Evaluation of Sitting Comfort of Leather Car Seat

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Abstract

Sitting comfort of leather car seat, whose grain leather pattern were different, were evaluated by the sensory evaluation. Physical properties and body pressure distributions of leather car seat were also measured. The adjectives used for sensory evaluation were examined by principle component analysis. From the results of subjective measurements, samples with larger unevenness of the grain were evaluated as not high-quality, not relaxed and not comfortable. Samples with smaller unevenness of the grain and smooth were evaluated as simple, familiar and comfortable. From the use of principal component analysis, two principal components were obtained, therefore, the sitting comfort were evaluated by "high-class" and "familiar". From the correlations between sensory evaluations and physical properties or body pressure distributions, the sitting comfort of leather car seat have correlations with the physical properties, which are friction properties of surface, and with the contact pressure of the mannequin and the car seat. From the correlations of tactile sensations and sitting images adjectives, the sitting comfort for leather car seat could not be predicted by the tactile sensations of leather car seat covers. There were greatly difference between the evaluation of sitting comfort for the fabric car seat and those for the leather car seat.

Key Words: Grain leather pattern, Covering fabric, Sensory evaluation

1. Introduction

Consumers are paying closer attention to the kansei elements of a car. The demand for luxury cars is increased, and due to this, high-quality interior parts and luxury components are also being sought. The consumer has a particularly great interest in the seat, the part the human body touches directly. Leather, moquette or tricot is used to cover luxury car seats; of these, the demand for genuine leather in particular is the strongest. It has been noted that characteristics of genuine leather are excellent moisture absorption and desorption, heat insulation, and fire retardancy. Genuine leather also exhibits moderate elasticity and plasticity as well as moldability. Because of these characteristics, genuine leather has been used as a cover material for luxury car seats. Particularly in Japan, the consumers have a great interest in genuine leather as a luxury material.

A considerable number of studies have been made on driver and passenger seat comfort, including a study on the design factor from deflection and vibration [1], a study on how seat angle influenced sitting comfort [2], a study on the relationship between body weight distribution and sitting comfort [3], and a study on the visual or tactile evaluation of sitting comfort [4, 5]. In recent years, several research papers have been devoted to the study of how the structure of each layer, pad or wadding influenced sitting comfort [6, 7]. For example, there has been a study on the relationship between the combination of padding and cover fabric and sitting comfort and a study on how the physical properties of cover fabric influenced sitting comfort [8, 9]. These studies revealed that a car seat’s structure and cover fabric greatly influence sitting comfort. As for genuine leather, which is used in automobile interiors, there are studies on how the grain pattern or material influenced the sensations consumers have when touching the trim [10, 11]. Here, the grain pattern is the design pattern drawn on the genuine leather. On the tactile sensations of car seats, we investigated how the grain leather pattern influenced the tactile sensations of leather car seat covers. The tactile sensations of leather covers were influenced by the grain leather pattern, and those sensations could be predicted by the physical properties [12]. However our previous study only focused on the genuine leather as car seats’ cover material. Then, on the genuine leather seat, the effect of the grain leather pattern on sitting comfort has not been clarified. To design a new car seat, some sample seats are made and tested several times. If the sitting comfort of leather car seats could be predicted by their cover material not the formed seat, it will be useful for designing
car seats. Accordingly, it will be quantified by the objective measurements of their physical properties, and be able to contribute to the design of the leather car seats finally.

Our primary goal was to clarify how grain leather pattern and physical properties influences the sitting comfort of car seats. For the hand evaluation of genuine leather, it is known that judging their feelings were influenced by the tactual motion such as tracing and pressing, and the tactile sensations has a relationship with the compression properties and the surface friction properties. We examined the correlations between objective measurements (physical properties) and subjective measurements (sensory values), and performed principal component analysis to reveal the characteristics of the genuine leather seats. And we also investigated the relationship between the tactile sensations of leather cover and the sitting comfort of leather seats. Then, it was examined whether the consumers’ sitting comfort could be quantified by the objective measurement of the physical properties or the hand evaluation of leather material. In other words, we finally aimed at the establishment of the basic method in order to contribute to the design of the leather car seats.

