Doctoral Dissertation (Shinshu University)

Investigation into the sitting comfort of train seats by using numerical analysis and psychophysiological evaluation

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Contents

Chapter 1

Introduction

1.1 Background

1.1.1 Importance of investigating the sitting comfort of train seats

Locomotion is an essential function for humans. Primitive humans had to move to acquire food and shelter. Later, the purpose of moving shifted to the need to conquer a new territory or, in the modern world, to participate in commerce. Today, we experience and enjoy learning about many cultures, histories, and foods through travel. We endlessly desire to move farther, faster, and more conveniently. The train is one of the means we use to satisfy these desires.

The train, which can transport many passengers at a time, is an important means for communication within a population. The Japanese Shinkansen (a network of high-speed trains) connects many cities and is used for both pleasure and business travel. According to a 2012 survey conducted by the Ministry of Land, Infrastructure, Transport, and Tourism [1], 320 million passengers rode the Shinkansen, whose railway at that time covered 2600 km (Figure 1-1). New Shinkansen routes have been developed over the years, and its destinations are still increasing. Therefore, it is expected that domestic access will be even more convenient because of the advances in the railway system.

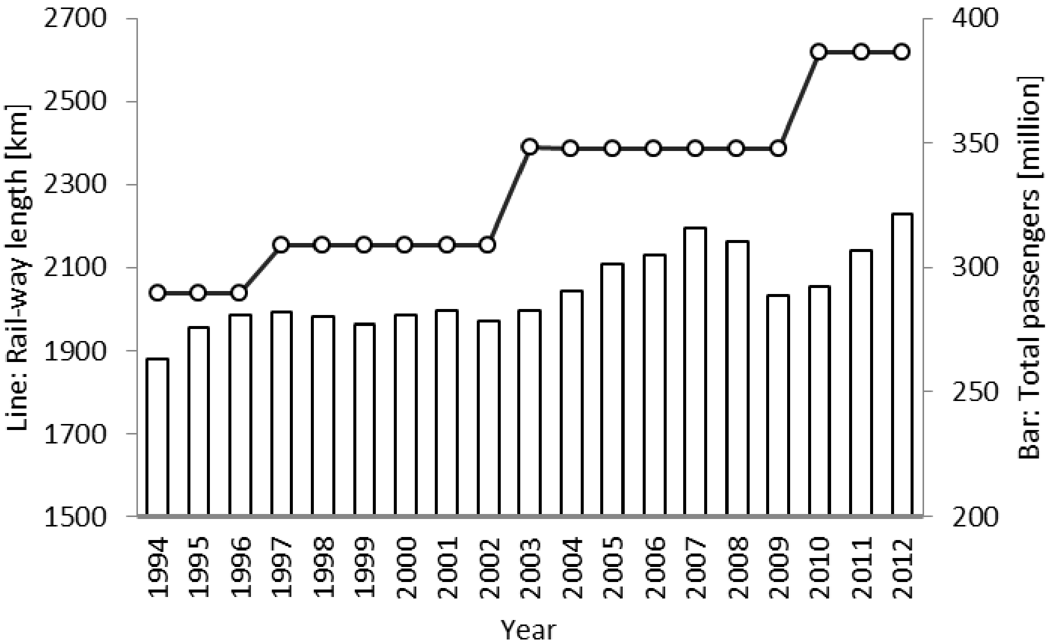


Figure 1-1 Changes in the scale of the Shinkansen [1]

Generally speaking, a product has two spheres of interest. One is the mechanics of the product, and the other is the human viewpoint. The mechanical aspect includes the fundamental function to enhance the high-speed aspect. The human aspect means the interactions between humans and the product. For instance, because passengers must sit on train seats—thus, in direct contact with them—it is important to investigate the relationship between the human and the train seat, that is, the sitting comfort.

To increase train comfort, we have focused on the train seat, especially for high-speed trains. According to Hino [2], sitting comfort is one of the most relevant factors for achieving customer satisfaction. It is presumed that long-term sitting not only decreases comfort [3,4] but risks incurring bodily damage such as deep vein thrombosis [5,6]. Therefore, because passengers sit for prolonged periods of time on a train, it may be assumed that the comfort provided by the seat is one of the most important factors that affect comfortable train travel. Few studies, however, have investigated the comfortableness of the train seat [3,4]. These few studies performed their sitting experiments in a large train simulator and investigated sitting comfort by subjective evaluations. They also mainly focused on the influence of the train's vibration and any discomfort felt by the "passenger." Thus, there is limited information on the sitting comfort of train seats. The sitting comfort of a train seat is therefore still not clear and is one of the issues to be addressed herein.

1.1.2 Features of train seats

We have clarified the features of train seats in comparison with other seats. Table 1-1 shows each characteristic of high-speed train seats and those of other seats.

Table 1-1 Comparison of train seats and other seats

	Train seat	Car seat	Office chair	Sofa
Movement	**Difficult**	Difficult	Easy	Easy
Equipment	**Backrest angle**	Backrest angle, Seat height, Seat angle, Seat position	Seat height	None
User	**Unspecified**	Owner	Owner	Owner
Task	**Various (Eating, Typing, Reading, Resting)**	Driving	VDT	Reading, Resting

When riding on a train or in a car, one cannot simply leave one seat in exchange for another—in contrast to changing from a chair to a couch, for example, at home. This restriction indicates that the sitting comfort on a train seat is important. It is also relatively easy to suit one's body size when in a car because car seats have several functions that can adjust the seat's height, angle, and position. Train seats, in contrast, are designed for an "average person," and the backrest angle is the only movable part. While sitting on a car seat, the driver is occupied only with driving tasks. When sitting on a train seat, however, there are various tasks that can be undertaken, such as eating, typing, reading, and resting. Therefore, a train seat has characteristics distinct from those of other seats. Also, passengers pay money to ride on a train each time, so it is necessary that the value of the train seat is continuously enhanced. Therefore, it is essential to investigate the sitting comfort of train seats to satisfy the KANSEI of the passengers.

1.1.3 Topics of this study and relevant studies about sitting comfort

Many ergonomic studies have examined the sitting comfort of chairs in general. Figure 1-2 shows the general topics about sitting comfort. It indicates that sitting comfort consists of many factors and should be investigated not only by multiple methods but also from new standpoints. We focused on three topics in this study: 1) determining internal stress around the intervertebral discs using finite element method (FEM) analysis; 2) the visual influence of seat colors on sitting comfort; 3) the footrest angle that reduces leg swelling. Figure 1-3 shows the three topics in this study. The originality of this study and relevant studies that address each topic are following.

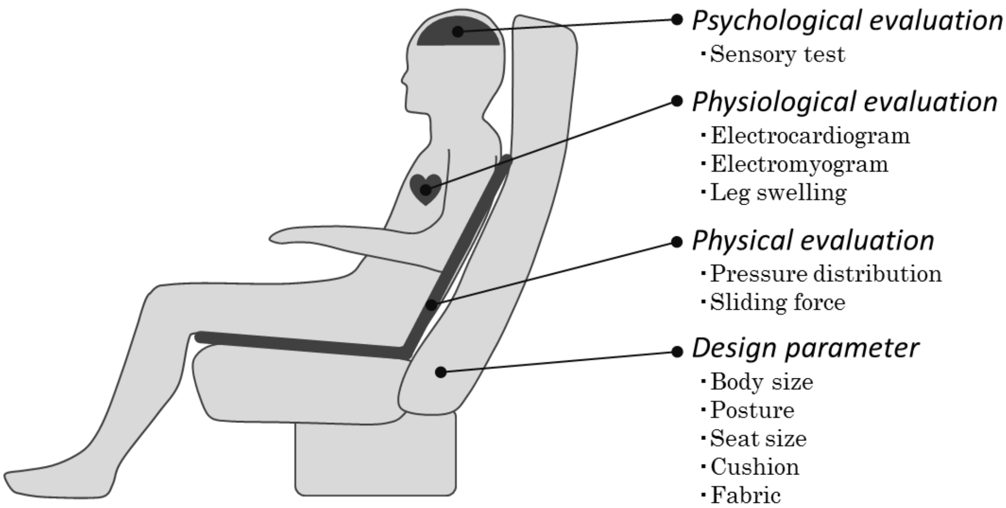


Figure 1-2 General topics about sitting comfort

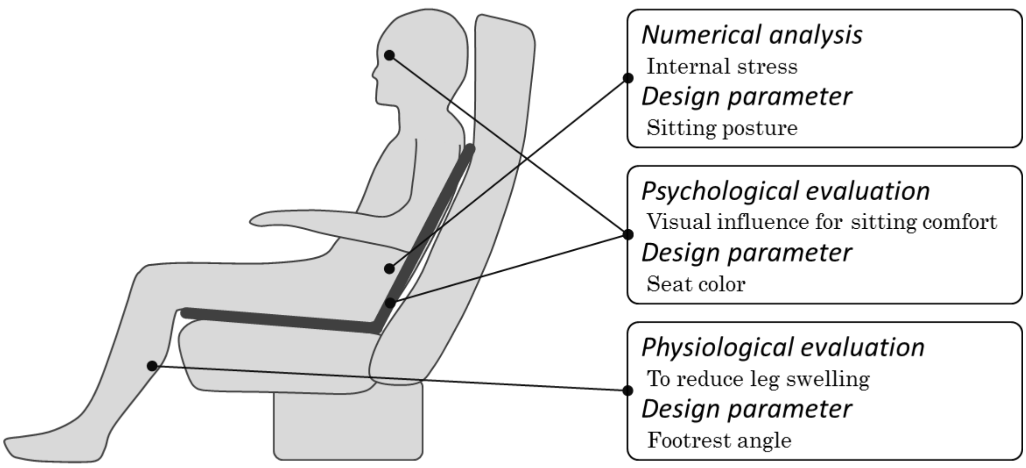


Figure 1-3 Three topics in this study

The first topic is determination of the internal stress around the intervertebral discs using FEM analysis. Many previous studies examined sitting comfort by using not only objective evaluation (e.g., surface electromyography, pressure distribution on the seat) but subjective evaluation such as sensory tests [7-12]. In addition to these previous methods, examining deformation in the human body could provide valuable information to help us understand sitting comfort because it is assumed that sensory receptors detect internal deformation while sitting. These indices, however, are superficial, and there are only a few studies that have examined the condition in the human body [13,14]. Therefore, we focused on internal distribution of stress in this study, which would enable us to evaluate sitting comfort from a new standpoint. However, physical fatigue, manifesting as low back pain, can occur while sitting, causing partial stress to the human body, according to Rohlmann [13,14]. There is an ethical concern, however, that great physical stress due to the direct measurement of stress in the human body is invasive. Therefore, we focused on numerical analysis, which has recently been used in biomechanical studies [15-20] as an alternate method. Previous studies [15-18] focused on dynamic analysis (e.g., riding comfort and impact biomechanics), but little attention has been paid to static analysis (i.e., sitting comfort [19] and sleeping comfort [20]). Therefore, we calculated internal stress by static analysis because it is presumed that static analysis is important for analyzing the sitting comfort. We also considered the fact that train seats are sat upon by passengers in various postures, and FEM analysis can change sitting postures on a computer and analyze the differences in stress distribution in the human body.

Next, it was presumed that train seat characteristics generally include not only a somatic factor but also a visual factor. The fundamental structure of seats is almost completely confined because trains must comply with regulations such as internal space and the number of seats. However, various colors can be applied to the seats. Indeed, humans have different reactions to the seats based on their color. In fact, it is well known that colors influence psychological responses [21,22]. Nishimatsu [23] reported that impressions or usability can be changed by altering visual information. Therefore, we hypothesized that seat color influences the sitting comfort. That is, it is possible that visual sensation affects somatic sensation—in this case, sitting comfort. Few studies [23,24] have examined the influence of visual information that affects somatic sensation. Therefore, we focused on the visual influence of the colors of the train seats on sitting comfort.

Finally, leg swelling, which frequently occurs during sitting, results in languor of the lower legs and decreases the sitting comfort. According to Kawakami [25], 90% of women and 15% of men are bothered by leg swelling while sitting. Sudo [26] also noted that 90% of women experienced leg swelling daily during their working hours. Leg swelling is therefore a problem of daily life that must be addressed. It is generally believed that leg swelling is generated by an increase in leg volume secondary to an increase in extracellular interstitial fluid [27-33]. Leg swelling while sitting has several causes, including blood stagnation due to pressure on the thigh and diminution of the pumping effect of the gastrocnemius [33]. Many studies have examined the mechanism of increased leg swelling [25-31] and discussed how to restrain increasing leg swelling. However, it is more meaningful to decrease leg swelling than restrain increasing leg swelling. It has additional value for high-speed train travelers. Nevertheless, few have investigated the mechanism of decreased leg swelling [32], so the overall mechanism of leg swelling remains unclear. The gravity effect secondary to lifting the legs and the pumping effect secondary to the activity of the gastrocnemius effectively decrease leg swelling. It is difficult, however, to perform these exercises in a limited space while sitting on a train. Therefore, we focused on footrests, particularly the footrest angle, because leg raising is difficult in a limited space such as in a train. Therefore, the presence of a footrest and changing its angle are alternative methods by which to decrease leg swelling. Reducing leg swelling is not only taking control of a possibly dangerous factor, it increases sitting comfort, thereby enhancing the value of the train seat.

1.2 Purposes

This thesis proposes design guidance for developing train seats. It was developed via multiple investigations. We investigated three major topics for sitting comfort of train seats.

Using the FEM analysis described in Chapter 2, we investigated the relation between internal stress and subjective evaluation by using human-seat FEM models. The information gained about stress distribution in the human body during sitting is valuable.

We investigated how seat color influences sitting comfort in Chapter 3. If it is revealed that seat colors improve sitting comfort, it would guide the manufacturer to design seats in an easier, economical way that still pleases the traveler.

We addressed the subject of leg swelling in Chapter 4. We investigated the footrest angle to determine if leg swelling could be avoided by changing the angle of the footrest. We also examined the relation between leg swelling and blood flow. If adjusting the footrest decreases leg swelling, it could increase sitting comfort.

Chapter 2
Investigation of sitting comfort using the finite element method

2.1 Introduction

As mentioned in Section 1.1.3, many previous studies have examined sitting comfort. However, these investigations involved superficial evaluations. In addition to the data obtained from previous methods, information on deformation within the human body would be valuable with respect to an understanding of sitting comfort. Therefore, we focused on internal distribution of stress. An understanding of the stress distribution that occurs secondary to internal deformation in the human body would enable us to evaluate sitting comfort from a new standpoint.

Previous studies have indicated that physical fatigue such as low back pain secondary to sitting causes partial stress within the human body [13,14]. However, the use of direct measurement of stress in the human body is difficult. Therefore, we performed a numerical analysis as an alternate method of stress measurement; this analysis involved the finite element method (FEM). We constructed human–seat FEM models and calculated internal stress by static analysis to investigate sitting comfort.

We also focused on the effects of differences in sitting postures because train seats allow for various postures such as those used when working on a computer, reading, and resting by adjusting the backrest angle (Figure 1-2). Therefore, we investigated the sitting comfort of different postures by comparing different internal stress levels as analyzed by FEM and evaluating subjective feelings such as pain.

