*Advances in Human Factors of Transportation,* Vol. 148, 2024, 615–623
https://doi.org/10.54941/ahfe1005253

# Seat Comfort Evaluation Method Using X-Ray: A Case Study in Compact Sedan

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## ABSTRACT

The aim of this research is to gather driver data to determine the comfort of a car seat by analyzing the correlation between various X-ray measurement variables and the satisfaction, comfort, and support of the seat, back, and cushion. The X-ray measurement variables include the seat angle at optimal posture, C7-SVA, Backset, the distance between Hip Joint and Head Centerline, height between Hip Joint and Head Centerline, cervical lordosis angle, thoracic kyphosis angle, and lumbar lordosis angle. The study was conducted on 17 participants using the Compact Sedan car. The results of the experiment showed that overall seat satisfaction was negatively correlated with the lumbar lordosis angle ($r=-0.511$, $p< 0.05$). The satisfaction of headrest support showed a negative correlation with the seat angle at the optimal posture ($r=-0.597$, $p< 0.05$). The comfort of the headrest support was negatively correlated with the distance between the hip joint and the head centerline ($r=-0.609$, $p<0.01$), the seat angle ($r=-0.511$, $p< 0.05$), and the lumbar lordosis angle ($r=-0.502$, $p< 0.05$). Headrest support satisfaction was negatively correlated with the distance between the Hip Joint and the head centerline ($r=-0.486$, $p<0.05$). In conclusion, the X-ray data analysis confirmed musculoskeletal variables that showed a significant correlation with seat comfort. However, this study is limited to Compact Sedan seats only, and it is expected that more meaningful data can be obtained if additional research is conducted on various class seats such as hatchbacks and SUVs in the future. Additionally, the study can include L3 of the spine, L4 of the spine, Thorax Angle, and Abdomen Angle variables in the future.

**Keywords:** Vehicle seat comfort, X-ray, Seat angle, Cervical Lordosis angle, Thoracic kyphosis angle

## INTRODUCTION

As a result of recent technological advancements such as autonomous driving and purpose-based mobility (PBV), automobiles are transforming from a simple means of transportation to a new space. Users can now engage in various activities other than driving in their vehicles, allowing them to make the most of their time. Consequently, the importance of car seats, which are the devices that users interact with the most, is increasing. Nowadays, users are demanding a differentiated high level of comfort beyond the basic performance of the seat. The automobile industry is currently conducting various research activities to achieve a high level of comfort in car seats.

 

Chung et al. (2023) analyzed the comfort of slim seats according to seat material and ergonomic design through questionnaire evaluation and pressure distribution. Jun et al. (2014) presented a methodology related to deflection, body pressure distribution, and human body vibration to objectively evaluate seat comfort, and established an evaluation procedure by securing actual data. Kim et al. (2010) investigated the comfort evaluation items of car seats that had been previously studied and developed 36 evaluation items.

As such, researchers in the automobile industry are trying to secure the reliability of seat comfort by using various evaluation methods. Representative methods include using surveys and body pressure distribution data. However, these two methods were difficult to intuitively evaluate and had limitations in time and result reproducibility (Kim et al., 2021).

To provide comfortable seats, an advanced evaluation method that can numerically compare and judge seat comfort is needed. X-ray is a useful test that can be used to evaluate seat comfort because it can obtain musculoskeletal information and view the internal condition without any special preparation (Asan Medical Center, 2023). X-ray, also called a radiation test, refers to a test in which X-rays are transmitted through the human body. It is a highly reliable test method that has been used in the fields of diagnosis and treatment as the only technique that can obtain images of the inside of the human body for about 50 years since its discovery (Seoul National University Hospital, 2023). Measures measured through radiography of the adult spine are correlated with disability and health-related quality of life. As the imbalance in spinal alignment worsens, muscle use increases, and fatigue and fatigue occur. It has been shown that it can cause pain and disability (Kim et al., 2021).