2. Experimental method

2.1 Samples

The cover of car seat which consists of fabrics and wadding made of slab urethanes have a great influence on texture, because they are in direct contact with the human body. We selected five car seats as samples, whose cover fabrics were made of cow leathers with grain processing. The grain leather patterns of these samples were different in the size of grain, roughness or the drawn pattern, and typical samples as car seat material [12]. The shape and size of samples were same, but only cover leather was different. Fig. 1 shows the details of sample car seat and measuring points. Fig. 2 shows five cow leather samples with different grain leather patterns used as cover fabric for car seats [12]. Since leather has anisotropy, we defined head to tail directions as warp. A wadding 6 mm thick was glued to the back of each leather.

2.2 Physical properties of leather covers [12]

To clarify the differences between grain patterns, surface properties were measured by a 3D coordinate measuring machine (SURFCOM 480A, TOKYO SEIMITSU CO., LTD.). This machine has a contact probe made by diamond with a tip radius of 2 micrometers. The contact probe moved at a speed of 0.6 mm/sec for 40 mm distance in warp direction, 0.077 gf of weight were loaded at the tip, and the sampling frequency was 434 Hz. Each test was repeated ten times in a 0.5 mm pitch in weft direction. The measurements were performed in a room maintained at a temperature of 19.4 ± 1.4ºC with 38 ± 5% relative humidity.

Two roughness parameters were calculated from the measuring
result. The Ra of an arithmetic average of absolute values is a parameter of undulation and the Rz of average distance between the highest peak and lowest valley is a measure of unevenness. Ra is the characteristic of the grain, and samples with larger Ra were squishier. Details of each leather cover are shown in Table 1 [12]. Sample E with the largest Ra and Rz was with the largest unevenness of the grain, and varied widely in Ra and Rz. Sample B, similar to Sample E, was with larger Ra and Rz, and was with larger unevenness of the gain, but with smaller unevenness than those of Sample E. Sample C with the smallest Ra and Rz was with the smallest unevenness of the grain, that is, smooth. Sample D, similar to Sample C, was with smaller unevenness and smooth, but Sample D was not smoother than Sample C. Sample A was with average Ra and Rz, and was with average unevenness of the gain.

Compression properties measured by a tensile and compression testing machine (STA-1225, ORIENTEC Co. LTD.) were T0 (thickness at 49Pa, mm), TM (thickness at 7.8kPa, mm), T0-TM (displacement of compression, mm), WC (compression energy, gf.cm/cm²), RC (compressional resilience, %), LC (linearity of compression curve) and TC (thickness ratio of compressed to T0, %). These measurements of compression properties were referring to the KES system [13]. The compression plate was 36 cm², and the compression speed was 6 mm/min. The measurements of compression properties are shown in Table 2 [12]. TC was larger for samples A, B and E than samples C and D. TC was the reduction ratio of the thickness due to compression, and TC was different from their grain patterns. However the difference in the compression properties between leather car seat samples were smaller than the general fabric car seat [9].

Surface properties measured by a surface friction testing machine (NT-01, KATO TEC Co. LTD.) were MIU (mean coefficient of friction), MMD (mean deviation of MIU) and MIU/MMD. The contacting area of the friction contactor was formed by piano wire of 0.5 mm in diameter, and was 10 mm x 10 mm. The friction measurement pressure was 7.4 kPa, the moving rate of the friction contactor was 8 mm/sec [14] and the effective measuring distance was 50 mm. The measurements of surface friction properties are shown in Table 3 [12]. MIU was larger for samples D and E than the other samples; these were the samples without slipperiness. Sample A had lower MIU and MIU/MMD; it was slippery and felt bad. Sample C had lower MMD and higher MIU/MMD; sample C was smooth and felt soft.

All operations were performed in a room maintained at a temperature of 23 ± 0.7ºC with 50 ± 3% relative humidity.