2.2 Purpose

The purpose of this study was to investigate the relationship between stress in the human body and subjective feelings such as pain. For this purpose, we constructed accurate FEM models and evaluated their validity.

This chapter comprises three sections, each describing a stage in our investigation. 1) We performed a sitting experiment in advance to categorize various sitting postures. 2) We constructed accurate FEM models with three categorized sitting postures and calculated internal stress. 3) We conducted a sitting experiment to evaluate subjective sitting comfort and further examined sitting comfort by comparing internal stress and subjective feelings such as pain.

2.3 Categorization of sitting postures

2.3.1 Outline

Before constructing the FEM models, it was necessary to categorize the various sitting postures. As previously mentioned, train seats allow for various postures such as those used when working on a computer, reading, and resting through adjustment of the backrest angle. We performed a sitting experiment to categorize various postures while sitting on a train seat. Three categorized postures, namely working, reading, and resting, were used in the FEM analysis (Section 2.4) and sensory tests (Section 2.5).

2.3.2 Methods

We prepared a general train seat (Figure 2-1) that allows for adjustment of the backrest angle from 98 to 126 degrees.

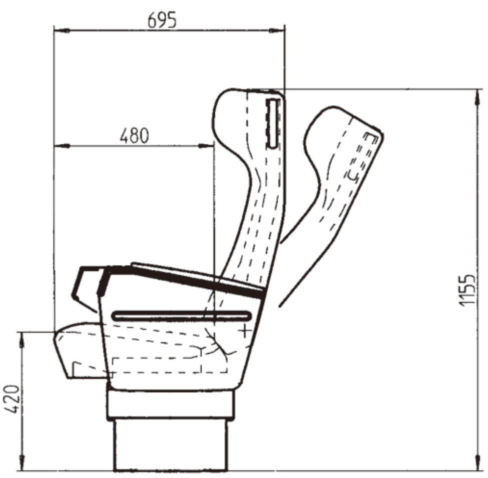


Figure 2-1. Train seat used in this study [mm]

According to a previous report [34], we broadly divided the various sitting postures into three categories that are often used on trains: working on a computer, reading, and resting. The subjects in this study performed each task for 15 minutes. The subjects were able to adjust the backrest angle and sit with effortless posture during each task. The three tasks were given to each subject in random order.

A camera system that included three cameras (AQ-VU; TEAC Corporation, Tokyo, Japan) was used to record the sitting postures. One camera shot diagonally to the front of the seat to record the full view, and the others shot from the side to record the reclining angles and leg angles. Additionally, two pressure sensor sheets (BIG-MAT 2000; Nitta Corporation, Osaka, Japan) were applied to measure the pressure distribution on the seat and contact points on the seat and backrest. One was placed on the seat, and the other was placed on the backrest. Each pressure sensor sheet had 44 × 48 cells, and one cell was 10 × 10 mm. Pressure distribution was measured at a 1-Hz sampling frequency. Figure 2-2 shows the experimental set-up.

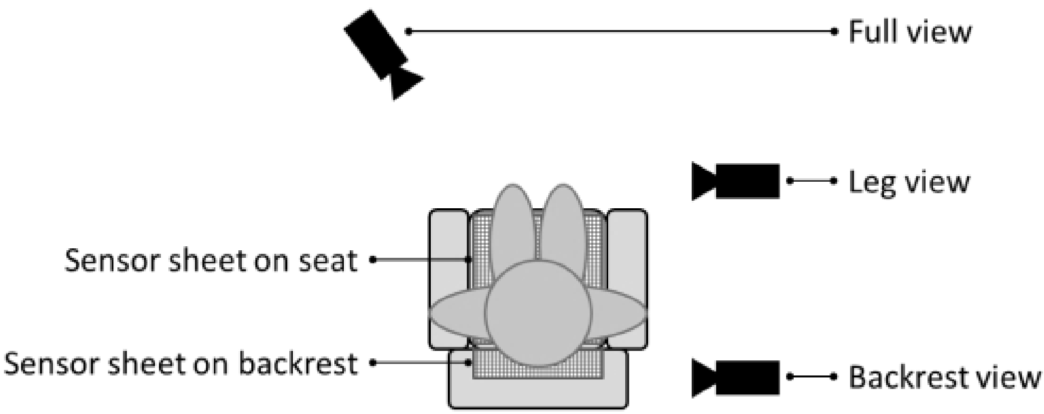


Figure 2-2. Experimental set-up

The study subject comprised nine male university students of standard size (as explained below) and aged, 22 ± 0.9 years. This experiment was conducted in a laboratory with a 25°C ambient temperature and 50% relative humidity.

Standard size was defined as height and depths within the average range ± the standard deviation defined by the AIST human size database [35]. Height is measured while standing or sitting, and depths are measured at the chest, abdomen, and buttock. These measurements were employed because the FEM models in this study were two-dimensional models of the median plane of the human body.

Table 2-1. Standard sizes according to AIST [35] [mm]

	Average	**Standard deviation**
Height	1714	63
Sitting height	926	34
Median chest depth	186	15
Abdominal depth	188	18
Buttock depth	230	17

2.3.3 Results and Discussion

We evaluated the recorded pictures and stress distribution 15 minutes after each task because we hypothesized that such a stable posture is the most natural posture for the subjects during each task.

Table 2-2 shows the results at a reclining angle. The subjects reclined the backrest to increase the rest level of the task. The resting angle exhibited a wider deviation than the other angles, and the backrest angle while resting was slightly distributed.

Table 2-2. Reclining angles

	Working	**Reading**	**Resting**
Average	103°	109°	119°
Standard deviation	4.5°	2.7°	6.9°

We observed the back contact points on the full-view video and the pressure distribution on the backrest. We identified the contact points on the backrest by evaluating the full-view video and determined whether the contact pressure appeared consistent with the pressure distribution. The overall results are as follows. Almost all subjects contacted the backrest with their low back in the working position. The contact points on the backrest were the low back and shoulder for the reading posture. Finally, the contact points were the low back, shoulder, and head for the resting posture. These results indicate that the contact points on the backrest were transferred upward as the rest level of the task increased.

Figure 2-2 shows the measurement points indicated by the pressure sensor sheet, and Table 2-3 shows the position of the ischial tuberosity on the seat. We hypothesized that the position of the ischial tuberosity falls on the coordinates of maximum pressure, and the average coordinates of the maximum pressure were calculated. The sitting position moved farther as the resting level of the task increased.

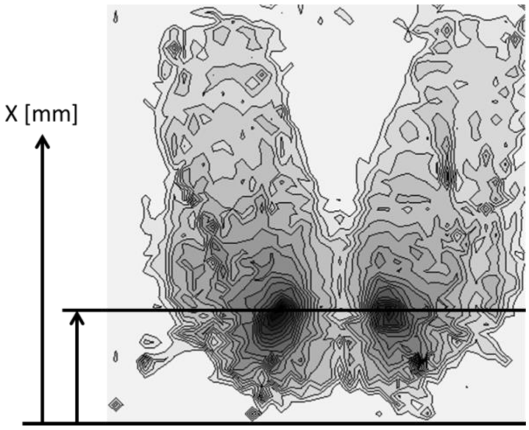


Figure 2-2. Measurement points of ischial tuberosity position

Table 2-3. Ischial tuberosity position

Unit [mm]	Working	Reading	Resting
Average	150	210	230
Standard deviation	35	36	55

Figure 2-3 shows the measurement points of the leg angle. The angle increased when the subjects extended their leg forward from perpendicularity. Figure 2-4 shows the results of the leg angle measurements. There were no clear differences among the three tasks, and we assumed that the leg angle while sitting was divided among the individuals.

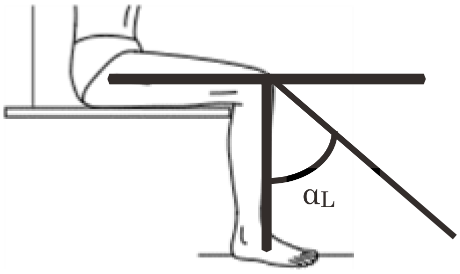


Figure 2-3. Measurement points of leg angle (α_L)

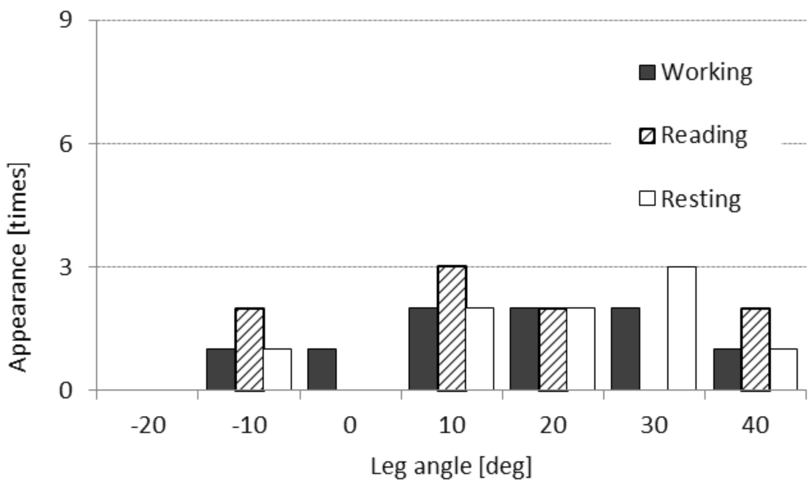


Figure 2-4. Leg angles

Based on these results, we categorized the three types of sitting postures as shown in Table 2-5. As the rest level increased, the subjects lay in the chair and the position of the ischial tuberosity moved forward. Because the leg angle exhibited a wide deviation, it was fixed at 10 degrees. These postures were used for both the FEM analysis in Section 2.4 and the sitting experiment in Section 2.5.

Table 2-4. Posture categorization

	Working	**Reading**	**Resting**
Reclining angle	100°	110°	120°
Position of ischial tuberosity	150 mm	210 mm	230 mm
Backrest contact	Low back	Low back - Shoulder	Low back - Shoulder - Head
Leg angle	10°	10°	10°
Task	Computer work	Reading a book	Resting

2.4 FEM analysis

2.4.1 Outline

Section 2.4 describes our estimation of internal stress by FEM analysis. We constructed FEM models using the three above-mentioned categorized postures and investigated their validity. The stresses around the intervertebral disks were then calculated, and we investigated the stress distribution in the human body.

2.4.2 Seat model

The seat model used in this study was modified based on a design drawing and a car seat model previously shown by Uenishi et al. [36]. The seat model comprised a cushion and frame (Figure 2-5), and the material properties of the seat are shown in Table 2-6. The backrest angle was adjusted to 100°, 110°, and 120° for each posture. The cushion and frame were plane elements (plane stress state, Plane 182 [37]); i.e., a two-dimensional (2D), four-node solid structure. Each seat model had the same number of nodes (n = 686) and elements (n = 864).

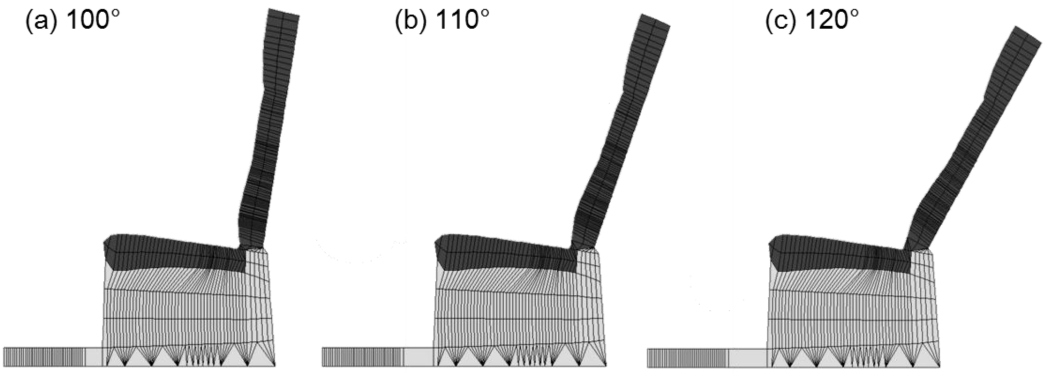


Figure 2-5. Seat FEM model

Table 2-6. Material properties of the seat model

	Young's modulus [MPa]	Poisson's ratio
Cushion	0.0056	0.01
Frame	150,000	0.30

2.4.3 Human model

We used 2D FEM human models because we believe that a 2D model is adequate for qualitative estimation of sitting comfort. We constructed three types of human FEM posture models. These models comprised four parts: bones, ligaments, intervertebral disks, and human soft tissues (Figure 2-6). The bone elements included the skull, spine, ribs, pelvis, and some leg bones. The ligaments included the anterior and posterior longitudinal ligaments. The soft tissues included muscles, skin, and viscera (Figure 2-7). The material properties are shown in Table 2-6 [36]. The density of each material was set at 1000 kg/m^3. The element type was a plane element (plane stress state, Plane 182 [37]); i.e., a 2D, four-node solid structure. The FEM models had a 220-mm thickness against the plane because an average adult male is about 62 kg. Each human model had the same number of nodes (n = 1090) and elements (n = 1127).

