffness difference between left and right sides of bolster area, stiffness difference between hip area and thigh area, stiffness difference between hip area and bolster area, and stiffness difference between thigh area and bolster area. Table 2 shows average values for seat stiffness differences per subjects' human body area. Considering stiffness difference category for the hip area, Seat A has a stiffness difference of 0.197kgf/mm, Seat B 0.018kgf/mm, and Seat C 0.045kgf/mm. Seat A can be seen to have a higher stiffness difference compared with other seats, which indicates that Seat A has the highest relative difference for the hip area among 3 types of seat. Considering stiffness difference category for the thigh area, Seat A has a stiffness difference of 0.013kgf/mm, Seat B 0.011kgf/mm, and Seat C 0.063kgf/mm. All 3 types of seat can be seen to have insignificant differences in stiffness. Considering stiffness difference category for the bolster area, Seat A has a stiffness difference of 0.049kgf/mm, Seat B 0.069kgf/mm, and Seat C 0.043gf/mm. All 3 types of seat can be seen to have insignificant differences in stiffness. Considering stiffness difference category for between hip and thigh, Seat A has a stiffness difference of 0.049kgf/mm, Seat B 0.069kgf/mm, and Seat C 0.043kgf/mm. Seat A is relatively high compared to other seats. Considering stiffness difference category for be-tween hip and bolster, Seat A has a stiffness difference of 0.294kgf/mm, Seat B 0.230kgf/mm, and Seat C 0.110kgf/mm. The difference in stiffness is larger than other categories. Considering stiffness difference category for between thigh and bolster, Seat A has a stiffness difference of 0.096kgf/mm, Seat B 0.138kgf/mm, and Seat C

0.064kgf/mm. The difference in stiffness is larger than other categories. Seat B is relatively high compared to other seats. Consequently, Seat A can be seen to have a larger difference in stiffness in most categories compared with other seats, and particularly difference in left/right stiffness of hip area as well as difference in stiffness between hip and thigh can be seen to show a large difference. The Figure 7 shows the partitioned area of the seat cushion to illustrate Table 2.

Table- II: The average of the stiffness difference of the seat cushion according to the human body area

Classification	Average stiffness of each seat (kgf/mm)		
	Seat A	Seat B	Seat C
Difference between right and left stiffness of hip area: | a - b |	0.197	0.018	0.045
Difference between right and left stiffness of thigh area: | c - d |	0.013	0.011	0.063
Difference between right and left stiffness of bolster: | e - f |	0.049	0.069	0.043
Difference between stiffness of hip area and stiffness of thigh area: | (a+b) – (c+d) |	0.198	0.092	0.059
Difference between stiffness of hip area and stiffness of bolster: | (a+b) – (e+f) |	0.294	0.230	0.110
Difference between stiffness of thigh area and stiffness of bolster: | (c+d) – (e+f) |	0.096	0.138	0.064

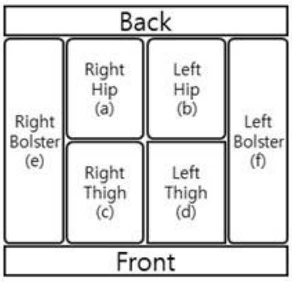


Fig 7. The partitioned area of the seat cushion

C. Multiple linear regression analysis of stiffness and subjective evaluation of seat cushion

To identify the effects of stiffness of seat cushion on comfort, multiple regression analysis has been con-ducted, variable settings are as follows. First, for independent variable, six types in total were selected, including stiffness difference between left and right sides of hip area, stiffness difference between left and right sides of thigh area, stiffness difference between left and right sides of bolster area, stiffness difference between hip area and thigh area, stiffness difference between hip area and bolster area, and stiffness difference between thigh area and bolster area. And then, for dependent variable, seven types in total were selected, including stiffness of hip area, stiffness of thigh area, sense of support of thigh side, sense of support of hip side, comfort of hip area, comfort of seat cushion bolster, and overall satisfaction of comfort. Lastly, variable selection for the multiple linear regression analysis was conducted according to the backward removal method. Table 3 shows categories for independent variable and dependent variable