2.3 Subjective measurements for sitting comfort

2.3.1 Adjective words for evaluation

We selected sixteen adjectives as image words for concepts of car design, namely “luxurious”, “elegant”, “relaxed”, “adult”, “simple”, “masculine”, “casual”, “natural”, “delicate”, “high-class”, “heavy”, “high-quality”, “genuine”, “sporty”, “familiar” and “comfortable”. As adjectives to express physical properties, we selected thirteen adjectives, namely “warm”, “fluffy”, “firm”, “thick”, “elastic”, “voluminous”, “smooth”, “soft”, “bumpy”, “slippery warpwise”, “slippery weftwise”, “moist” and “slimy”. And as adjectives for sitting comfort, we selected eight adjectives, namely “held at seat”, “held at back”, “fit at seat”, “fit at back”, “oppression at seat”, “oppression at back”, “sinking in seat” and “sinking in back”. These adjectives were selected based on previous research [7] and the results of a preliminary survey sent to car users.

2.3.2 Subject panelists and subjective measurements

Subject panelists were 12 men aged 23 ± 1, whose average height and weight were 173 ± 6.3 cm and 61.5 ± 6.8 kg, and body mass index were 20.5 ± 2.1. The sitting comfort of the five car

| Sample | MIU | MMD | MIU/MMD |
|--------|-----|-----|---------|
| A      | 0.142 | 0.019 | 7.6     |
| B      | 0.169 | 0.019 | 8.8     |
| C      | 0.176 | 0.012 | 14.7    |
| D      | 0.236 | 0.019 | 12.4    |
| E      | 0.204 | 0.021 | 9.7     |

| T0 (mm) | TM (mm) | T0-TM (mm) | WC (gf/cm²/cm) | RC (%) | LC | TC (%) |
|---------|---------|------------|-----------------|--------|----|--------|
| A       | 7.01    | 1.38       | 5.63            | 6.50   | 41.3 | 0.29   | 80.3    |
| B       | 7.20    | 1.51       | 5.69            | 6.64   | 41.3 | 0.29   | 79.0    |
| C       | 7.74    | 1.88       | 5.86            | 7.02   | 41.1 | 0.30   | 75.7    |
| D       | 7.37    | 1.63       | 5.74            | 6.77   | 40.8 | 0.30   | 77.9    |
| E       | 7.10    | 1.51       | 5.59            | 6.43   | 41.5 | 0.29   | 78.8    |
seats were judged by the Scheffe-Nakaya’s paired comparison method [15]. The car seats were set on same condition shown in Fig. 3. The panelists evaluated the sitting comfort of car seats with the aforementioned 37 adjectives. The panelists wore jersey cloth and sat on their samples without seeing them, and evaluated them using five grades from -2 to +2 points. The panelists were allowed to sit the samples repeatedly for evaluating with these adjectives except “warm” which influenced by the temperature of the sample. However, they always finished sitting 2nd sample of a pair. The response of each subject was tested individually without a time limit in a quiet room maintained at 23ºC and 50% relative humidity. We calculated the mean preference scores of the five samples for each sensory adjective from the results of the paired comparisons.

2.4 Body pressure distribution

Body pressure distributions and contact areas between a human body 3D mannequin and a car seat were measured by a tactile sensor system (BIGMAT-2000, NITTA Co., Ltd.). The sensor system consists of mat that was made up of thin flexible sensors, and sensors were set on a car seat. The measuring area was 430 × 480 mm (2064 points) for each sensor mat. The sensor mat set up between the mannequin and the seat. The mannequin shown in Fig. 4 was 62.4 kg and set up a same position in each car seat. The measurements were performed in a room maintained at a temperature of 23 ± 0.7ºC with 50 ± 3% relative humidity.

3. Results and discussion

3.1 Body pressure distribution

Body pressure distributions of the seat were analyzed by being divided into buttocks part and thigh part shown in Fig. 5. The results of the body pressure distribution are shown in Table 4. Since using the same mannequin with a same position, there was no difference in the contact area. The grain leather patterns did not affect the contact area between a human body 3D mannequin and a car seat. On the other hand, since the compression properties of the sample differed, there was a difference in the contact pressure. Contact pressures were larger for samples A and C than the others at the seat and thigh part, and larger for samples C and E than the others at the buttocks part. It was found that the characteristics of the leather cover affected the body pressure distributions. The contact pressure between a human body and a car seat was affected by the compression properties of cover fabrics [5], in the same way, the compression properties of cover leather affected the contact pressure between a human body 3D mannequin and a car seat.