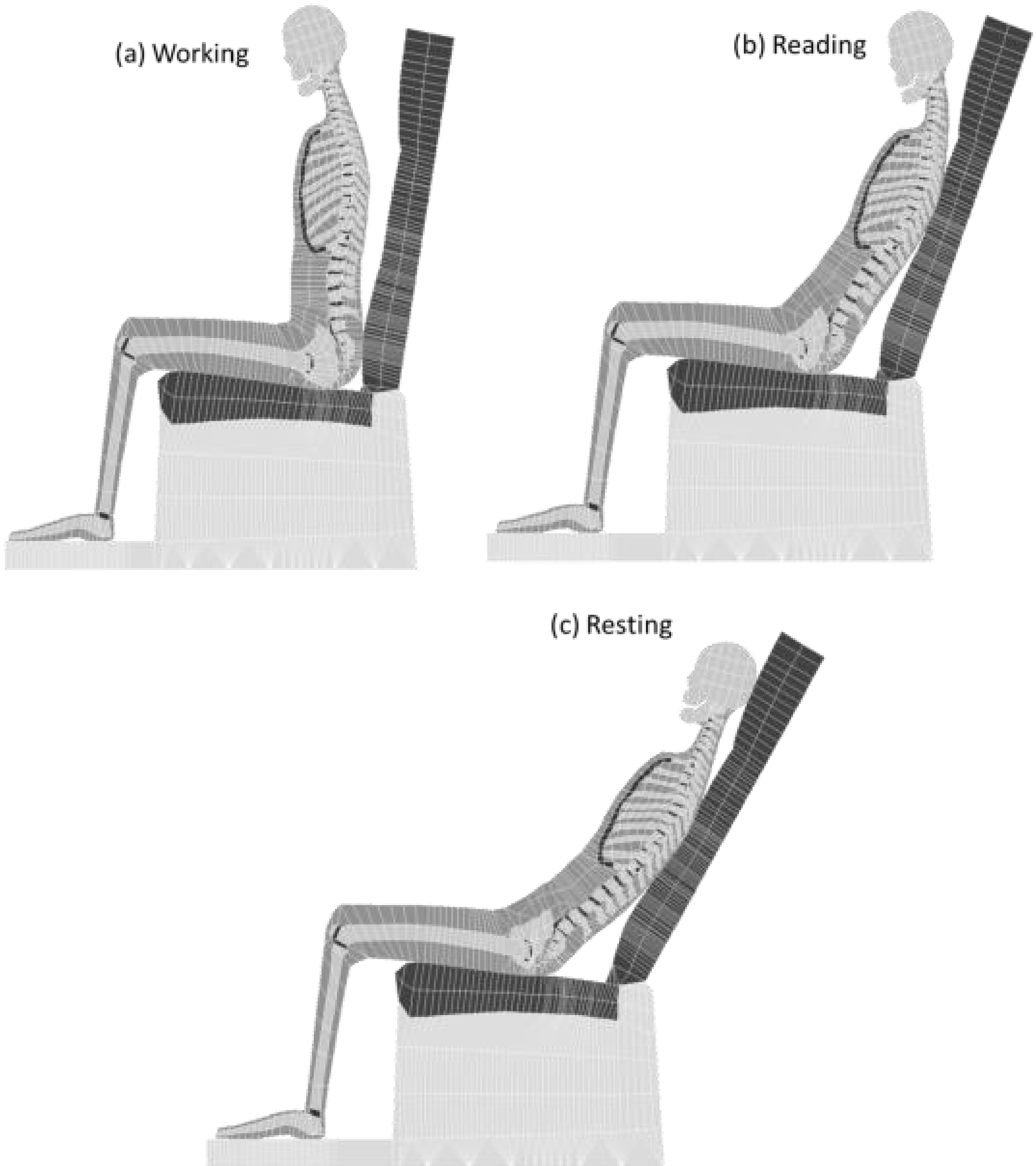


Figure 2-6. FEM model of each posture (a: Working, b: Reading, c: Resting)

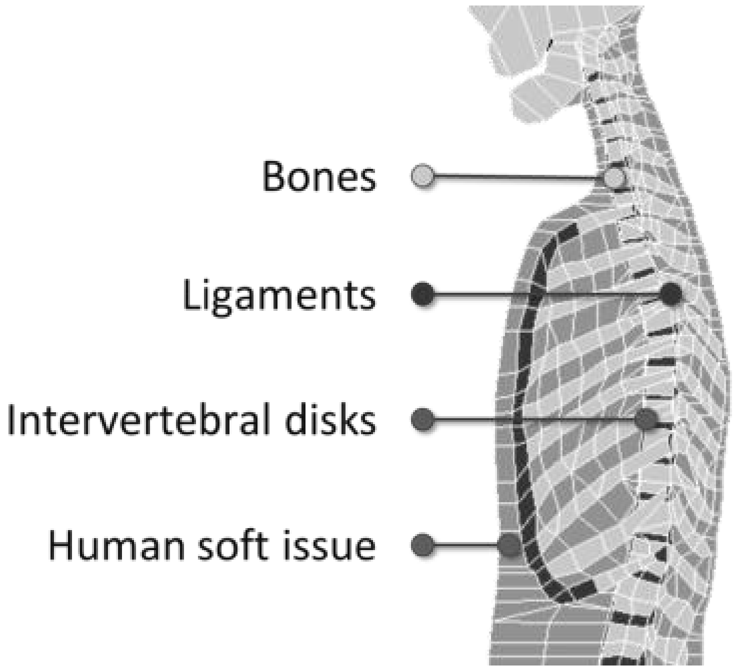


Figure 2-7. Detail of the human model

Table 2-6. Material properties of the human model [36]

	Young's modulus [MPa]	Poisson's ratio
Bone	10,000	0.30
Ligament	5.0	0.30
Intervertebral disks	1.0	0.49
Human soft issues	0.42	0.49

2.4.4 Contact conditions

The coefficient of friction between the human model and seat model was 0.284, which was measured on an actual train seat using a tribometer (Type 37N Portable Friction Meter Muse; Shinto Scientific Co., Ltd., Tokyo, Japan). Contact was defined by the 2D, two-node contact element (master side on human side: CONTA171 [37], slave side on seat side: TARGE 169 [38]).

2.4.5 Analysis conditions

As a boundary condition, all nodes on the bottom of the seat and outer side of the backrest were fixed. The sitting state was reproduced by application of gravity (9.8 m/s^2) to the human model.

All analyses in this study were performed using ANSYS ver. 12.1 (Mechanical APDL; ANSYS Japan K.K., Tokyo, Japan).

2.4.6 Validity of FEM analysis

2.4.6.1 Outline

FEM models with high validity are needed for accurate estimation of internal stress. We evaluated the validity of the FEM models by comparing the analyzed and measured sitting pressure values.

2.4.6.2 Methods

We compared the analyzed and measured sitting pressures to evaluate the validity of analysis for each posture. The analyzed value was obtained by FEM analysis on the seat, and the measured value was obtained using the pressure sensor sheet (BIG-MAT 2000; Nitta Corporation).

The sitting pressure by FEM analysis was determined as follows. A node shared between the seat cushion and backrest was set as the origin. We chose pressure values for each node on the seat surface from the origin to a distal node in the thigh region and thus obtained a pressure curve for each posture (Figure 2-8).

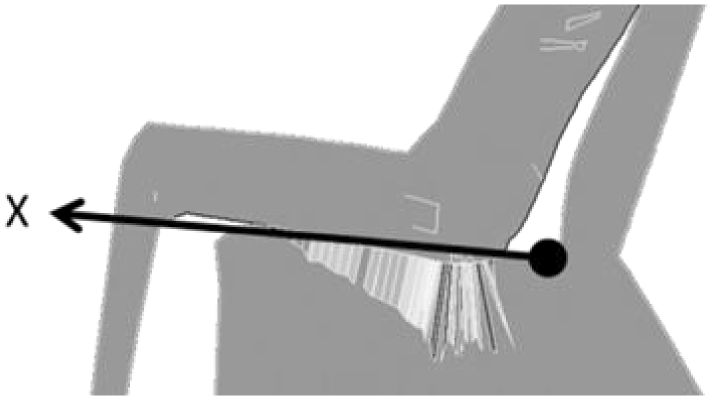


Figure 2-8. Sitting pressure: FEM analysis

The measured value was obtained using the pressure sensor sheet, which provided a 2D pressure distribution (Figure 2-9). We converted this into a one-dimensional pressure curve corresponding to the above-described analyzed value. First, we obtained the pressure distribution of each posture from the nine subjects and established the maximum pressure cell as the position of the ischial tuberosity. We then created a straight line extending through the maximum pressure point along the femur, and the end point on the backrest side on the line was set as the origin. We plotted a pressure curve and chose pressure values of each cell from the origin along this line.

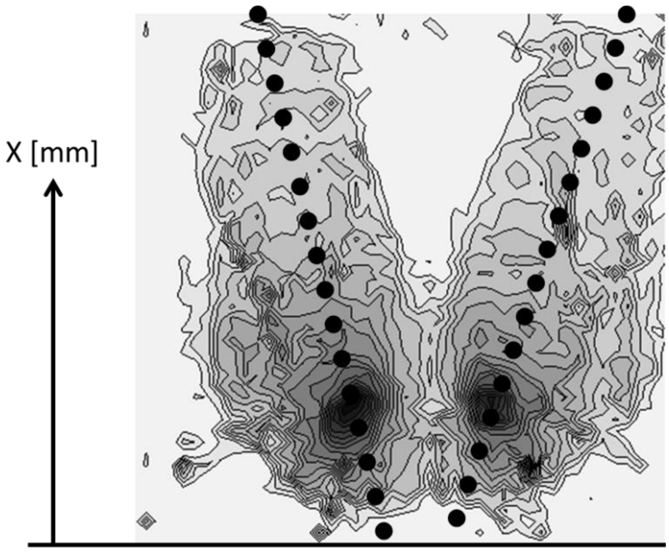


Figure 2-9. Sitting pressure: measured

2.4.6.3 Comparison between analysis and measurement

Figure 2-10 shows the results of the comparison between the analyzed and measured values obtained at each posture. The horizontal axis represents the distance from the back to the knee, and the vertical axis represents the sitting pressure. Based on the maximum pressure results, the peak position of the maximum value differed among the three postures, and the subjects sat back while in the working posture and moved the buttocks forward while in the resting posture. The maximum pressure was largest while in the working posture and smallest while in the resting posture. We considered that the subjects lay on the backrests while in the resting posture, increasing the contact area and decreasing the maximum pressure. This tendency was observed for both analysis and measurement. Moreover, the profiles of the pressure curve showed good agreement except for the region near the backrest (shaded area in Figure 2-10) in each posture. This occurred because of deformation of the sensor sheet while sitting. However, good consistency was observed in the maximum pressure and curve profiles; thus, we considered that the three FEM models had high validity for reproduction of the sitting posture.

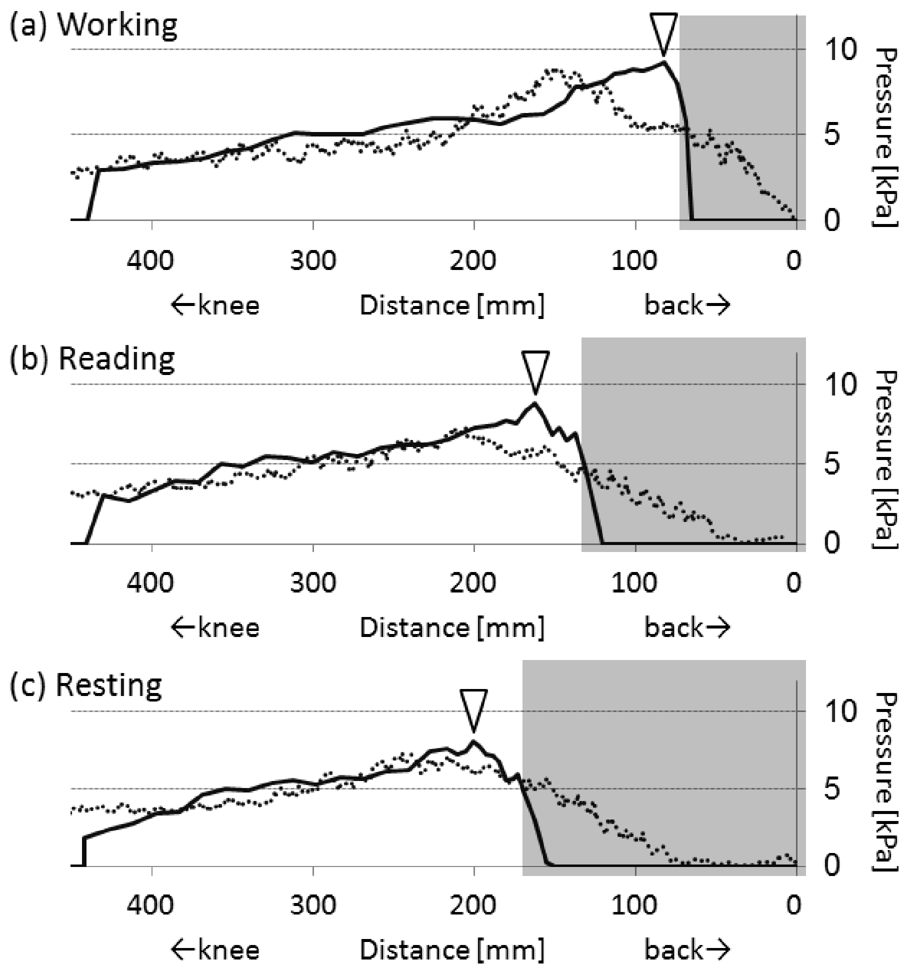


Figure 2-10. Comparison of analyzed and measured sitting pressure. Solid lines show the analyzed values, broken lines show measured values averaged over all subjects.

2.4.7 Results and Discussion

We focused on the von Mises stress around the intervertebral disks. The von Mises stress is the scalar quantity calculated as the square sum of all principal stresses and enables estimation of the degree of a stress load. Figure 2-11 shows the von Mises stress distribution in the upper body of each posture. The stress distribution differed among the three postures. The stress was concentrated around the waist region in the working posture and was dispersed in the resting posture.

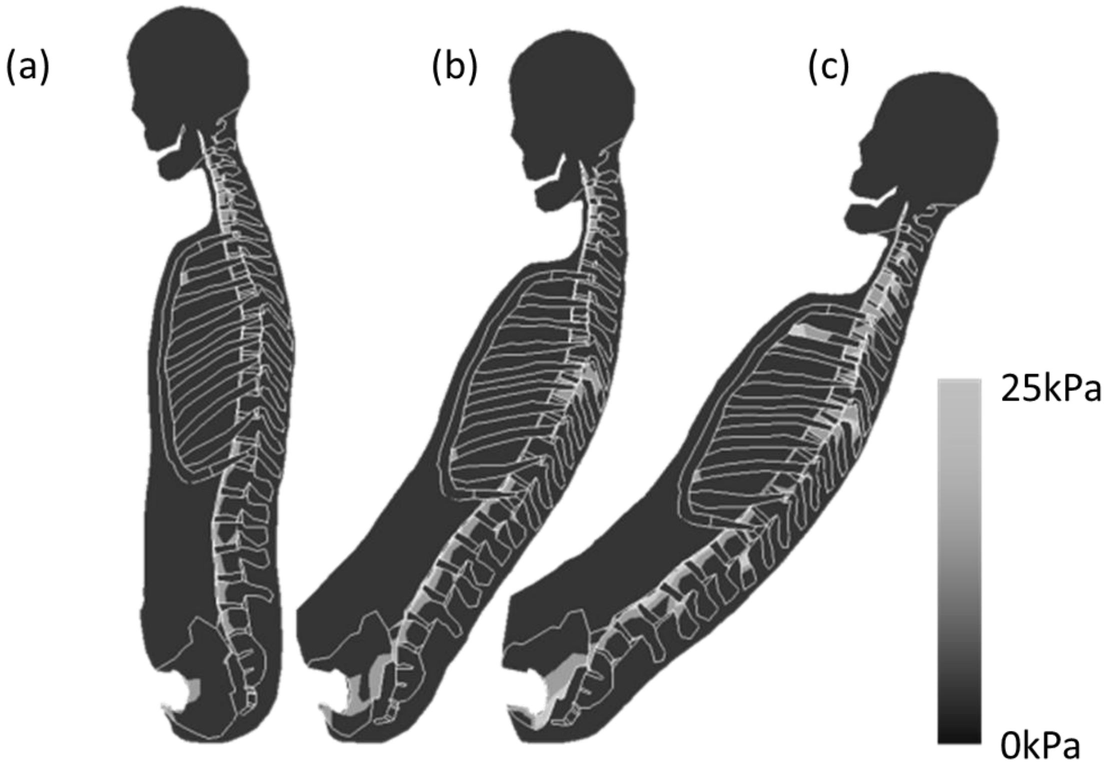


Figure 2-11. von Mises stress in each posture (a: Working, b: Reading, c: Resting)

Because the intervertebral disks of the FEM model comprised several nodes, the stress of one disk was calculated as the average of these nodes. Figure 2-12 and Equation 2-1 show how to calculate the average stress of one disk. There are 6 disks in the cervical region, 12 in the thoracic region, and 5 in the lumbar region (total of 23 disks). Figure 2-12 shows the stress around the intervertebral disks in each posture.

