# Ergonomic Evaluation of Child Car Seat Design

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**Abstract.** An ergonomic child car seat design should consider safety, sitting posture and comfort. The purpose of this study is to evaluate child car seat cover thicknesses and hardness in its design. Twenty children from 3 to 6 years old were recruited to participate in the experiment with nine treatment combinations (three thicknesses: 5, 10, 15 mm and three hardness: 10, 12, 15 ILD of child car seat cover). Experimental setup included a platform with real back seat and the car safety seat placed on the back seat. In the experiment, each participant was asked to take one of the nine child car seats that were randomly assigned. Seat pressure distribution and skin temperature were collected to find the best combination of child car seat cover designs. The results indicated that the 5 mm thick with 10 ILD hardness child car seat cover had the best thermal comfort performance. The 15 mm thick with 10 ILD hardness child car seat cover had the lowest sitting pressure and highest seating comfort. These research findings provide very useful information for child car seat design, seat comfort improvement and selection.

**Keywords:** Child car seat, Pressure distribution, Temperature distribution, Seat covers design, Seat comfort.

## 1. INTRODUCTION

Several countries with advanced industries have passed related laws concerning about the safety of child car seats to ensure the safety of children in passenger vehicles to avoid injuries and death caused by traffic accidents. In Taiwan children weighing under 20 kg have been required to use a car safety seat since 2005 (CNS11497 D2188, 2010). The design issues for child car seats have therefore become important issues worldwide (Lai & Chang, 2004).

Child restraints for automobiles are intended to keep children safe. A child car seat reduces the risk for death to infants by 71% and to toddlers by 54% in passenger vehicles (Durbin, 2011). Child car seats are vital for keeping children safe in the car and also play important roles in the healthy development of a child, as they accompany the child throughout a longer period of time. Given that the child's body grows constantly during this phase of his/her life, it is particularly important for a child car seat to have an ergonomic design.

Comfort is considered the most important aspect next to safety in car seat design. Vehicle seat comfort may be divided into static and dynamic comfort. Static comfort involves the sitting impressions on occupants when there is no vibration. The seat comfort measurement method adopts physiological measurements with the aid of subjective measurements (Lueder, 1983; Fátima & Josep, 1999).

Various studies have investigated the relationship between seat characteristics and seat comfort. Lee & Ferraiuolo (1993) reported that foam thickness and foam hardness were important parameters affecting seat comfort. Gross et al. (1994) recorded the perceived comfort of 12 seat aspects for 50 different car seats, with each seat trial lasting 5-10 minutes. The statistical results showed that pressure data were strongly related to perceived comfort and thus the perceived comfort could be predicted.

If the driving distance was long, it is also important for the seat to offer a constant pleasant sitting climate and ideal sitting pressure distribution. Continuous air circulation must be present between the child's body and the child seat. Thus, child car seat design with ride comfort is an important issue that cannot be overlooked.

Although conventional methods such as subjective questionnaires (Chae et al. 2011; Donnelly et al. 2009), and pressure distribution mapping (Chae et al. 2011; Paul, Daniell, et al. 2012; Paul, Pendlebury, et al. 2012) are used for studying the comfort of adults in vehicles, ergonomic evaluations on child car seats for child occupants are still lacking. The purpose of this study is therefore to evaluate the thicknesses and hardness effects of child car seat covers on seat pressure distribution and skin temperature.

## 2. METHODS

### 2.1 Participants

Twenty children (11 boys, 9 girls,) from 3 to 6-years-old were recruited to participate in these experiments. Their average body height was 108.0 (S.D. = 7.9) cm, and their average body weight was 18.3 (S.D. = 3.8) kg. The participant's demographic data are listed in Table 1. All subjects were free of cardiovascular, musculoskeletal disorders and metabolic problems. The children and parents were fully informed about the purpose, procedure and potential risk of these experiments. This study was approved by the Research Ethics Committee (REC) of National Taiwan University.

Table 1: The subject characteristics (S.D.)

| | boys | girls |
|---|---|---|
| N | 11 | 9 |
| Body height (cm) | 106.4 (8.4) | 109.6 (7.4) |
| Body weight (kg) | 17.6 (3.2) | 18.9 (4.3) |

S.D.: standard error of the mean.

### 2.2 Experimental design

A factorial experimental design was employed. The independent variables were thickness: 5, 10, and 15 mm and hardness: 10, 12, and 15 ILD (ILD: Indentation Load Deflection, unit: kg/ 314 $cm^2$) of child car seat cover. The dependent variables included the seat pressure distribution (i.e. average seat pressure, peak seat pressure, seat pressure area (Figure 1), and skin temperature (left upper back, left lower back, and left buttock; Figure 2). Data were collected to identify the best child car seat cover design combination.