3.2 Subjective measurements

3.2.1 Mean preference scores

To test the subjects’ ability in judging, the adjective “bumpy” was chosen and a circular triad was counted for this adjective. In this study, we focused on the grain leather patterns’ uneven surfaces, so we selected the adjective “bumpy” which describes an uneven surface. This test was in order to determine the subjects’ ability to judge adjectives, not to find faults in the sensory test. It was ultimately determined that only a subject on the panelist was not able to judge the adjective; therefore, we used the results of those 11 men.
From the results of paired comparison, the mean preference scores of five leather seats for each sensory adjective were calculated using Scheffe-Nakaya’s method [15]. To test the main effect and the combination effect, analysis of variance was conducted for all adjectives.

From the results of the analysis of variance, the main effects for the mean preference scores of the physical adjectives except “warm”, “elastic” and “voluminous”, of the image adjectives except “elegant”, “natural”, “delicate” and “sporty” and of the sitting image adjective except “sinking in back” were significant at 1% or 5% level. The combination effects were not significant at 1% or 5% level, except “fluffy”, “slippery warpwise”, “slippery weftwise”, “smooth” and “firm” as the physical adjectives. Therefore, we used the results of 5 physical adjectives, 12 image adjectives and 7 sitting image adjectives.

The mean preference scores of each sample are shown in Figs. 6, 7 and 8. Sample A was soft, sample C was not bumpy, not moist, not slimy and thin, sample D was hard, moist, slimy and thick, sample E was bumpy. As the results of image adjectives, sample A was not high-class, sample B was genuine, relaxed, adult, and heavy, sample C was not genuine, not luxurious, not adult, very simple, not masculine, casual, not high-class, not heavy, familiar and comfortable, sample D was high-quality, luxurious, not simple, high-class, heavy and not familiar, sample E was not high-quality, not relaxed and not comfortable. As the results of sitting image adjectives, sample A was sinking in seat, sample B was not sinking at seat, sample C was not held at seat and back, not fit at seat and back and not oppression at seat and back, sample D was held at seat and back, fit at seat and back and oppression at seat and back. Sitting comfort of sample C and D were contrastive. It was found that the covers’ grain leather patterns influenced the physical adjectives “moist” and “slimy” related to wet-dry sensations, but did not influence “thick”. As the image adjectives, the covers’ grain leather patterns influenced “high-class”, “casual”, “relaxed”, “heavy” and “simple”. As the sitting image adjectives, the covers’ grain leather patterns influenced “held” and “fit” related to static image, but didn’t influence “oppression” and “sinking” related to dynamic image.

### 3.2.2 Principal Component Analysis

Principal component analysis for the mean preference scores of image adjectives, physical adjectives and sitting image adjectives was performed using 23 words; “comfortable” was excluded because only words describing the full sensation affected the principal component analysis. Principal component analysis was carried out to summarize a large number of explanatory variables to less explanatory variable. Principal components analysis of the correlation matrix suggested a two-dimensional solution, with the first principal component accounting for 83.5% of the variance.
and the second principal components accounting for 11.5%. The first two principal components were accounting for 95.0% of the variance. From this result, the two principal components were used for analysis. Principal component loadings of 23 adjectives were shown in Fig. 9.

The first principal components of “heavy”, “luxurious”, “adult”, “high-class” and “casual” were high principal component loadings. Therefore, the first principal component (PC1) describes “high-class”. At second principal components, “familiar” and “bumpy” were high principal component loadings. Therefore, the second principal component (PC2) describes “familiar”. Principal component scores of each leather samples were shown in Fig. 10, samples A and E were not familiar and low-class, sample B was high-class and familiar, sample D was high-class, sample C was familiar and low-class. That is, the samples with smaller contact pressure or smaller WC were high-class, the samples with bigger contact pressure or larger WC were low-class.