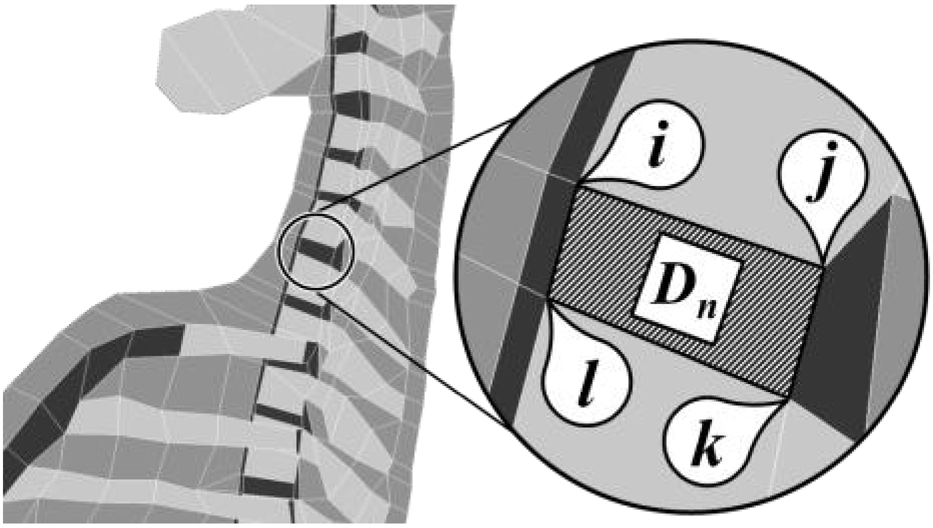


Figure 2-12. Nodes comprising the element of one intervertebral disk

$$\sigma_{D_n} = \left(\sigma_i + \sigma_j + \sigma_k + \sigma_l\right)/4 \qquad (2\text{-}1)$$

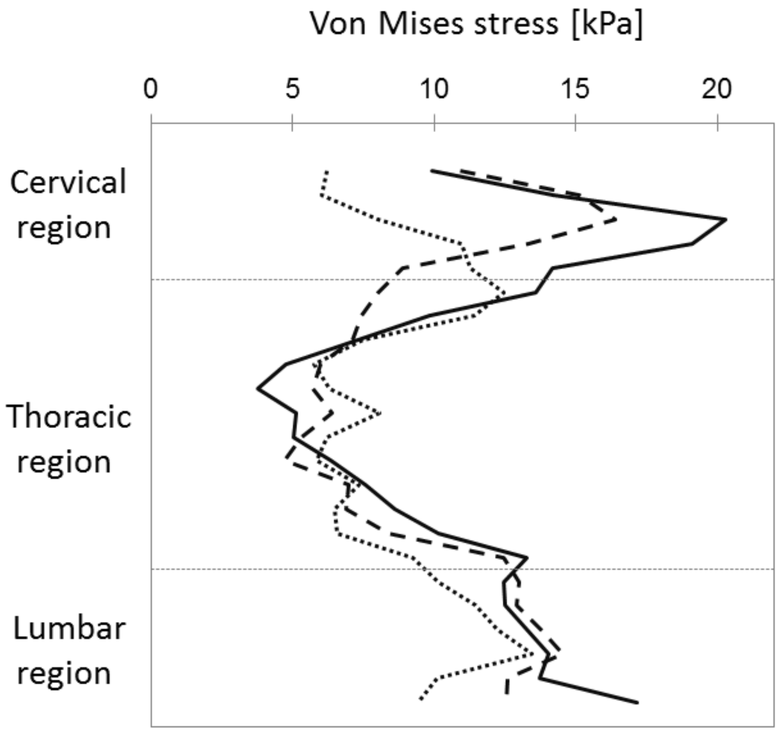


Figure 2-12. Stress around the intervertebral disks for different sitting postures. Solid line shows 'Working' posture, dashed line shows 'Reading' posture, dotted line shows 'Resting' posture.

High degrees of stress appeared around the cervical and lumbar regions, and low degrees of stress appeared around the thoracic region. According to Ohara et al. [38], the human body generally comprises two major regions while sitting: one is the block region including the head, chest, and pelvis, and the other is the joint region of the neck and waist. In the present study, slight deformation occurred around the thoracic region because this region is the "block" region that includes some ribs, resulting in low stress. Around the cervical region, the degree of stress was smaller in the resting posture than in the other postures; this is because the head lay on the headrest only while in the resting posture. The stress around the lumbar region differed among the three postures. The highest degree of stress was observed in the working posture, and the lowest degree of stress was observed in the resting posture. This low stress around the lumbar region while lying on the backrest is in agreement with the findings in a study by Antonius et al. [13, 14]. We assume that the stress around the intervertebral disks decreased because the body weight was dispersed while lying on the backrest with a large contact area in the resting posture.

2.5 Sensory test

2.5.1 Outline

We conducted a sitting experiment to compare the results of the FEM analysis with those of the sensory test. This comparison enabled clarification of the meaning of internal stress and confirmation of the efficiency of FEM as a simulator of sitting comfort.

2.5.2 Methods

We used an actual train seat (Figure 2-1) to perform a sensory test. The subjects sat on the seat for 30 minutes in each posture (Table 2-5), which was assigned in random order. The subjects were not reseated. The sitting impression was evaluated twice: just after sitting and 30 minutes later. Pain at the neck, shoulder, dorsum, lumbar region, and buttock were evaluated using a seven-grade scale. The experiment was conducted in a laboratory with the ambient temperature set at 25°C and relative humidity of 50%, and all subjects wore the same clothes. We recruited eight male university students aged 22 ± 1.5 years.

2.5.3 Results and Discussion

Figure 2-13 shows the average score increase calculated by subtracting the score just after sitting from the score 30 minutes later to investigate the increase in pain caused by sitting. We performed one-way ANOVA with differences in posture for each term, but there were no main effects. Therefore, we evaluated tendencies.

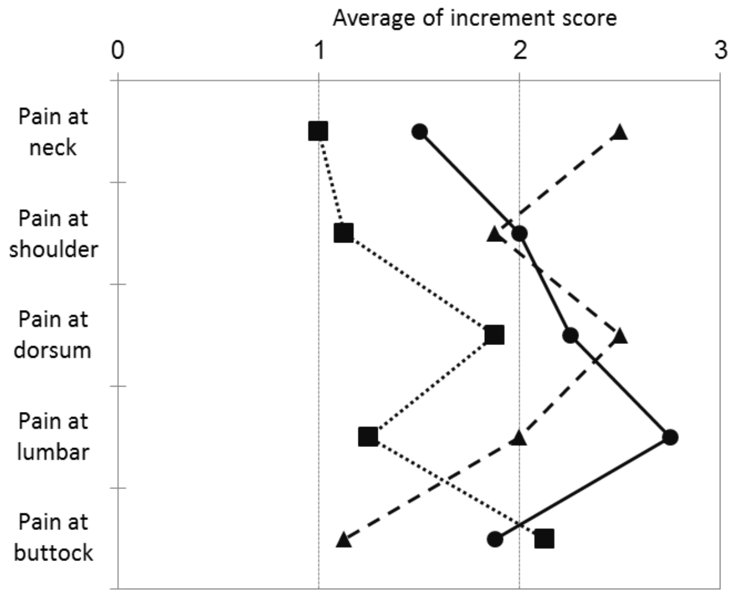


Figure 2-13. Results of sensory test. Circles show results for the 'Working' posture, triangles for the 'Reading' posture, and squares for the 'Resting' posture.

We focused on the differences in the scores for each posture. The overall score was lower in the resting posture because the subjects were relaxed and inhibited from feeling fatigued. However, the working posture was associated with a much greater increase in lumbar pain because the only contact point on the backrest was the lumbar region.

We also evaluated the pain scores for each region. Pain in the neck region was high in the reading posture because the subjects inclined their head forward to read a book. Around the dorsum, there was little difference among the three postures because the thoracic region is hypothesized to represent a block according to Ohara et al. [38], and a smaller deformation of the thoracic region likely causes only a slight difference in pain, as also shown in the FEM analysis. Around the lumbar region, there were differences among the three postures; the pain scores in the resting posture were smallest because the load on the lumbar region was inhibited while lying on the backrest. Around the buttock, the increase in pain was largest while in the resting posture. Matsuoka et al. [19] described slipping of the buttock while sitting, and we consider that the subjects felt pain around the buttock secondary to such slipping because the position of the ischial tuberosity shifts forward while in the resting posture.

2.6 Comparison between analysis and sensory test

We focused on the lumbar region because this region exhibited wide differences among the three postures. Figure 2-14 compares the stresses on the lumbar intervertebral disks and increases in the pain scores in the lumbar region among the three postures.

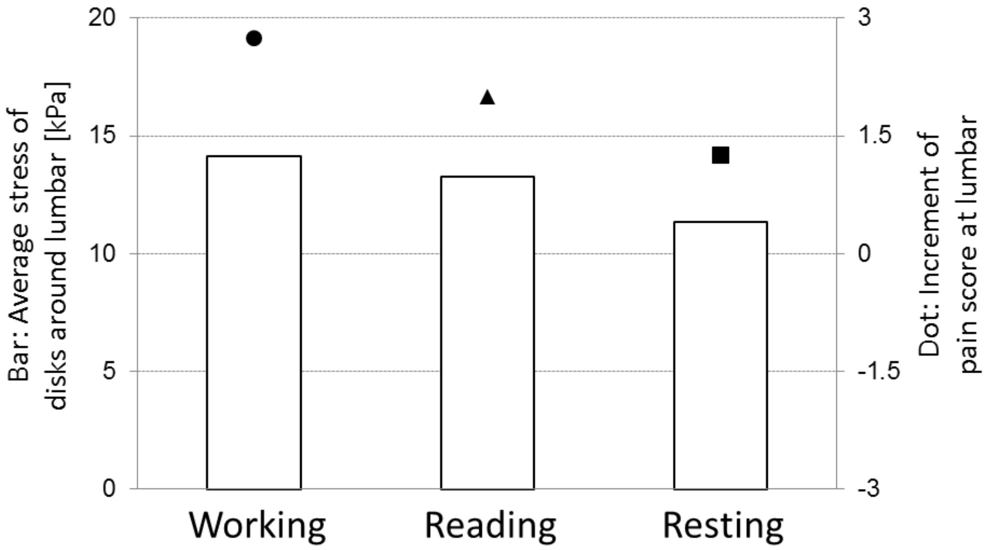


Figure 2-14. Comparison of stress and pain scores in the lumbar region among the three postures

The results of the FEM analysis corresponded with those of the sensory test; that is, there was a correlation between them. These results indicate that the FEM may be used as a simulator of sitting comfort and particularly as an estimator of lumbar pain.

However, less pain and fatigue are felt in the lumbar region when sitting or standing upright. Ohara et al. [39] investigated the pressure on the intervertebral disks and obtained pressures of 2.1 kg/cm^3 while standing and 2.3 kg/cm^3 while sitting. Therefore, the load on the disks was lower while standing than while sitting, and they considered that standing was more comfortable than sitting because of a lower stress load. According to Andersson et al. [40, 41], lower stress was found while sitting erect than while bending the body. However, in the present study, although the working posture corresponded with sitting erect, the pain scores were largest; these results differ from those of the above-mentioned studies. Therefore, because it is hypothesized that an unbalanced condition such as bending the body or rolling in a chair is the main factor contributing to pain, we investigated the stress distribution in detail. Figure 2-16 shows the differences in stress around the intervertebral disks in which the stress of the nodes on the front was subtracted from that on the dorsum. The horizontal axis indicates the difference in the von Mises stress on each intervertebral disk.

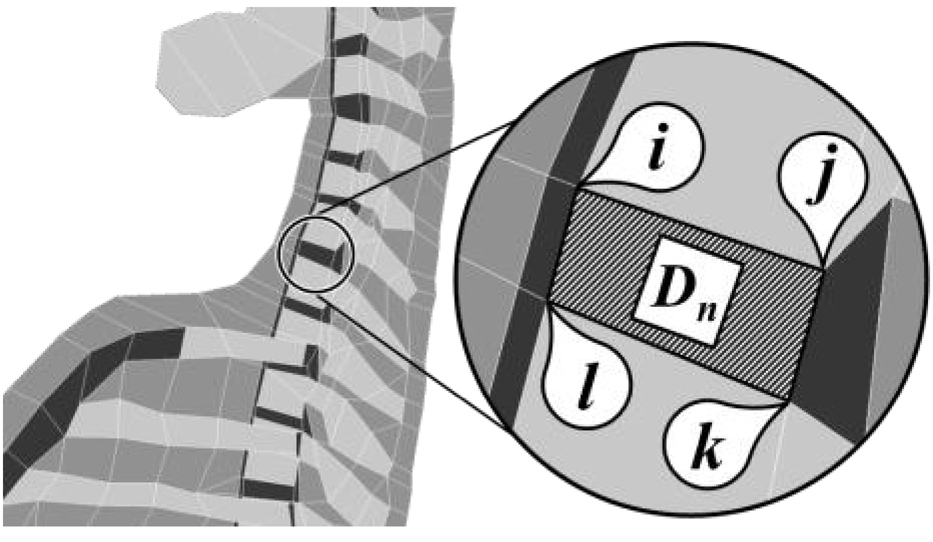


Figure 2-15. Nodes comprising the element of one intervertebral disk

$$\text{Difference in stress}_{D_n} = (\sigma_j + \sigma_k)/2 - (\sigma_i + \sigma_l)/2 \quad (2\text{-}2)$$

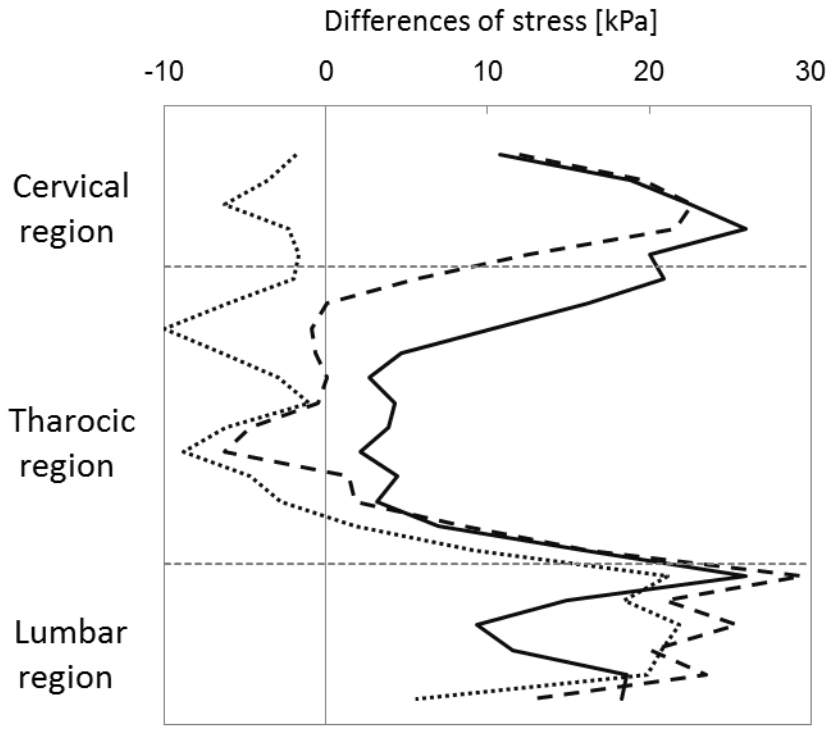


Figure 2-16. Differences in stress around intervertebral disks. Solid lines represent ‘Working’ posture, dashed lines represent ‘Reading’ posture and dotted lines represent ‘Resting’ posture.