Table- III: Categories of independent variables and dependent variables

No.	Independent Variable (Variables of seat stiffness)	Dependent Variable (Variables of Subjective Evaluation)
1	Stiffness difference between left and right sides of hip area (A)	Stiffness of the hip area
2	Stiffness difference between left and right sides of thigh area (B)	Stiffness of the thigh area
3	Stiffness difference between left and right sides of bolster area (C)	Sense of support of hip side
4	Stiffness difference between hip area and thigh area (D)	Sense of support of thigh side
5	Stiffness difference between hip area and bolster area (E)	Comfort of hip area
6	Stiffness difference between thigh area and bolster area (F)	Comfort of bolster
7		Overall satisfaction of comfort

Table- Ⅳ: Results of multiple linear regression analysis

Classification	Independent Variable	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (β)	t	P-value	Durbin-Watson	R^2	Adjusted R^2
Dependent Variable: Stiffness of hip	(Constant)	1.104	0.148		7.445	0.000	2.286	0.547	0.540
	A	5.247	1.695	-0.416	3.095	0.002			
	B	-2.798	1.103	-0.341	-2.536	0.012			
Dependent Variable: Stiffness of thigh	(Constant)	0.262	0.119		2.196	0.030	2.188	0.057	0.051
	A	-3.023	1.0174	-0.240	-2.972	0.003			
Dependent Variable: Hip side support	(Constant)	0.700	0.166		4.210	0.000	2.508	0.135	0.129
	D	-3.013	0.634	-0.367	-4.749	0.000			
Dependent Variable: Thigh side support	(Constant)	0.387	0.196		1.975	0.05	2.627	0.076	0.064
	E	-2.062	0.598	-0.391	-3.451	0.001			
	F	2.437	0.973	0.284	2.505	0.013			
Dependent Variable: Comfort of the hip area	(Constant)	0.601	0.177		3.395	0.001	2.157	0.347	0.333
	A	-7.115	0.863	-0.564	-8.241	0.000			
	C	4.458	2.166	0.152	2.059	0.041			
	F	-1.131	0.635	-0.132	-1.779	0.077			
Dependent Variable: Comfort of the bolster	(Constant)	0.332	0.196		1.694	0.092	2.524	0.076	0.063
	E	-2.036	0.598	-0.386	-3.406	0.001			
	F	2.657	0.973	0.309	2.730	0.007			
Dependent Variable: Comfort of	(Constant)	0.352	0.154		2.278	0.024	2.503	0.339	0.330

Retrieval Number:B10640782S619/2019©BEIESP
DOI:10.35940/ijrte.B1064.0782S619

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the seat cushion	A	-6.836	0.862	-0.542	-7.927	0.000			
	C	4.461	1.999	0.153	2.232	0.027			

$$stiffness\ regression\ model\ for\ hip\ area = 1.1104 - 5.247 * A - 2.798 * B \quad (1)$$

$$comfort\ regression\ model\ for\ hip\ area = 0.601 - 7.115 * A + 4.458 * C - 1.131 * F \quad (2)$$

$$overall\ satisfaction\ regression\ model\ for\ comfort = 0.352 - 6.836 * A + 4.461 * C \quad (3)$$