Leather car seat covers evaluated by tactile sensations were describes with two principal components, “high-class” and “smoothness” [12]. “High-class” was an image common to two evaluations, and it was found that “high-class” was useful to evaluation of leather car seat.

3.3 Correlation of objective measurements and subjective measurements

The correlation coefficients between the compression properties of each leather covers and each mean preference scores of image adjectives were calculated. There were no significant correlations of them at the 5% level. The leather covers, although with different grain leather patterns, were only small difference in compression properties. Then the evaluation of image adjectives could not be affected by the compression properties of leather covers with a slight difference. For the surface properties, there were significant correlations of MMD and “simple” (R=-0.91) and “familiar” (R=-0.91). Samples with smaller MMD were “simple” and “familiar”, and it was shown that the samples with smaller friction were “simple” and “familiar”. Some of image adjectives had correlations with surface properties, however most of image adjectives had no correlations. The surface properties could be affected by the grain leather patterns, so the evaluation results of image adjectives were more affected by surface properties than by compression properties. Therefore as the image adjectives, it was found that subjective measurements almost not correlated with the physical properties of leather covers as compared with the hand evaluation [12].

Also, there were no significant correlations between physical properties and the mean preference scores of physical adjectives, and those of sitting image adjectives at the 5% level. The physical adjectives were not affected by the physical properties between leather covers, because there was a slight difference in the physical properties of the leather covers compared with the fabric covers.
The sitting images adjectives, such as “held”, “fit” and “sinking”, were complex sense, to receive greater influence of the whole seat design. Then, for the leather covers with a slightly difference in the physical properties, there were no correlation between sitting image adjectives and physical properties of the leather covers.

The sitting image adjectives were also not affected by the physical properties of the leather covers. The images for sitting comfort of leather seats could not predict by the physical properties. The correlation coefficients between the body pressure distributions of each sample and each physical adjective’s mean preference score are shown in Table 5, the image adjectives correlation coefficients are shown in Table 6. In terms of the correlation coefficients in Table 5 and 6, the CP (contact pressure) of all had a significant correlation with “thick”, “genuine”, “luxurious”, “adult”, “simple”, “masculine”, “casual” and “heavy” at the 1% or 5% level. Body pressure distributions were measured in the state of simulating the sitting on car seats, not seat covers. Therefore the physical adjectives and the image adjectives had correlations with the body pressure distributions. Those sitting comfort were affected by the body pressure distributions, so those sitting comfort were quantitatively predicted by the contact pressures between leather seats and the 3D mannequin measured in a practical situation. Samples with smaller CP were “thick”, “genuine”, “luxurious”, “adult”, “complicated”, “masculine”, “formal” and “heavy”, and it was found that the image adjectives were more affected by the body pressure distributions. From the result of correlation coefficients of the body pressure distributions and mean preference score of each sitting image adjective, there is no significant correlation. The sitting comfort, such as “held”, “fit” and “sinking”, were complex sense, and they would be evaluated with panel’s movement on the car seat. The body pressure distribution with the 3D mannequin was the physical properties in the static state, so there were no correlation between sitting image adjectives and the body pressure distributions.

### 3.4 Correlation of tactile sensations and sitting comfort

Texture images of the five leather covers glued to 6-mm pads were judged Scheffe-Nakaya’s paired comparison method [15] by the same panelists as the those of sitting comfort, in the same quiet environment. We selected the same sixteen adjectives as image words for concepts of car design and the same thirteen adjectives to express physical properties. The eight adjectives for sitting comfort were excluded from the evaluation. The leather covers were put in a box, and the panelists touched the samples without seeing them and evaluated while touching them in the palm [12].

The correlation coefficients of the evaluation by tactile sensations and the sitting comfort of mean preference score of each adjective are shown in Table 7. There were no significant correlations between the tactile and the sitting at the 5% level except the image adjective “simple”. Therefore, the sitting comfort for fabric car seats could predict by the tactile sensations [9], however, the sitting comfort for leather car seats could not predict by the tactile sensations. It was found that there were greatly difference between the evaluation of sitting comfort for the fabric car seat and those for the leather car seat.