Antonius et al. [13, 14] considered that both an increase in stress around the intervertebral disks and a deviation of stress influenced the uncomfortable feeling felt during long-term sitting. Figure 2-16 shows the balance between the abdominal and dorsal stress around a disk; this was hypothesized as a deviation of stress in the present study. There was little difference in the stress around the lumbar region in the working posture, likely because the stress load is uniform on the disks in the lumbar region while in this posture. In contrast, large differences in the stress around the lumbar region were noted in the reading and resting postures. Therefore, there was a difference in the deviation of stress among the three postures, and we assume that this difference explains the lack of pain or fatigue in the lumbar region while sitting upright, as shown in previous studies. Moreover, we consider that the summation of stress has an influence during 30 minutes of sitting, but that deviation of stress influences long-term sitting.

2.7 Conclusion

In this chapter, we categorized common sitting postures on a train seat into three postures (working, reading, and resting), calculated internal stress by FEM, and conducted a sitting experiment based on the posture categorization. Through comparison of internal stress and subjective evaluation, we conclude the following.

1) The working, reading, and resting postures are influenced by the level of resting associated with each posture.
2) The human-seat FEM model for each posture had high validity for reproduction of the sitting posture.
3) Comparison of internal stress and subjective evaluation indicates that a large degree of stress in the lumbar region causes lumbar pain during 30 minutes of sitting and that the stress distribution is important for long-term sitting.

In addition to previous psychological and physiological measurements, internal deformation of stress is valuable information. FEM analysis can be applied to seat design and can approximately estimate sitting comfort by computer simulation before fabrication of the seat prototype.

Chapter 3
Visual influence of seat color on sitting comfort

3.1 Introduction

As mentioned in Section 1.1.3, the characteristics of train seats are presumed to include not only somatic factors but also visual factors. Indeed, we feel different impressions according to seat color.

It is well known that colors influence the psychological responses of subjects [21,22]. Nishimatsu et al. [23] reported that impression or usability can change as visual information changes. Therefore, we hypothesized that seat color influences sitting comfort; that is, that visual sensation may affect the somatic sensation of sitting comfort. Few studies have examined the influence of visual information on somatic sensation [23, 24]. Therefore, we focused on the visual influence of the color of train seats on sitting comfort. Information on whether seat colors affect sitting comfort would be helpful in effective and economical seat design.

3.2 Purpose

In this chapter, we examine the relationship between the color of a train seat and sitting comfort to investigate the visual influence of seat color on sitting comfort.

Three experiments were performed. In the first, we prepared images of seat colors. In the second, we performed sensory tests on a personal computer (PC) display. In the third, we performed a sitting experiment to examine the visual influence of seat color on sitting comfort using of various seat colors on actual train seats. Because it is hypothesized that differences in hues have a great influence on perception, we used three hues that are frequently used for train seats (red, green, and blue).

3.3 Preparation of train images for seat covers

3.3.1 Outline

Because it is difficult to study many different colors, we fabricated seat colors for the sitting experiment. We performed a color-making experiment and then selected the colors for the study

3.3.2 Methods

We examined the relationship between image words and seat colors to investigate which seat colors the subjects desire or prefer. Some image words were extracted from printed books or websites that are generally associated with trains; thus, graphic images of a seat color were created with PC software. The image word "relaxed" is considered to be a significant term for determining the comfort of train seats (http://n700.jp/) [42]. The image words "high-class feeling" or "feeling of luxury" are also significant terms. Addition of the term "I want to use" allowed the subjects to directly express the seat color that they desired. Therefore, we selected the three image words "relaxed," "high-class feeling," and "I want to use."

We obtained the graphical image of a first-class (green-car) seat of the Shinkansen N700 series high-speed train from the train's web page (http://n700.jp/know/08.html) [42] (Figure 3-1). The original image had R:140, G:108, and B:87 as RGB values and x:0.441 and y:0.400 as the CIE color system values measured by a spectroradiometer (SR-3AR; Topcon Technohouse Corp., Tokyo, Japan) on a PC display (Diamondcrysta RDT223WM; Mitsubishi, Tokyo, Japan).

Figure 3-1. Original image of first-class seat on Shinkansen N700 series bullet train

A masking effect was applied to this original image using Adobe Photoshop Elements ver. 6 (Adobe Systems Inc., San Jose, CA, USA), and only the color of the seat region was altered. All other parts of the image remained in their original color. The color generally comprised three components: hue, saturation, and brightness. Four hues (red, green, blue, and brown) were prepared in this study because brown is a basic color of train seats and the others are three primary colors. Each hue value for the original image on the software was set as follows: red, −30; green, 95; blue, −150; and brown, 0. The subjects adjusted both the saturation and brightness on a PC by dragging the “slider” of the software (Adobe Photoshop

Elements ver. 6) as long as the seat color matched the impression of the three above-mentioned image words (Figure 3-2). The experiment was conducted in a laboratory with daylight fluorescent lamps.

We performed this experiment twice. The first experiment included 12 university students (6 male, 6 female; age range, 21–23 years), and 144 graphical images were finally produced to cover 12 subjects × 3 image words × 4 hues and thus fabricate red seat covers. The second experiment included 16 university students (8 male, 8 female; age range, 21–23 years), and 96 graphical images were finally produced to cover 16 people × 3 image words × 2 hues and thus manufacture green and blue seat covers.

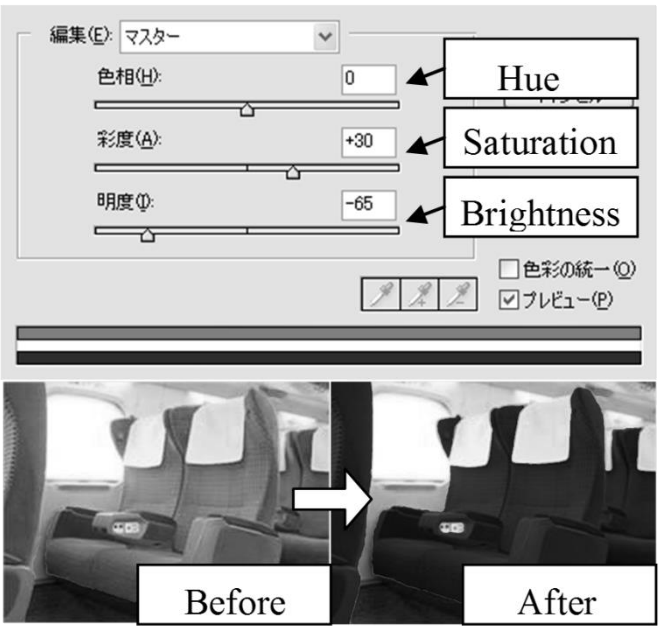


Figure 3-2. Adjustment of sliders to create seat color

3.3.3 Results and Discussion

3.3.3.1 Results of color-making experiment for red colors

Figure 3-3 (a–d) shows the results of the first experiment involving 12 subjects. The horizontal axis indicates the saturation value, and the vertical axis indicates the brightness value of the software. Because almost all colors had low brightness and widely varying saturation, the brightness more strongly affected the impression of the seat than did the saturation, and it was assumed that the subjects preferred dark colors.

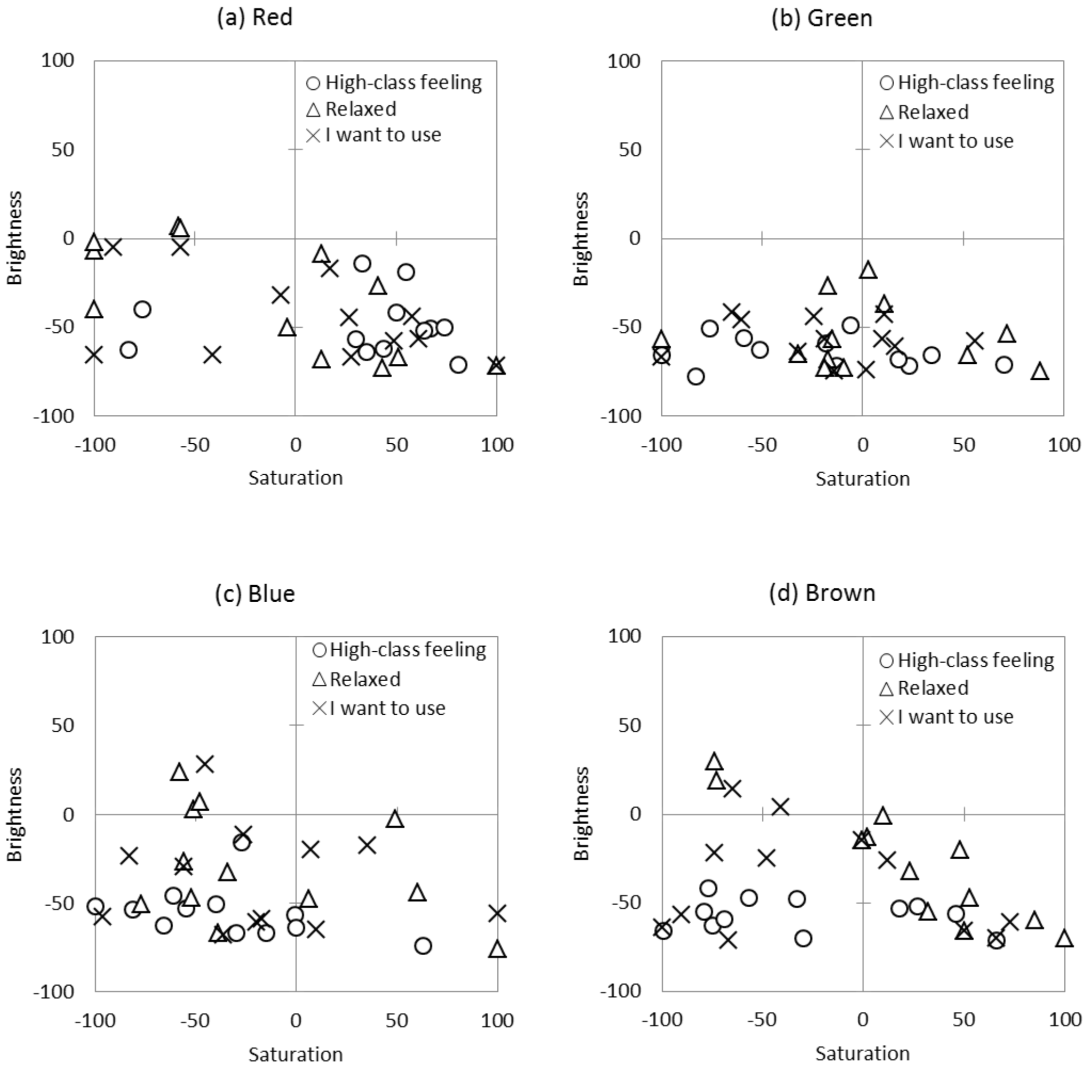


Figure 3-3. Results of color-making experiment (a: Red, b: Green, c: Blue, d: Brown)

Because it was difficult for the subjects to evaluate their impressions of all 144 images, we attempted to decrease the number of images. We selected three images for each image word under the condition that we chose a graphical file with a median color intensity value if the brightness and saturation values were nearly identical; we also chose images that exhibited distinct differences in brightness and saturation. Therefore, we obtained 9 images for each hue for a total of 36 images, as shown in Table 3-1.

Table 3-1. Saturation and brightness of selected images

(A-I: Red, J-R: Green, S-AA: Blue, BB-JJ: Brown)

Red	A	B	C	D	E	F	G	H	I
Saturation	81	67	55	−58	−100	43	−100	−41	17
Brightness	−71	−51	−19	7	−7	−73	−66	−66	−17
Green	J	K	L	M	N	O	P	Q	R
Saturation	−51	70	−13	−100	−17	72	−60	56	−19
Brightness	−63	−71	−72	−57	−27	−54	−46	−58	−57
Blue	S	T	U	V	W	X	Y	Z	AA
Saturation	63	0	−27	−58	60	6	35	−36	−56
Brightness	−74	−64	−16	24	−44	−48	−18	−68	−30
Brown	BB	CC	DD	EE	FF	GG	HH	II	JJ
Saturation	−30	66	18	−74	10	53	−48	12	−41
Brightness	−70	−71	−53	30	−1	−47	−25	−26	4

3.3.3.2 Results of color-making experiment for green and blue colors

Figure 3-4 shows the results of the second experiment involving 16 subjects. The results were the consistent with those described in Section 3.3.3.1; namely, that almost all colors had low brightness and widely varying saturation. We thus assumed that the subjects preferred dark colors even with different hues.

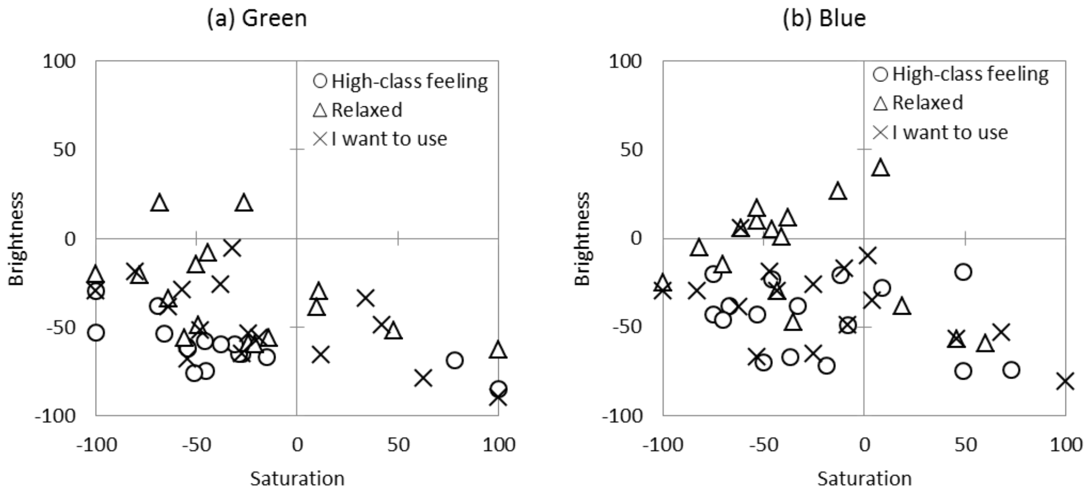


Figure 3-4. Results of color-making experiment (a: Green, b: Blue)

Because it was difficult for the subjects to evaluate their impressions of all 96 images, we attempted to decrease the number of images. We selected some images for each image word under the conditions that the graphical file that had median color intensity value if the brightness and saturation values were nearly identical; we also chose images that exhibited distinct differences in brightness and saturation. Therefore, we obtained eight green and nine blue images, as shown in Table 3-2.