The seat pressure distribution was measured using a Tekscan seating sensor system that includes pressure sensors, transducers and analysis software (Tekscan Inc., USA). The seating sensor system is made of soft plastic material with areas of 18.6*18.6 inches. This sensor system provides precision measurement of 5 square mm areas with four sensors in one square cm. The whole matrix sampling rate was set at 100 Hz and each acquisition lasted 1 sec. The working range was 0–250 mmHg, with a spatial resolution of 3.0 sensels/ in2. The skin temperature was measured by wearing three thermistors (NX-TMP1A, Mind Media B.V., Nederland) attached to the left upper back, left lower back and left buttock area. All temperatures were recorded continuously with a sampling rate of 64 Hz and stored in a data storage unit (NeXus-10, Mind Media B.V., Nederland). All data were transferred wirelessly to a computer with the display updated every second on a computer screen. Static seat comfort was also evaluated. The room temperature was controlled at 25 °C, simulating the inside temperature of a standard vehicle.

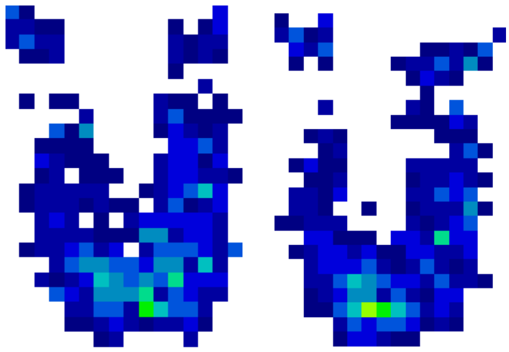

Figure 1: Seat pressure distribution.

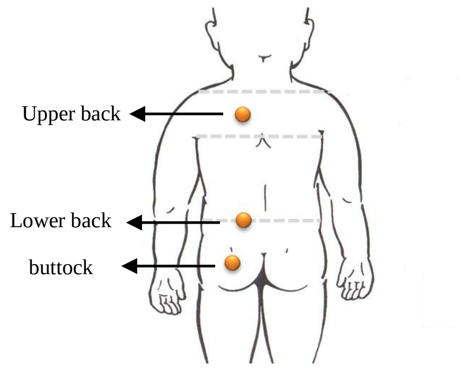


Figure 2: Skin temperature setting position (back view).

### 2.3 Experimental procedure

The experimental setup included a platform with a real car seat back. The child car safety seat was placed on the back seat (Figure 3). A typical child car safety seat (Combi Prim Long, Japan) was adopted in this experiment. The angle between seat cushion and seat back was adjusted to 30° . The experimenters explained the measurement process to all participants and parents before the experiment and asked for the parents' assistance in placing the children into the car seats. During the experiment each participant was asked to take one of the nine randomly assigned child car seats. Participants were required to wear a pair of provided light cotton pants and a cotton long-sleeved shirt. Children were to sit in the child car seat in a stable posture.

The experimental task simulated the children riding in the child car seat. Each trial lasted 10 minutes. Fifteen minutes rest was given between experiments. A total of 25 minutes was involved in each treatment condition. Seat pressure distribution and skin temperature were collected during each experiment.

Figure 3: The experimental set-up.

## 2.4 **Statistical analysis**

Analyses of variance were conducted (ANOVA). Post hoc testing with Duncan multiple range test was then performed to identify which condition was significantly different from each other. ANOVA and Duncan multiple range tests were performed using SPSS version 17 (IBM Corporation, USA). The significance level of α = 0.05 was used for all statistical analyses.

# 3. RESULTS

## 3.1 Pressure distribution

The ANOVA results in Table 2 reveal a significant thickness and hardness effect on the average pressure and peak pressure ($p < 0.05$). The average pressure of 5 mm thickness child car seat cover (17.8 mmHg) was higher than that of 10 mm and 15 mm thickness (17.4, and 17.0 mmHg). The average pressure (18.0 mmHg) of the 15 ILD hardness was significantly higher than the average pressure (16.7 mmHg) of 10 ILD hardness (Figure 4; $p < 0.05$).