Research on using these X-ray measurements to develop car seats is ongoing, although minimal, both domestically and internationally. Choi et al. (2023) attempted to find items that could improve performance by measuring spine-pelvic variables in a standing state and while sitting in a car seat using X-rays. Yang et al. (2013) conducted X-ray imaging to analyze medical imaging images and identified the support position of the lumbar support most preferred by drivers. Bertil et al. (2007) used X-rays to compare and analyze the degree of neck reduction (cervical retraction capacity) in a comfortable and upright position when sitting in a car seat. As a result, it was found that the neck shrank more in a comfortable position than in an upright sitting position.

However, past studies were limited to simply measuring changes in drivers' conditions through X-ray imaging. Research comparing and analyzing the correlation between X-ray measurement variables and seat comfort is very insufficient, so further research is needed, which can be greatly utilized in improving seat comfort.

Therefore, in this study, variables measured using X-ray (the seat angle at optimal posture, C7-SVA, Backset, the distance between Hip Joint and Head Centerline, height between Hip Joint and Head Centerline, cervical lordosis angle, thoracic kyphosis angle, and lumbar lordosis angle) and the satisfaction, comfort, and support of each part of the seat, back, and cushion to obtain driver data to determine the comfort of the Car seat.

## METHOD

This experiment involved 17 volunteers (10 men, 7 women) with driver's licenses, and X-ray data was measured and analyzed while sitting in the optimal position on the car seat. The average age of the volunteers was 36.4 ± 5.1 years, and their weight was 69.4 ± 12.2 kg. The car seat used for the research experiment was the driver's seat of a compact sedan and was installed on a large jig with fixed wheels in a flat X-ray room. Experiment participants adjusted the seat to their desired optimal posture, including backrest angle, slide, and height.


**Figure 1**: Experiment environment.

In the X-ray images obtained through the experiment, the seat angle at optimal posture, C7-SVA, Backset, the distance between Hip Joint and Head Centerline, height between Hip Joint and Head Centerline, cervical lordosis angle, thoracic kyphosis angle, and lumbar lordosis angle were measured.

The cervical lordosis angle measures the angle between the inferior border of the second cervical vertebra and the inferior border of the seventh cervical vertebra (Lee et al., 2014). The cervical lordosis angle measures the angle between the upper border of the 4th thoracic vertebra and the lower border of the 12th thoracic vertebra. The lumbar lordosis angle measures the angle between the superior border of the first lumbar vertebra and the superior border of the first sacral vertebra (Cho et al., 2016). C7-SVA refers to the distance between a line drawn vertically from the front of the body of the cervical 7th vertebra and the line connecting the rear end of the 1st sacral vertebra (Choi et al., 2023).

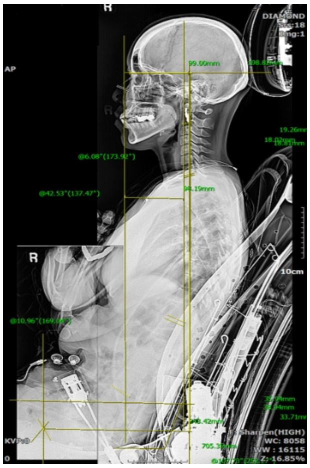

**Figure 2:** Sitting on an automotive seat by radiographic assessment.

After the measurement was completed, a survey was conducted. The survey questions were structured on a 10-point Likert scale. The survey questions consisted of overall seat comfort, headrest comfort, cushion overall comfort, back overall comfort, seat overall support, cushion support, back support, overall seat satisfaction, headrest satisfaction, cushion satisfaction, and back satisfaction.