Table 3-2. Saturation and brightness of obtained images

(G1-G8: Green, B1-B9: Blue)

Green	G1	G2	G3	G4	G5	G6	G7	G8	
Saturation	−54	−31	34	−49	−57	−50	−26	−68	
Brightness	−68	−60	−34	−49	−29	−15	20	20	
Blue	B1	B2	B3	B4	B5	B6	B7	B8	B9
Saturation	49	−19	46	19	4	−10	−41	−61	−13
Brightness	−19	−72	−57	−38	−35	−17	1	6	27

3.4 Evaluation of seat colors on PC display

3.4.1 Outline

Next, we chose colors for use in the sitting experiment described in Section 3.5. The colors fabricated in Section 3.3 were evaluated and selected based on the results of a sensory test performed on a PC display.

3.4.2 Methods

The subjects evaluated each individual image displayed on a monitor (Mitsubishi RDT223WM) using the semantic differential (SD) method. The images were presented to each subject in random order. Nine evaluation terms ("Bad fitting–Good fitting," "Bad touch feeling–Good touch feeling," "Not relaxed–Relaxed," "Cold–Warm," "No high-class feeling–High-class feeling," "Hard to sit–Easy to sit," "Somber–Garish," "Hard–Soft," and "I don't want to use–I want to use") were evaluated on a seven-grade scale. The experiment was conducted in a laboratory with daylight fluorescent lamps.

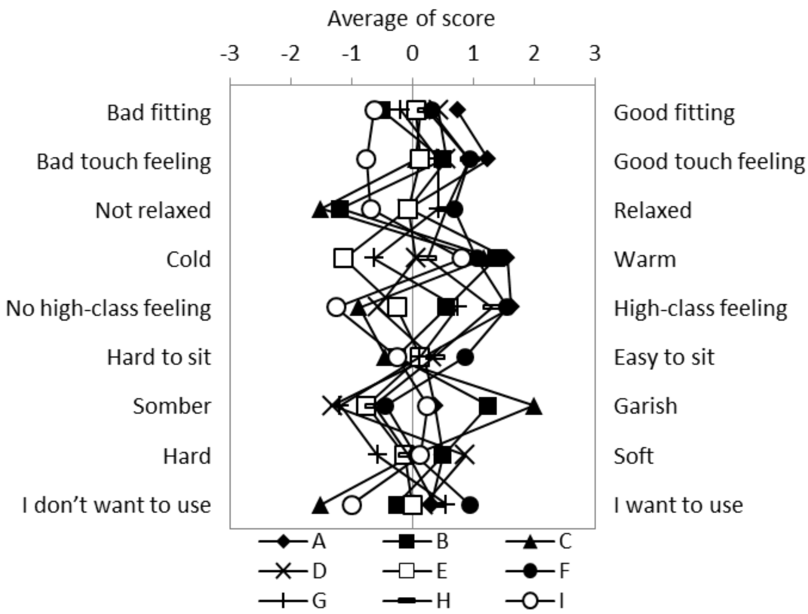
We performed this experiment twice. In the first experiment, 16 university students (8 male, 8 female; age range, 21–23 years) evaluated the 36 colors shown in Table 3-1 to fabricate red seat covers. In the second experiment, 16 university students (8 male, 8 female; age range, 21–23 years) evaluated the 17 colors shown in Table 3-2 to fabricate green and blue seat covers.

3.4.3 Results of first experiment for fabrication of red covers

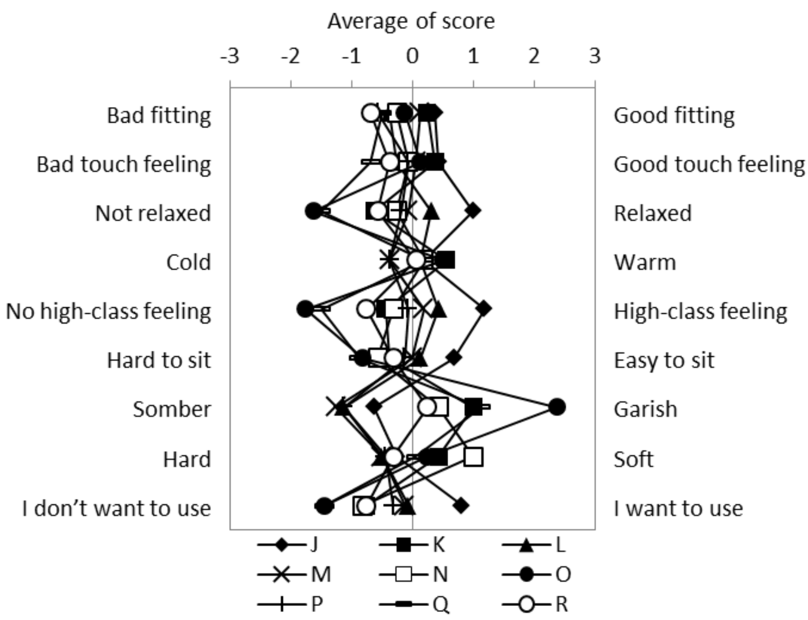
3.4.3.1 SD profile

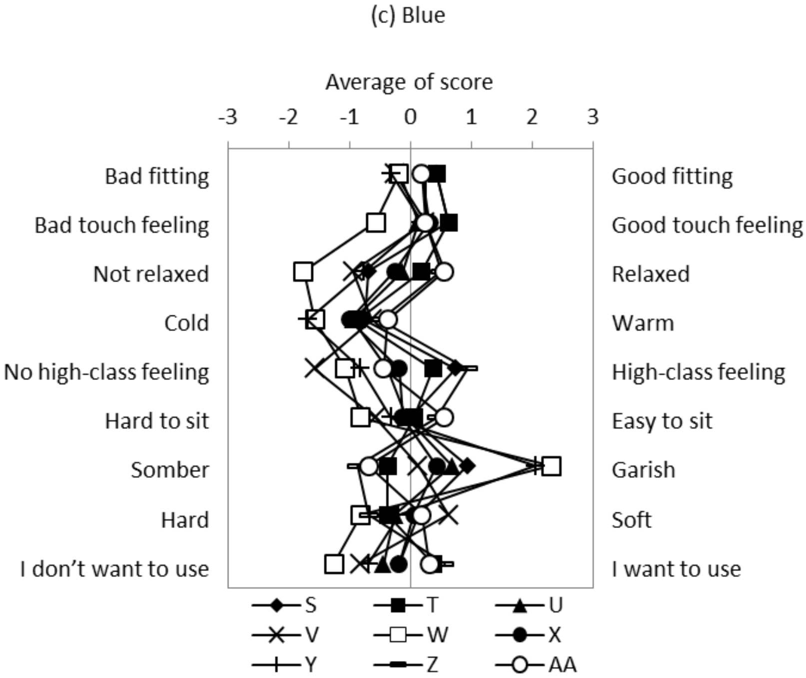
Figure 3-5 (a–d) shows the SD profiles of the first experiment for fabrication of red covers. The horizontal axis indicates the average scores of each evaluation term. There were significant differences among the colors for each hue, and we considered that the subjective evaluation was influenced by these differences in colors. There was a tendency toward an overall preference for colors evaluated as somber for each hue. For instance, F for red, J for green, and Z for blue were especially preferred (Figure 3-5), and they also had low brightness (Table 3-1). Therefore, we considered that dark colors were both evaluated as somber and preferred. This tendency corresponds the results of Section 3.3.3.1, namely that dark colors were preferred.

(a) Red


Average of score
-3
-2
-1
0
1
2
3
Bad fitting
Bad touch feeling
Not relaxed
Cold
No high-class feeling
Hard to sit
Somber
Hard
I don’t want to use
Good fitting
Good touch feeling
Relaxed
Warm
High-class feeling
Easy to sit
Garish
Soft
I want to use
A
B
C
D
E
F
G
H
I

(b) Green


Average of score
-3
-2
-1
0
1
2
3
Bad fitting
Bad touch feeling
Not relaxed
Cold
No high-class feeling
Hard to sit
Somber
Hard
I don’t want to use
Good fitting
Good touch feeling
Relaxed
Warm
High-class feeling
Easy to sit
Garish
Soft
I want to use
J
K
L
M
N
O
P
Q
R



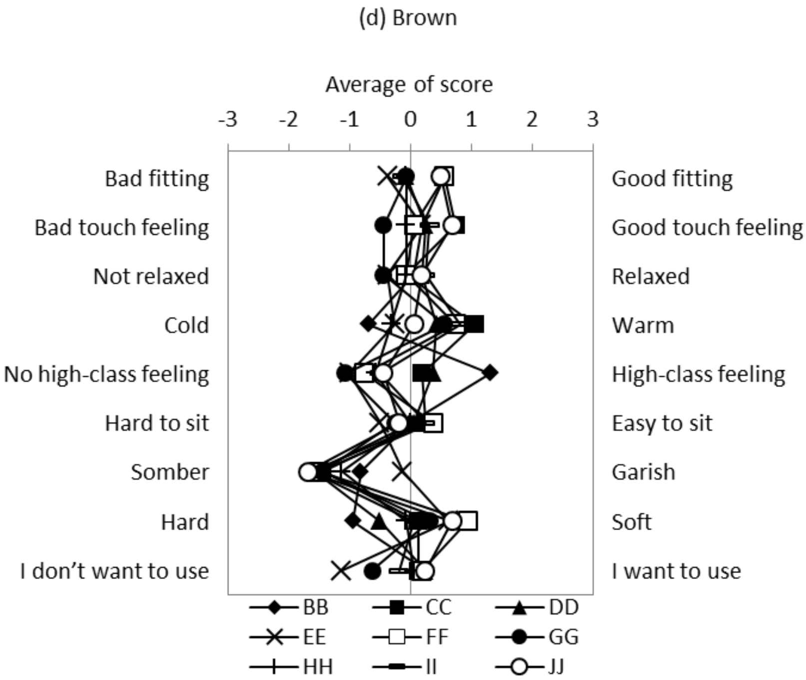


Figure 3-5. SD profile of sensory test on PC display in first experiment

(a: Red, B: Green, c: Blue, d: Brown)

3.4.3.2 Factor analysis

We performed factor analysis (principal factor method, varimax rotation, n = 3 factors) using the SD scores of each seat image to clarify the image structure for the seat colors (Table 3-3). The cumulative contribution ratio was 82.8%. The first factor was "Relaxation" because the factor loadings of "Relaxed–Not relaxed," "I want to use–I do not want to use," and "Easy to sit–Hard to sit" were especially large. The second factor was "High quality" because the factor loadings of "High-class feeling–No high-class feeling" and "Good touch feeling–Bad touch feeling" were large. The third factor was considered to be "Tactile feeling" because the factor loading of "Soft–Hard" was large.

Table 3-3. Results of factor analysis

	Factor 1	Factor 2	Factor 3
Fitting	0.249	0.641	0.189
Touch feeling	0.137	0.891	0.276
Relaxed	0.875	0.389	−0.064
Warm	0.051	0.127	0.436
High-class feeling	0.390	0.754	−0.215
Easy to sit	0.734	0.548	0.000
Garish	−0.855	−0.058	−0.087
Soft	−0.102	−0.058	0.987
I want to use	0.748	0.633	−0.084

Figure 3-6 plots the factor scores of each image on a diagram. The horizontal axis represents the first factor, "Relaxation," and the vertical axis represents the second factor, “High quality.” The tagged alphabetical letters beside the points are the image numbers (Table 3-1).

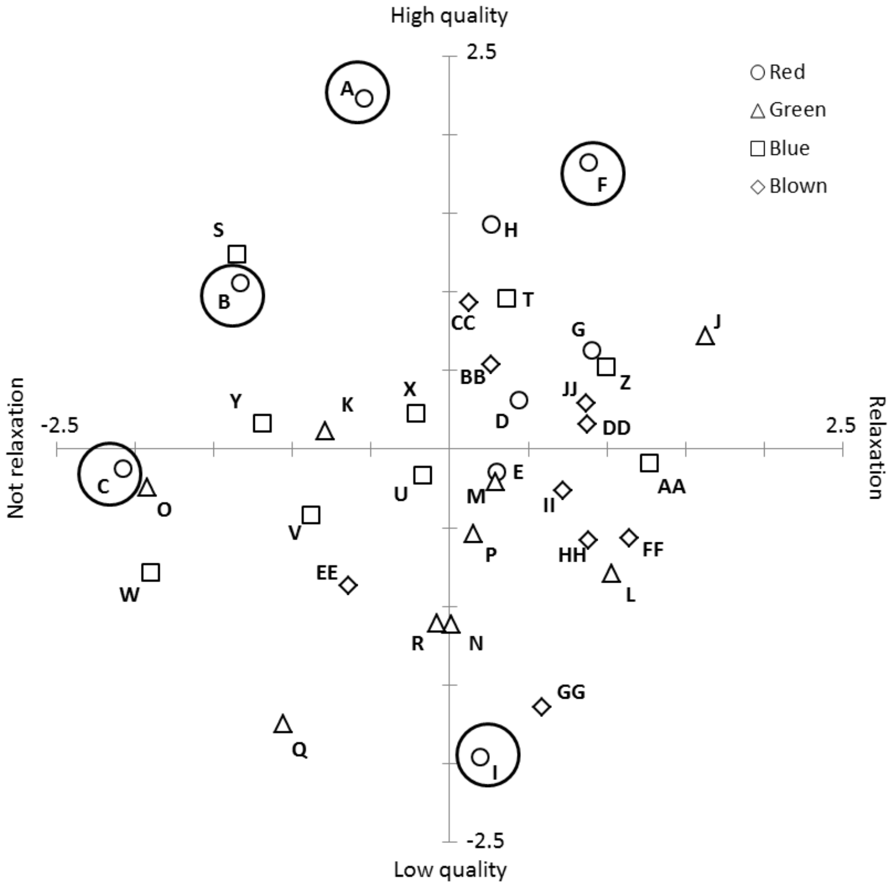


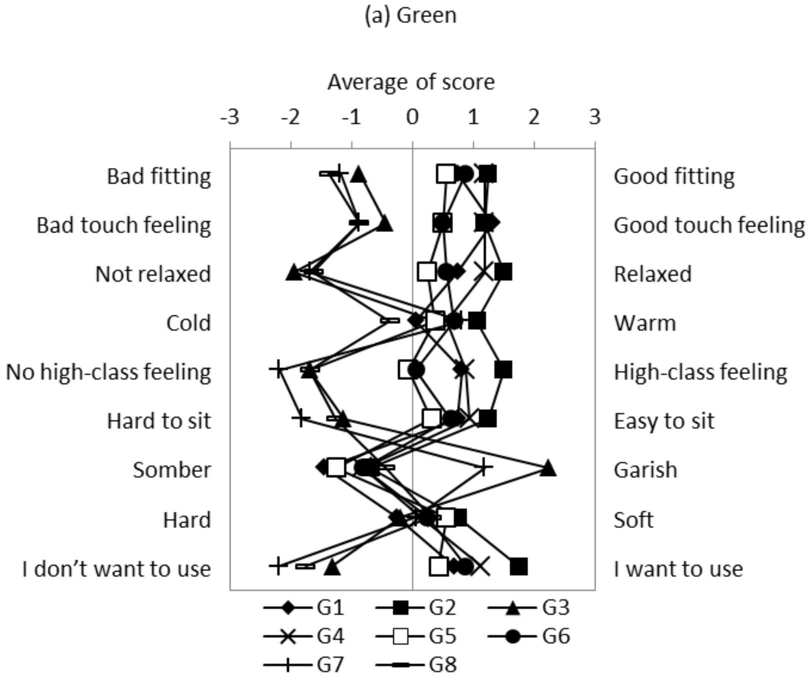
Figure 3-6. Results of factor analysis

Based on these results, half of the red images were plotted in the area of slight “Relaxation” and “High quality,” and the others were plotted in the area of largest “High quality,” lowest “High quality,” and worst “Relaxation”; that is, the evaluation of the red seat color exhibited wide variation. Five red colors (A, B, C, F, and I) were selected to fabricate the red seat covers because these five colors had characteristics distinct from the other colors and were scattered in each quadrant. A and F were evaluated as good and had low brightness (Table 3-1). C and I were evaluated as bad; their brightness was not lower than that of the others, and their saturation was higher than that of the others (Table 3-1).