Table 2: summary of ANOVA for the seat pressure results

| | Average pressure (mmHg) | Peak pressure (mmHg) | Seat pressure area ($cm^2$) |
|---|---|---|---|
| (T)hickness | * | * | n.s. |
| (H)ardness | * | n.s. | n.s. |
| (T)*(H) | n.s. | n.s. | n.s. |

* Significant at $p < 0.05$; n.s. not significant

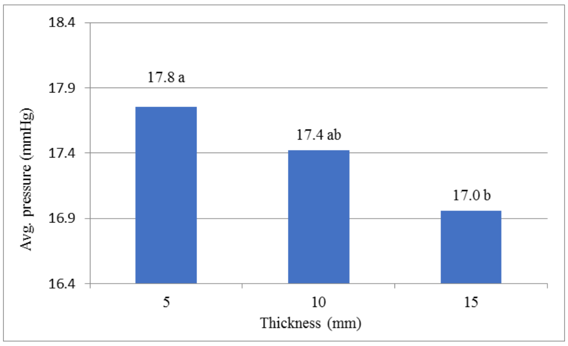


Figure 4: The thickness effect on average pressure (a, b: Duncan grouping code), mean.

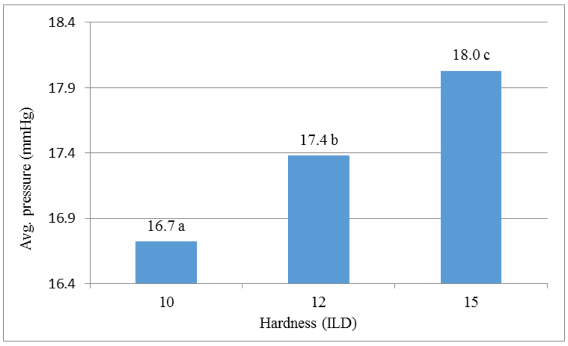


Figure 5: The hardness effect on average pressure (a, b: Duncan grouping code), mean.

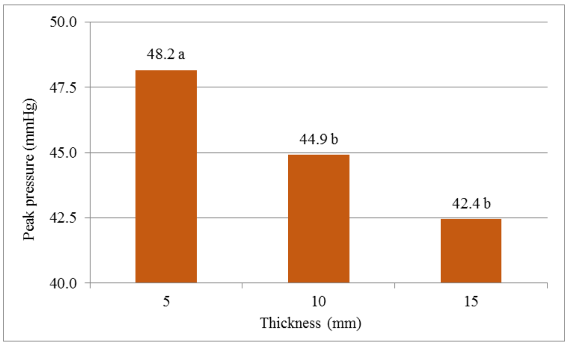


Figure 6: The thickness effect on peak pressure (a, b: Duncan grouping code), mean.

The 5 mm thickness child car seat cover (48.2 mmHg) was significantly greater in peak pressure than that of the 10 and 15 mm thickness child car seat covers (44.9 and 42.4 mmHg) (Figure 5; $p < 0.05$). There were no significant thickness and hardness effects in the seat pressure area ($p > 0.05$). This was because the child car seat was upholstered.

### 3.2 Skin temperature

The ANOVA results in Table 3 reveal a significant thickness effect on the increase in skin temperature in the lower back and buttocks. A similar trend was found in the increase of maximum skin temperature in the lower back and buttocks (Table 3; $p < 0.05$).

Figure 7 show that the 15 mm thickness child car seat cover produced higher average skin temperature increase on the lower back (0.70 °C) and buttock (0.53 °C) regions than the 5 mm thickness child car seat cover (0.55 and 0.44 °C)($p < 0.05$). In addition, Figure 8 shows the 15 mm thickness child car seat cover produced higher maximum skin temperature increase in the lower back (1.04 °C) and buttocks (0.91 °C).

Table 3: summary of ANOVA for the skin temperature results

| | The average skin temperature increase (°C) | | Maximum skin temperature increase (°C) | |
|---|---|---|---|---|
| | Lower back | Buttock | Lower back | Buttock |
| (T)hickness | * | * | * | * |
| (H)ardness | n.s. | n.s. | n.s. | n.s. |
| (T)*(H) | n.s. | n.s. | n.s. | n.s. |

* Significant at $p < 0.05$; n.s. not significant

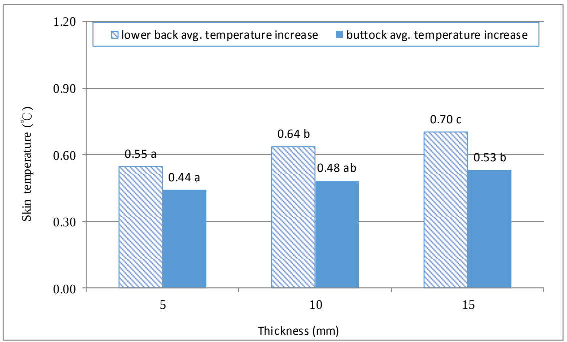


Figure 7: The thickness effect on average skin temperature increase (a, b: Duncan grouping code), mean.