## RESULTS

### Descriptive Statistics

#### X-Ray Measurement Variables

**Table 1.** X-ray measurement variables.

| Parameter | Seat Angle At Optimal Posture (°) | C7-SVA (mm) | Backset (mm) | Distance Between Hip Joint and Head Centerline (mm) | Height Between Hip Joint and Head Centerline (mm) | Cervical Lordosis Angle (°) | Thoracic Kyphosis Angle (°) | Lumbar Lordosis Angle (°) |
|---|---|---|---|---|---|---|---|---|
| Average | 110.03 | 87.72 | −0.39 | 223.38 | 777.05 | 10.40 | 33.64 | 34.86 |
| SD | 3.72 | 45.52 | 16.69 | 45.47 | 43.91 | 5.59 | 7.02 | 11.37 |

#### Questionnaire

**Table 2.** Questionnaire.

| Parameter | Overall Seat Comfort | Headrest Comfort | Cushion Comfort | Back Comfort | Back Support | Cushion Support | Seat Satisfaction | Cushion Satisfaction | Back Satisfaction | Headrest Satisfaction |
|---|---|---|---|---|---|---|---|---|---|---|
| Average | 7.06 | 6.15 | 7.41 | 7.09 | 6.93 | 7.12 | 7.26 | 7.24 | 6.91 | 5.85 |
| SD | 1.74 | 2.16 | 1.67 | 1.99 | 1.40 | 1.64 | 1.45 | 1.31 | 1.29 | 1.74 |

## Correlation Analysis Among Variables

### Correlation Between Questionnaires and X-Ray Variables

As a result of correlation analysis between Questionnaires and X-ray data variables, overall seat satisfaction showed a negative correlation with thoracic kyphosis angle ($r=-0.511$, $p<0.05$). Satisfaction with the headrest showed a negative correlation with the seat angle at optimal posture ($r=-0.597$, $p<0.05$). Headrest comfort was measured by the distance between Hip Joint and Head Centerline ($r=-0.609$, $p<0.01$), the seat angle at optimal posture ($r=-0.511$, $p< 0.05$), and thoracic kyphosis angle ($r=-0.502$, $p< 0.05$) and a negative correlation was observed. Headrest satisfaction showed a negative correlation with the distance between Hip Joint and Head Centerline ($r=-0.486$, $p<0.05$)

**Table 3.** Correlation coefficient between X-ray measurement variables and questionnaires.

| Parameter | Seat Angle At Optimal Posture (°) | C7-SVA (mm) | Backset (mm) | Distance Between Hip Joint and Head Centerline (mm) | Height Between Hip Joint and Head Centerline (mm) | Cervical Lordosis Angle (°) | Thoracic Kyphosis Angle (°) | Lumbar Lordosis Angle (°) |
|---|---|---|---|---|---|---|---|---|
| Overall seat comfort | −0.172 | −0.024 | 0.233 | −0.308 | −0.042 | −0.018 | −0.541* | −0.117 |
| Headrest comfort | −0.511* | −0.206 | 0.080 | −0.609** | 0.009 | −0.200 | −0.502* | −0.148 |
| Cushion comfort | −0.102 | 0.030 | −0.133 | −0.136 | 0.193 | −0.022 | −0.428 | −0.087 |
| Back comfort | −0.266 | 0.146 | 0.096 | −0.146 | −0.126 | 0.347 | −0.135 | 0.041 |
| Back support | −0.177 | 0.116 | 0.154 | −0.111 | −0.074 | 0.201 | −0.187 | 0.050 |
| Cushion support | −0.193 | 0.087 | 0.044 | −0.200 | −0.159 | 0.133 | −0.446 | −0.010 |
| Seat satisfaction | −0.110 | 0.206 | −0.404 | 0.109 | 0.176 | 0.265 | −0.027 | −0.094 |
| Cushion satisfaction | −0.260 | 0.023 | −0.160 | −0.270 | −0.129 | 0.254 | −0.346 | −0.097 |
| Back satisfaction | −0.253 | −0.082 | 0.246 | −0.257 | −0.137 | 0.341 | 0.255 | −0.010 |
| Headrest satisfaction | −0.597* | −0.210 | −0.113 | −0.486* | −0.080 | 0.091 | −0.122 | −0.083 |

*$^*p<0.05$, $^{**}p<0.01$*

### Correlation Analysis Among X-Ray Measurement Variables

As a result of correlation analysis among X-ray measurement variables, the seat angle at optimal posture was C7-SVA ($r=-0.597$, $p<0.01$), the distance between Hip Joint and Head Centerline ($r=-0.752$, $p<0.01$) A positive correlation was found. C7-SVA showed a negative correlation with Backset ($r=-0.483$, $p<0.05$) and a high-level positive correlation with the distance between Hip Joint and Head Centerline ($r = 0.836$, $p<0.01$). Additionally, the cervical lordosis angle showed a positive correlation with the thoracic kyphosis angle ($r = 0.523$, $p<0.05$).