3.4.4 Results of second experiment for fabrication of green and blue covers

3.4.4.1 SD profile

Figure 3-7 (a, b) shows the SD profiles of the second experiment for fabrication of green and blue covers. The horizontal axis represents the average scores of the evaluation terms. Significant differences were observed among the colors, and we considered that the subjective evaluation was influenced by the differences in colors, as described in Section 3.3.3.2. A tendency toward a preference for somber colors was also observed. For instance, G2 for green and B2 for blue were especially preferred (Figure 3-7), and they also had low brightness (Table 3-2). Therefore, we considered that dark colors were both evaluated as somber and preferred. This tendency corresponds the results of Section 3.3.3.2; namely, that dark colors were preferred.



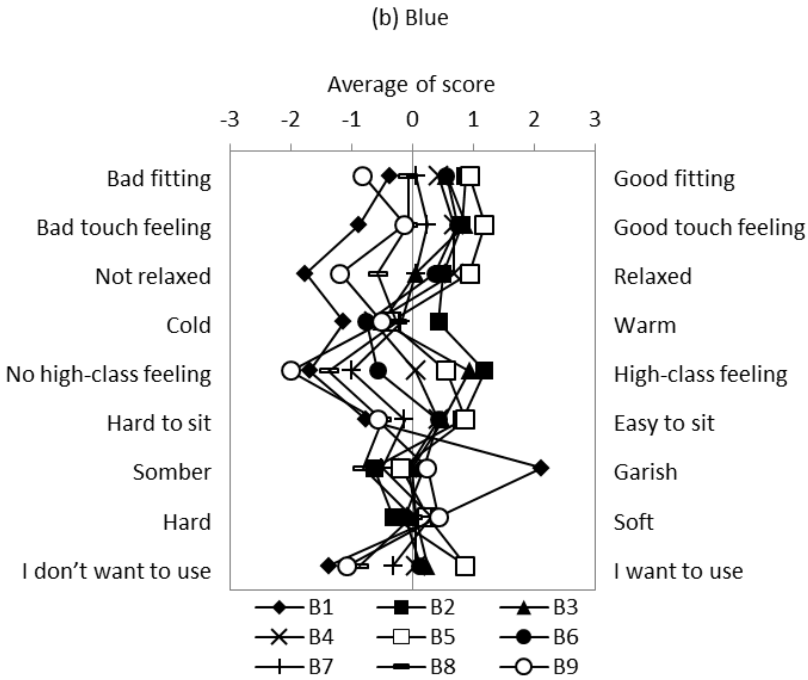


Figure 3-7. SD profile of sensory test on PC display (a: Green, b: Blue)

Based on the results of the green evaluation, the evaluation scores were divided into two groups. G3, G7, and G8 were evaluated as a bad feeling, and both G3 and G7 were evaluated as garish. G3 had high saturation, and G7 had high brightness (Table 3-2). Because G8 had low saturation and brightness, it is assumed that G8 was a dull color.

The blue evaluation scores were distributed around “Zero (Neither)” in comparison with the green colors. B1, B8, and B9 were evaluated as a bad feeling, and B1 was evaluated as the most garish color. B1 had high saturation, and both of B8 and B9 had low saturation and high brightness (Table 3-2). Based on the green and blue results, we considered that neither garish nor dull colors are preferred for train seats by university students.

3.4.4.2 Factor analysis

We also performed factor analysis (principal factor method, varimax rotation, n = 3 factors) using the SD scores of each seat image to clarify the image structure for seat color (Table 3-4). The cumulative contribution ratio was about 86.0%. The first factor was “Comfort” because the factor loadings of “Fitting,” “Relaxed,” “High-class feeling,” “Easy to sit,” and “I want to use” were especially large. The second factor was “Warm color–Cold color” because the factor loading of “Warm” was high. The third factor was considered to be “Tactile feeling” because the factor loading of “Soft” was high.

Table 3-4. Factor analysis

	Factor 1	Factor 2	Factor 3
Fitting	0.963	0.087	−0.008
Touch feeling	0.967	0.065	−0.150
Relaxed	0.972	0.127	0.056
Warm	0.163	0.963	0.039
High-class feeling	0.926	0.176	−0.089
Easy to sit	0.997	0.004	0.033
Garish	−0.643	−0.173	−0.090
Soft	0.003	0.030	0.773
I want to use	0.974	0.180	0.077

Figure 3-8 plots the factor scores of each image on a diagram. The horizontal axis represents the first factor, "Comfort," and the vertical axis represents the second factor, "Warm." The tagged alphabetical letters beside the points are the image numbers (Table 3-2).

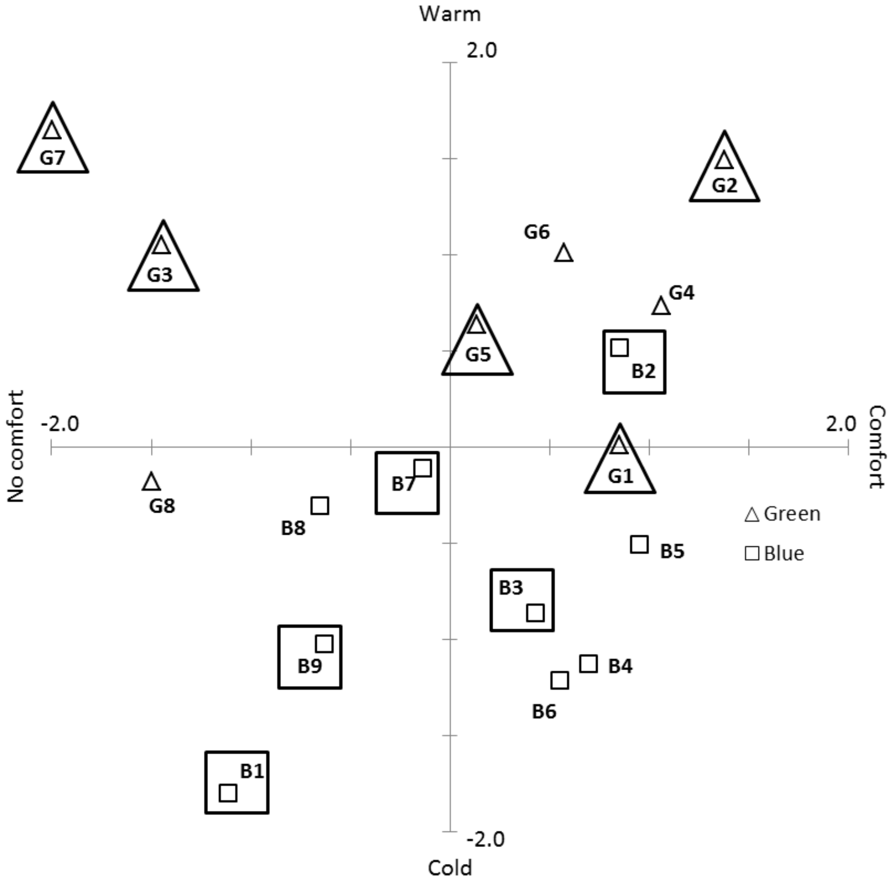


Figure 3-8. Results of factor analysis

Green colors were distributed on the "warm" side of the second factor. Blue colors were distributed on the "cold" side, and we considered that the subjects felt "cold" from blue colors. However, B2 was evaluated as "warm." B2 had the lowest brightness (Table 3-4) and was the darkest color of the nine blue colors; however, B2 was evaluated as the warmest color and was associated with a high-class feeling (Figure 3-7 (b)). Therefore, we considered that dark blue is preferred as a high-class color, and as such is evaluated as "warm."

Five green colors (G1, G2, G3, G5, and G7) and five blue colors (B1, B2, B3, B7, and B9) were selected to investigate the influence of seat color on sitting comfort in the sitting experiment. These colors were chosen because they were considered to have distinct features.

3.5 Evaluation of seat colors in sitting experiment

3.5.1 Outline

Finally, we investigated the influence of seat colors by performing a sitting experiment involving an actual train seat. We fabricated seat covers based on the colors selected in the previous sections (3.4.3.2 and 3.4.4.2) (five red, five green, and five blue colors).

3.5.2 Samples

We selected 15 seat colors (5 red, 5 green, and 5 blue colors) based on the results shown in Figures 3-5 and 3-8. We extracted RGB as the color information from 15 graphical images and compared this information with the DIC color guide (DIC Graphics Corporation) to fabricate 15 seat covers. Table 3-5 shows the numbers of the DIC colors. The texture of the seat cover was moquette, and the material was the same for all covers.

Table 3-5. Selected sample colors according to DIC color guide

Red	A DIC 2251	B DIC 2243	C DIC 2258	F DIC 2253	I DIC 2441
Green	G1 DIC 2360	G2 DIC 2352	G3 DIC 92	G5 DIC 2375	G7 DIC 2143
Blue	B1 DIC 641	B2 DIC 435	B3 DIC 2601	B7 DIC 2598	B9 DIC 2188

3.5.3 Methods

The sitting experiments were performed by replacing the original seat covers of high-speed railway seats. The subjects evaluated the seat color three times (before sitting, just after sitting, and 10 minutes later) using the SD method.

We prepared two kinds of high-speed railway seats: a pair of standard-sized seats and a pair of first-class (green-car) seats (Figure 2-1). The standard-sized seats were set in front of the first-class seats, and all subjects sat on the right side of the first-class seat. To remove the influence of a contact feeling, the seat cover on which the subjects sat was fixed for the default green color, while the other three seat covers were exchanged. The structure and shape of the seat and the texture of the seat cover were identical among all seats (Figure 3-9).

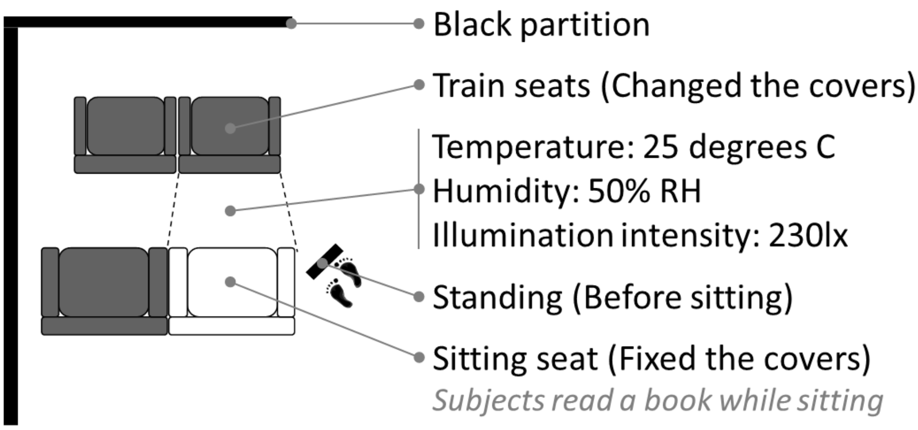


Figure 3-9. Experiment set-up

Evaluations were performed using the same nine evaluation terms and seven-grade scale described in Section 3-4. The order of the five seat colors was randomized. The experiment was performed in a room with a constant temperature (25ºC), relative humidity level (50%), and illumination intensity (230 lx).

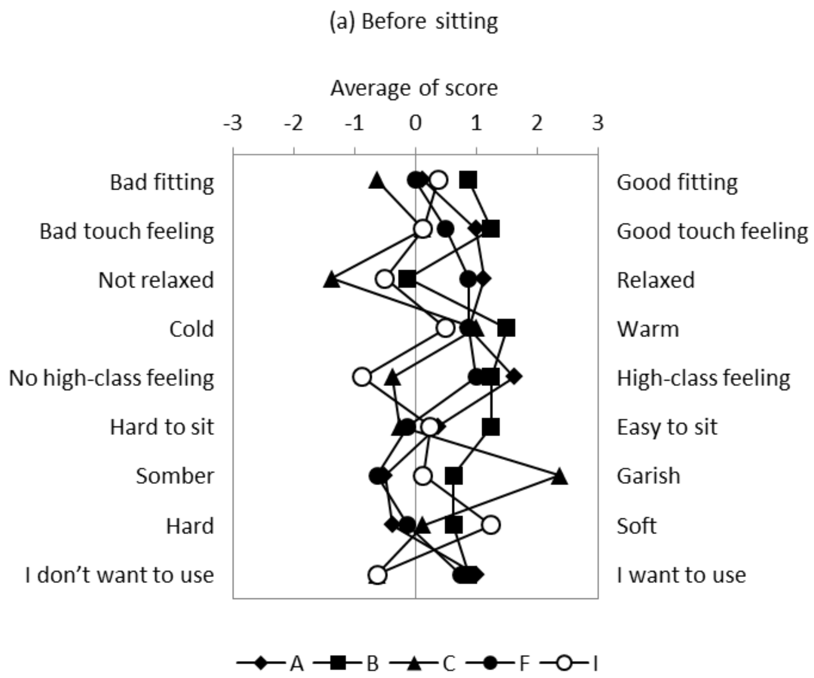
The experimental procedure was as follows. (1) We explained the experiment to the subjects at a location where they could not see the experimental train seats. (2) After we selected one seat color from among the five seat colors, the subjects visually evaluated the seat in a standing position behind the first-class seats (first evaluation). (3) Just after sitting on the seat, the subjects immediately evaluated the seat while sitting in it (second evaluation). (4) The subjects read a book or a magazine while sitting in the first-class seat for 10 minutes. (5) Ten minutes later, the subjects re-evaluated the seat while sitting in it (third evaluation). (6) When the subjects finished the third evaluation, we asked them to leave the laboratory and exchanged the seat color for another. (7) Steps (2) to (6) were repeated until all five seat colors had been evaluated.