Fabric car seats were with complex components, such as the structure of the weaving or knitting, yarn count, density, pile length, pile depth, while leather car seats in this study were only with different grain leather patterns. Since the sitting comfort were not affected by the physical properties of the leather covers and the

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**Table 5** Correlation coefficient of contact pressure (CP) of seat and physical adjectives.

|          | Soft | Bumpy | Moist | Slimy | Thick |
|----------|------|-------|-------|-------|-------|
| CP of all| 0.709| -0.734| -0.846| -0.878| -0.887*|
| CP of buttocks | 0.600| -0.762| -0.731| -0.731| -0.714|
| CP of thigh | 0.516| -0.135| -0.530| -0.644| -0.689|

**Table 6** Correlation coefficient of contact pressure (CP) of seat and image adjectives.

|          | High-quality | Genuine | Luxurious | Relaxed | Adult | Simple |
|----------|--------------|---------|-----------|---------|-------|--------|
| CP of all| -0.688       | -0.977 **| -0.916 *  | -0.844  | -0.926 * | 0.903 * |
| CP of buttocks | -0.498| -0.840  | -0.738  | -0.667  | -0.736 | 0.822  |
| CP of thigh | -0.635| -0.688 | -0.710 | -0.753 | -0.758 | 0.464 |

|          | Masculine | Casual | High-class | Heavy | Familiar | Comfortable |
|----------|----------|-------|------------|-------|----------|-------------|
| CP of all| -0.974 **| 0.960 **| -0.828 | -0.942 *| 0.564 | 0.376 |
| CP of buttocks | -0.927 * | 0.801 | -0.680 | -0.812 | 0.597 | 0.478 |
| CP of thigh | -0.426 | 0.704 | -0.623 | -0.607 | -0.001 | 0.230 |
tactile images were affected by theirs, then it was considered that there were no correlations between the tactile for leather covers and the sitting for leather seats. For the leather car seat, it was found that the evaluation of sitting comfort could not be replaced by the hand evaluation of leather cover.

4. Conclusion

We investigated how grain leather pattern influenced the sitting comfort of leather car seat. Sitting comforts were evaluated by sensory tests, and physical properties for leather car seat and body pressure distribution were measured as the objective evaluations. The relationship between the sitting comfort of leather car seat and the physical properties of those seats were examined by correlation analysis and the principal component analysis. The results were as follows.

(1) As the results of subjective measurements, the grain leather pattern of car seat influenced the sitting comfort, which were image adjectives, physical adjectives and sitting image adjectives. Samples with larger unevenness of the grain were evaluated as not high-quality, not relaxed and not comfortable. Samples with smaller unevenness of the grain and smooth were evaluated as simple, familiar and comfortable. Sample was with average unevenness of the gain was not characteristic.

(2) From the use of principal component analysis, two principal components were obtained. Therefore, the sitting comfort of leather car seat were evaluated by "high-class" and "familiar". The samples with smaller contact pressure were high-class, and with easy to compress were familiar.

(3) From the result of correlation coefficients between sensory value and physical properties of leather cover, some of image adjectives had correlations with surface properties, however most of image adjectives had no correlations, and sitting images had no correlations with compression properties. The sitting comfort of leather car seat was not predicted by physical properties of leather cover, except friction properties of surface.

(4) The grain leather pattern of car seat affected the body pressure distribution between a human body 3D mannequin and a car seat. The sitting comfort of leather car seat was predicted by body pressure distributions correlated with image adjectives.

(5) The sitting comfort for leather car seat could not be predicted by the tactile sensations of leather car seat covers. There were greatly difference between the evaluation of sitting comfort for the fabric car seat and those for the leather car seat.

It was shown that the comfort images of leather car seat could be predicted by the objective measurements of their physical properties and the body pressure distributions, namely, the results of our research could contribute to the design of the car seats. However, only one part of the consumers’ sitting comfort could be quantified by the hand evaluation of leather material. The samples in our study were typical genuine leathers as cover material of car seat, however it’s also necessary to consider be applied to other leather samples. In order to contribute to the design of leather car seats greatly, the further study on sitting comfort should be carried out.

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