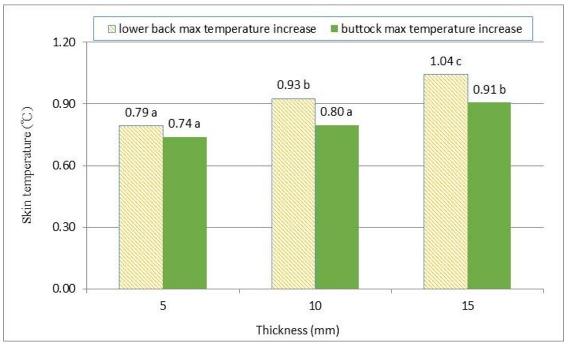


Figure 8: The thickness effect on maximum skin temperature increase (a, b: Duncan grouping code), mean.

## 4. DISCUSSION

The purpose of this study was to evaluate the effects of interactions on the child's comfort between two types of variables, including the child car seat cover thickness and hardness.

Various studies have investigated the relationship between seat characteristics and seat comfort. The foam thickness and foam hardness were important parameters for seat comfort (Lee & Ferraiuolo, 1993; Kazushige & Griffin, 2001). Blair et al. (1997) investigated the polyurethane foam (PUF) chemical structure effect on the seat cushion dynamic and static characteristics and concluded that cushions with moderate hardness and high thickness yield produced the lowest vibration transmissibility (Blair et al., 1997). In addition, Ebe & Griffin (2001) confirmed that the contact pressure values under the ischium bones can be applied as the principal criterion for foam hardness and seat comfort. Thus, a close correlation was found between the contact area and contact pressure values (Ebe & Griffin, 2001).

The child car seat cover with 15 mm thickness and 10 ILD hardness had the lowest sitting pressure and highest seating comfort. A child car seat with thick foam tends to cause supportive and cushioning to reduce sitting pressure. These results are in line with those of Ragan et al. (2002). Changing the foam characteristics will mostly affect the static seat comfort and could be a useful indicator of static seat comfort. Moreover, in high quality child car seats lumbar support is an important factor for increased comfort. Figure 5 indicates that as the hardness decreased, the child car seat cover foam had great indentation and deformation, resulting increased seat contact area and less pressure on the human body. These results are consistent with those of Ebe & Griffin (2001).

Temperature can affect the local feeling of discomfort, with both high and low temperatures being perceived as uncomfortable. Both the seat foam padding and surface material affect the skin temperature at the interface (Reed et al., 1994).

The significant thickness effect revealed that the increase in average skin temperature and maximum skin temperature from the 15 mm thick child car seat cover, as expected, was higher than that of the 5 and 10 mm thick child car seat covers. Moreover, heat transfer efficiency related to the material thickness. When the seat foam thickness increased the heat insulation effect would be significantly higher. That is the reason the cooling effect was poor with the high thickness cover. Diebschlag et al. (1988) reported on the foam type and thickness effects on vapor permeability and the resulting effect on the microclimate against the skin. Although different foam compositions varied in their permeability, water vapor transfer increased with foam compression up to about 80 percent of full thickness, above which the permeability dropped markedly.

Therefore, based on the thermal performance perspective, the 5 mm thick child car seat cover with 10 ILD hardness was the best.

Although the child car seat cover with 5 mm thickness and 10 ILD hardness had the best thermal comfort performance, the child car seat cover with 15 mm thickness and 10 ILD hardness had the lowest sitting average pressure and peak pressure. While considering the child's comfort, multiple evaluation criteria should be used, including sitting position, the child's subjective feelings and shaking effects (vibration magnitude). All of these factors are important indexes that affect child seat comfort.

## 5. CONCLUSION

This study evaluated the child car seat cover thicknesses and hardness effects on seat pressure distribution and skin temperature in child car seat design. The results indicate that the child car seat cover with 5 mm thickness and 10 ILD hardness presented the best thermal comfort performance. On the other hand, the child car seat cover with 15 mm thickness and 10 ILD hardness presented the lowest sitting pressure and highest seating comfort. These research findings can provide very useful information for child car seat design and selection and improve seat comfort.


## ACKNOWLEDGEMENT

The authors would like to thank the financial support of Ministry of Science and Technology (MOST) of R.O.C. The number of the project is NSC102- 2622- E-007-CC3.


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