### Correlation Coefficient Among Questionnaires

As a result of correlation analysis among survey questions, a high level of correlation was observed in the comfort, support, and satisfaction surveys.

**Table 4.** Correlation coefficient among X-ray measurement variables.

| Parameter | Seat Angle At Optimal Posture (°) | C7-SVA (mm) | Backset (mm) | Distance Between Hip Joint and Head Centerline (mm) | Height Between Hip Joint and Head Centerline (mm) | Cervical Lordosis Angle (°) | Thoracic Kyphosis Angle (°) | Lumbar Lordosis Angle (°) |
|---|---|---|---|---|---|---|---|---|
| Seat angle at optimal posture (°) | 1 | | | | | | | |
| C7-SVA (mm) | 0.646** | 1 | | | | | | |
| Backset (mm) | −0.160 | −0.483* | 1 | | | | | |
| Distance between Hip Joint and Head Centerline (mm) | 0.752** | 0.836** | −0.390 | 1 | | | | |
| Height between Hip Joint and Head Centerline (mm) | 0.406 | 0.093 | −0.252 | 0.153 | 1 | | | |
| Cervical lordosis angle (°) | −0.098 | 0.133 | 0.013 | 0.127 | −0.125 | 1 | | |
| Thoracic kyphosis angle (°) | −0.006 | 0.126 | 0.017 | 0.377 | −0.128 | 0.523* | 1 | |
| Lumbar lordosis angle (°) | −0.337 | −0.207 | 0.238 | −0.174 | −0.375 | 0.282 | 0.358 | 1 |

*$p<0.05$, $^{**}p<0.01$*

**Table 5.** Correlation coefficient among questionnaires.

| Parameter | Overall Seat Comfort | Headrest Comfort | Cushion Comfort | Back Comfort | Back Support | Cushion Support | Seat Satisfaction | Cushion Satisfaction | Back Satisfaction | Headrest Satisfaction |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall seat comfort | 1 | | | | | | | | | |
| Headrest comfort | 0.549* | 1 | | | | | | | | |
| Cushion comfort | 0.704 ** | 0.243 | 1 | | | | | | | |
| Back comfort | 0.594* | 0.305 | 0.582* | 1 | | | | | | |
| Back support | 0.718 ** | 0.276 | 0.566* | 0.844 ** | 1 | | | | | |
| Cushion support | 0.698 ** | 0.256 | 0.748* | 0.746 ** | 0.776 ** | 1 | | | | |
| Seat satisfaction | −0.123 | −0.116 | 0.313 | 0.560* | 0.293 | 0.433 | 1 | | | |
| Cushion satisfaction | 0.421 | 0.238 | 0.520 | 0.600* | 0.509* | 0.574* | 0.491* | 1 | | |
| Back satisfaction | 0.331 | 0.285 | 0.031 | 0.371 | 0.348 | 0.047 | −0.169 | 0.255 | 1 | |
| Headrest satisfaction | 0.299 | 0.734** | 0.167 | 0.280 | 0.310 | 0.176 | 0.039 | 0.089 | 0.461 | 1 |

*$p<0.05$, $^{**}p<0.01$*

## DISCUSSION

In this study, X-ray was used to determine the seat angle at optimal posture, C7-SVA, Backset, the distance between the Hip Joint and Head Centerline, height between Hip Joint and Head Centerline, cervical lordosis angle, thoracic kyphosis angle, and lumbar lordosis angle was measured. Additionally, the satisfaction, comfort, and support of the seat, back, and cushion were measured and analyzed.