Table 4 shows the results obtained by implementation of multiple linear regression analysis. First, when stiffness of the hip area was selected as a dependent variable, the selected variables were A and B. Since P-values for the relevant variables were 0.002 and 0.012, respectively, being included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.540, indicating that the regression model describes 54% for the stiffness of hip area. When the influence for this is compared, it can be confirmed to be -0.416 and -0.341, respectively. When stiffness of the thigh area was selected as a dependent variable, the selected variables was A. Since P-values for the relevant variables was 0.003, which included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.051, indicating that the regression model describes 5.1% for the stiffness of the thigh area. When the influence for this is compared, it can be confirmed to be -0.240, respectively. However, the above regression model had a considerably low R2 so that description power for stiffness of the thigh area was low. When sense of support of hip side was selected as a dependent variable, the selected variables was D. Since P-values for the relevant variables was 0.000, which included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.129, indicating that the regression model describes 12.9% for the sense of support of hip side. When the influence for this is compared, it can be confirmed to be -0.367, respectively. However, the above regression model had a considerably low R2 so that description power for stiffness of the thigh area was low. When sense of support of thigh side was selected as a dependent variable, the selected variables were E and F. Since P-values for the relevant variables were 0.001 and 0.013, respectively, being included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.064, indicating that the regression model describes 6.4% sense of support of thigh side. When the influence for this is compared, it can be confirmed to be -0.391 and 0.284, respectively. However, the above regression model had a considerably low R2 so that description power for stiffness of the thigh area was low. When comfort of hip area was selected as a dependent variable, the selected variables were A, C. Since P-values for the relevant variables were 0.000 and 0.041, respectively, being included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.333, indicating that the regression model describes 33.3% for the comfort of hip area. When the influence for this is compared, it can be confirmed to be -0.564 and 0.152, respectively. When comfort of bolster area was selected as a dependent variable, the selected variables were E and F. Since P-values for the relevant variables were 0.001 and 0.007, respectively, being included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.063, indicating that the regression model describes 6.3% for the comfort of bolster area. When the influence for this is compared, it can be confirmed to be -0.386 and 0.309, respectively. However, the above regression model had a considerably low R2 so that description power for stiffness of the thigh area was low. When overall satisfaction of comfort was selected as a dependent variable, the selected variables were A and C. Since P-values for the relevant variables were 0.000 and 0.027, respectively, being included within 0.05, it was determined to be significant. The adjusted R2 for the regression model was 0.330, indicating that the regression model describes 33% for the overall satisfaction of comfort. When the influence for this is compared, it can be confirmed to be -0.542 and 0.153, respectively. According to the results of multiple linear regression analysis, the regression models capable of describing subjective evaluation were stiffness regression model for hip area, comfort regression model for hip area, and overall satisfaction regression model for comfort. The following equations (1) to (3) are regression models derived from multiple regression analysis.

IV. CONCLUSION

In the present analysis, to analyze factors through which stiffness of seat cushion affects comfort, correlation analysis and multiple linear regression analysis were conducted, and the following conclusions could be derived.

[1] Among subjective evaluation categories, the overall satisfaction of comfort has correlation coefficients of 0.713 and 0.789 with stiffness of hip area and comfort of hip area, respectively indicating a strong positive linear correlation, while the stiffness of hip area has a correlation coefficient of 0.758 with comfort of hip area, also indicating a strong positive linear correlation. Therefore, overall satisfaction of comfort has been considered to have the highest linear correlation with stiffness of hip area.

[2] In terms of stiffness differences per area of seat cushion, Seat A could be seen to have a larger average stiffness difference per area than other seats for 3 types of seat, which was the same as the evaluation results for overall satisfaction of comfort. Thus, stiffness difference per area of seat cushion was considered to have a close relationship with the overall satisfaction of comfort.

[3] Stiffness of hip area could be seen to be associated with left/right-side stiffness difference of hip area and with left/right-side stiffness difference of thigh area through the regression model. Based on this, it could be seen that the driver felt the cushion, the smaller the left/right-side stiffness difference of the seat cushion excluding bolster.

[4] Through the regression model, the comfort of hip area could be seen to be associated with left/right-side stiffness difference of hip area, left/right-side stiffness difference of bolster area, and stiffness difference between thigh and bolster. Based on this, it was considered that comfort of hip area could be enhanced the more, the smaller the stiffness difference of hip area and the more identical the stiffness for bolster and thigh.

Through the regression model, overall satisfaction of comfort could be seen to be associated with left/right-side stiffness difference of hip area and left/right-side stiffness difference of bolster area. That is, the comfort of the cushion increased when the left and right balance of the stiffness distribution was maintained even if the body pressure distribution was concentrated on one side. Therefore, it is confirmed that the balance of the stiffness distribution has the greatest effect on the comfort.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (NRF-2018R1D1A1B07048491).

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