As a result, a significant relationship was confirmed between the seat angle at optimal posture and headrest comfort and satisfaction. This is presumed to be because as the seat angle, or torso angle, increases, the head support position changes as the driver bends his or her back to secure visibility. Additionally, there was a negative correlation between headrest comfort and H-Point distance. This is believed to have affected comfort as the head support position changed depending on the degree to which the driver sat with his or her buttocks out.

A negative correlation was found between thoracic kyphosis angle and seat comfort and headrest comfort. According to Kendall et al. (2005), the thoracic kyphosis angle increases in the Forward Head Posture, where the head is excessively protruded. If the upper part of the body is bent in a sitting position, the position of the head and neck may change due to compensation, stress may be added, and discomfort may appear. This discomfort can be interpreted as affecting seat comfort and head restraint comfort.

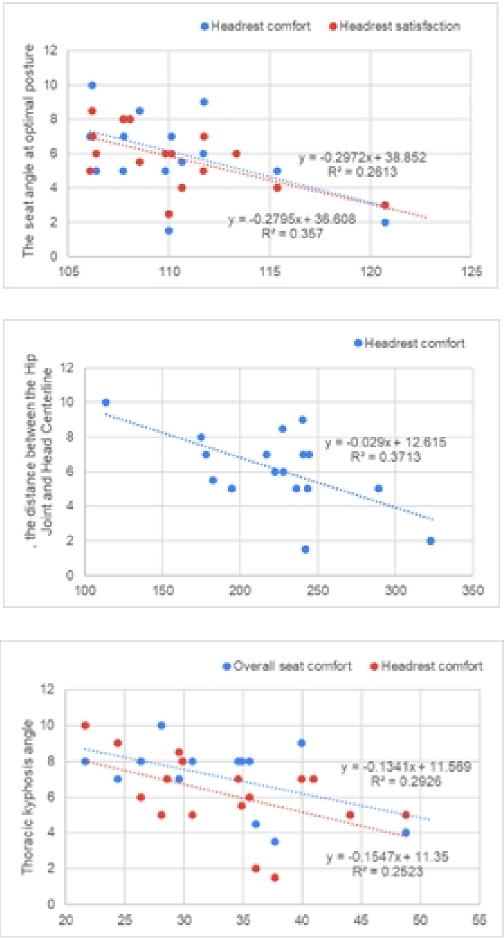


**Figure 3:** Results of correlation analysis.

The study's results have confirmed that the comfort of a seat decreases when the driver's seat back angle is small, the distance to the H-point is long, and the thoracic kyphosis angle is small. These findings indicate that not just the seat itself, but also driving posture, affects seat comfort. Previous studies have suggested that factors such as the pad, frame, suspension, and spring also play a role (Ebe et al., 2001; Yusof et al., 2004). In the future, it is believed that a specific level of comfort can be predicted by comprehensively analyzing the seat itself factors, psychological factors (Dumur et al., 2004), and driving posture.

## CONCLUSION

In order to quantitatively determine the comfort of the seat, this study analyzed the seat angle at optimal posture, C7-SVA, Backset, the distance between the Hip Joint and Head Centerline, height between Hip Joint and Head Centerline, cervical lordosis angle, thoracic kyphosis angle, and lumbar lordosis angle measured on X-ray and, the overall seat comfort, headrest comfort, cushion overall comfort, back overall comfort, seat overall support, cushion support, back support, overall seat satisfaction, headrest satisfaction, cushion satisfaction, and back satisfaction collected through a survey.

In conclusion, musculoskeletal variables that showed a significant correlation with seat comfort were confirmed through X-ray data analysis. This study has the limitation of testing only compact sedan seats, but it appears that meaningful quantitative data can be obtained if additional research is conducted on seats of various car classes such as hatchbacks and SUVs in the future. Furthermore, in addition to the existing thoracic kyphosis angle and the seat angle at optimal posture, it is believed that L3 of the spine, L4 of the spine, Thorax Angle, and Abdomen Angle could also be included in the study.

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