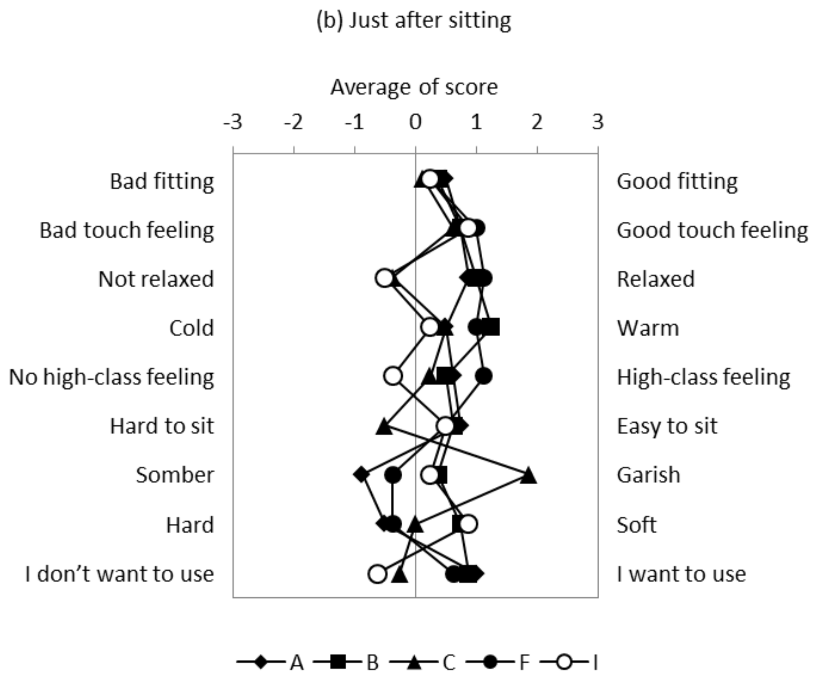
Eight university students (4 male, 4 female; age, 21–24 years) evaluated the red colors. Twelve university students (6 male, 6 female; age, 21–24 years) evaluated the green colors. Twelve university students (6 male, 6 female; age, 21–24 years) evaluated the blue colors.

3.5.4 Results and Discussion

3.5.4.1 Red colors

Figure 3-10 (a–c) shows the SD profiles of the average scores of the five red seats. Figure 3-10 (a–c) shows the results before sitting, just after sitting, and 10 minutes later. We also performed two-way ANOVA with the differences among the five colors and three time points (before sitting, just after sitting, and 10 minutes later) for each term, and the results are shown in Table 3-6.





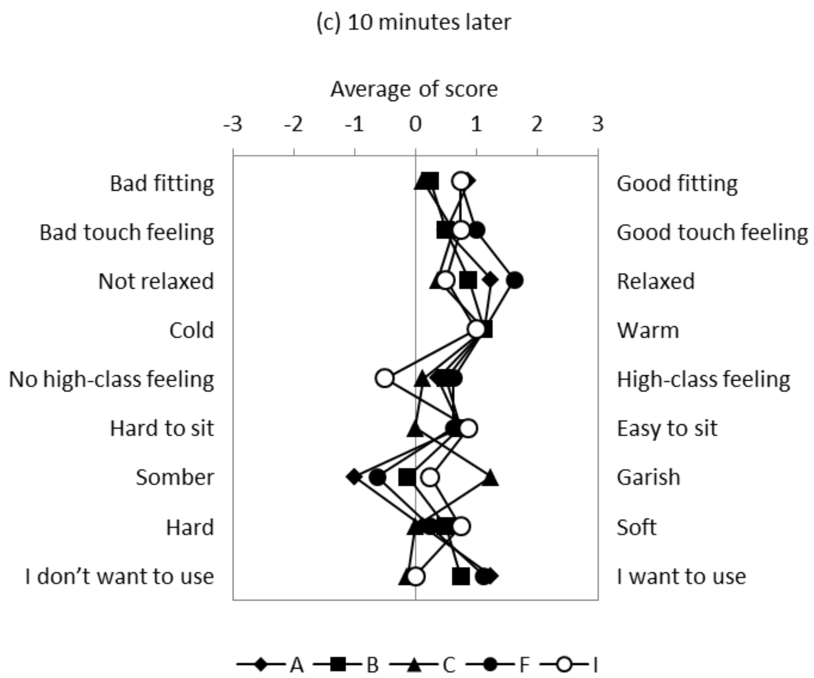


Figure 3-10. SD profiles of five red seats

(a: Before sitting. b: Just after sitting, c: 10 minutes later)

Table 3-6. Results of ANOVA for red colors in sitting experiment (*p < 0.05)

	Color	Timing	Interaction
Fitting			
Touch feeling			
Relaxed	*	*	
Warm			
High-class feeling	*		
Easy to sit	*		
Garish	*		
Soft	*		
I want to use	*		

Based on the results of the pair of evaluation terms "Easy to sit–Hard to sit," which generally indicates sitting comfort, the scores varied widely before sitting, but only one seat color differed from the others between just after sitting and 10 minutes after sitting. Although the structure or shape of the railway seat and material were identical among the five conditions, only one seat color was evaluated as "Hard to sit." This seat color was C, which was given the worst "Relaxation" rating (Figure 3-5 for factor analysis) and had high saturation and mid-brightness (Table 3-1). With respect to the evaluation term "High-class feeling," the color I was evaluated as a "No high-class feeling." This color was also evaluated as a "No high-class feeling" on the PC display (Figure 3-5), and it had lower saturation than the other four colors (Table 3-1). Thus, we assumed that the color I was a dull color and was not preferred by the subjects. With respect to the evaluation term "I want to use," that is, the overall evaluation, C and I were also given poor ratings (evaluated as bad). Therefore, we considered that neither garish nor dull colors are preferred for red seats.

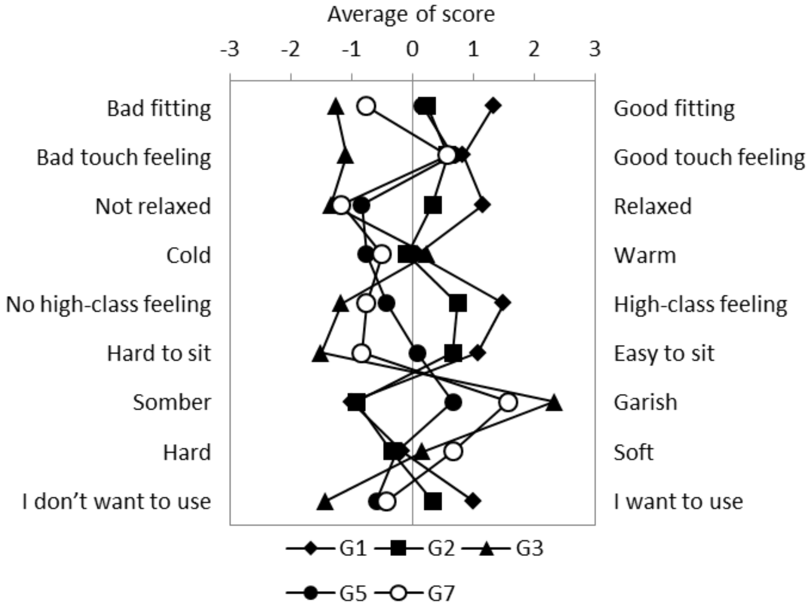
The ANOVA results shown in Table 3-6 indicate that there were main effects on the differences in colors with almost all terms; however, there was no main effect with the terms regarding tactile sensation (fit and touch) and the pair "Warm–Cold." Therefore, we considered that for red colors, visual information has little influence on somatic sensation. Additionally, we know that red colors are "warm colors," and all red samples were evaluated as warm in Figure 3-10. Conversely, there was a main effect on the difference in timing associated with the term "Relaxed." Figure 3-10 shows that the evaluation scores varied widely before sitting and just after sitting. However, the scores were shifted to the plus side; that is, all colors were evaluated as "Relaxed" 10 minutes later. Therefore, we considered that adaptation to sitting affected the experience of feeling "Relaxed."

In the overall evaluation, the average score of "I want to use" was around "Zero" (neither) to "One" (slightly agree), although red colors had a good influence on "Relaxed." Therefore, we considered that red colors have wide deviations.

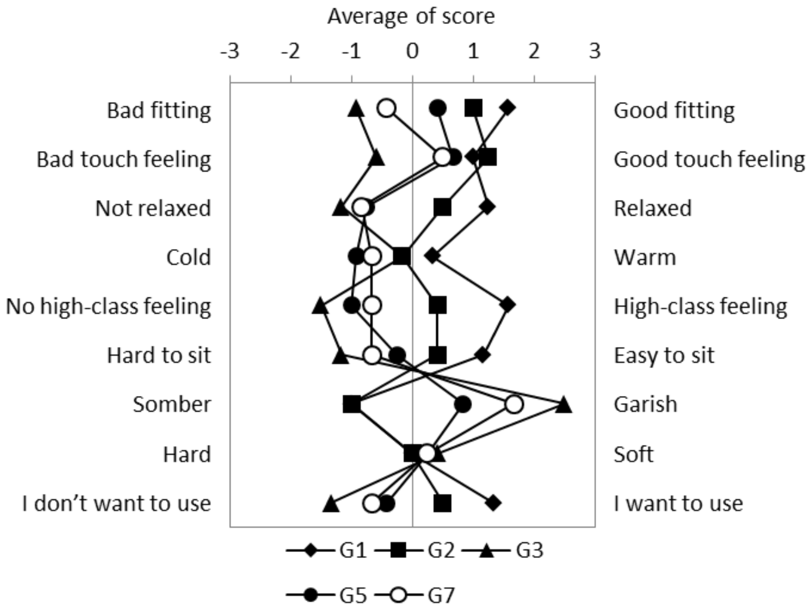
3.5.4.2 Green colors

Figure 3-12 (a–c) shows the SD profiles of the average scores for green color. Figure 3-12 (a–c) shows the results before sitting, just after sitting, and 10 minutes later. We also performed two-way ANOVA with differences among the five colors and three time points (before sitting, just after sitting, and 10 minutes later) for each term, and the results are shown Table 3-7.

(a) Before sitting



(b) Just after sitting



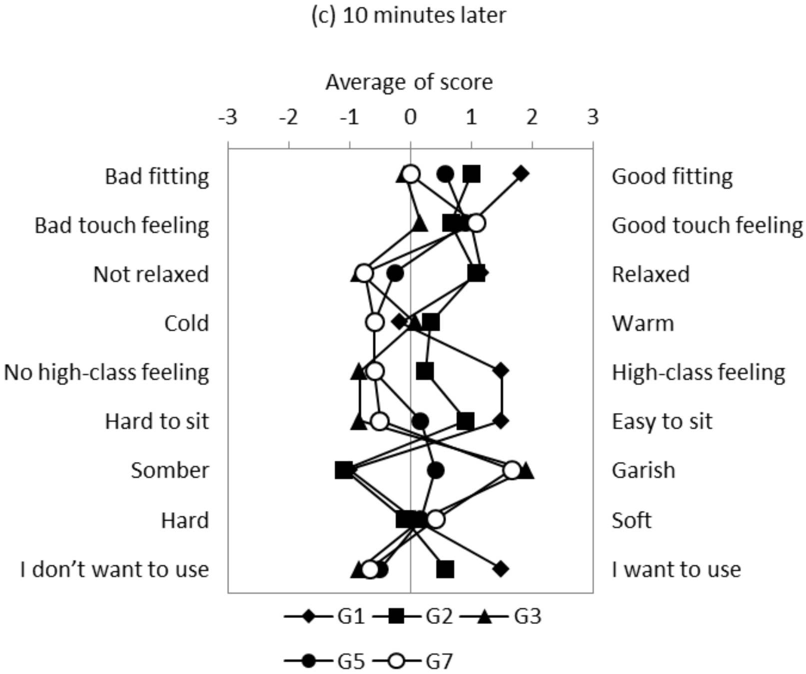


Figure 3-12. SD profiles of five green colors

(a: Before sitting, b: Just after sitting, c: 10 minutes later)

Table 3-7. ANOVA results for green colors in sitting experiment (*p < 0.05)

	Color	Timing	Interaction
Fitting	*	*	
Touch feeling	*		
Relaxed	*		
Warm	*		
High-class feeling	*		
Easy to sit	*		
Garish	*		
Soft			
I want to use	*		

The evaluation scores differed among the seat colors, indicating that the seat colors affected sitting comfort. Evaluations were generally divided into two groups, and this tendency was consistent with the results of the experiment on the PC display (Figure 3-7 (a)). Both G1 and G2 were evaluated as good-feeling on the PC display, and they were also preferred in the sitting experiment. G5 was evaluated as somber and slightly "I want to use" (Figure 3-7 (a)). However, G5 was evaluated as garish and "I don't want to use" in the sitting experiment, and there was a difference in the results between the PC display and real seat. G5 had low saturation (Table 3-2) and was a so-called dull color. We assumed that G5 on the real seat was evaluated as garish because of the area effect of the color [43], although G5 was evaluated as somber on the PC display; thus, G5 was not preferred during the sitting experiment. Overall, we considered that "vague" colors evaluated as "Neither" on the PC display are viewed as bad colors on the real seat.

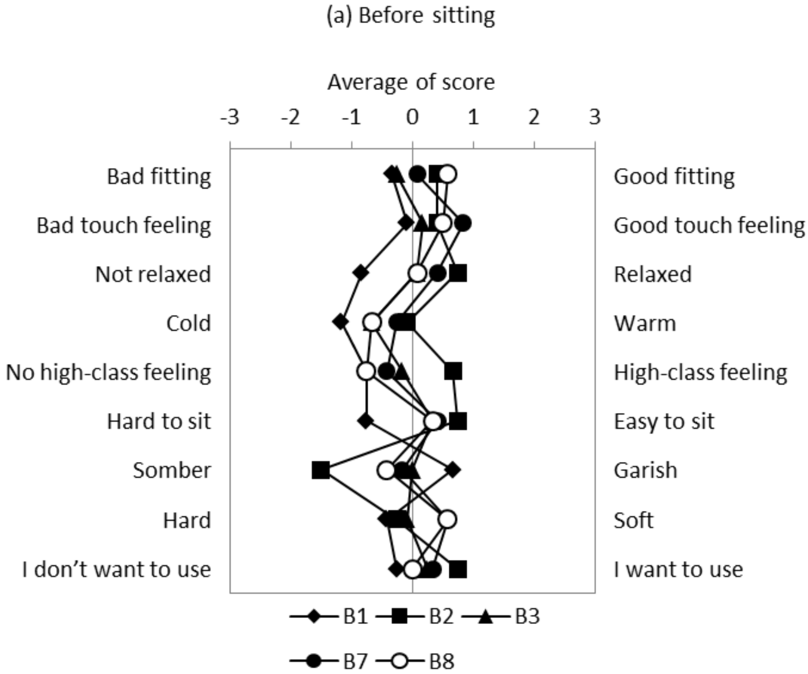
The scores for both fit and touch 10 minutes after sitting were better than those just after sitting. The fit scores for G3 and G7, which were evaluated as "bad fitting" before sitting, improved 10 minutes later; additionally, the touch score for G3, which was evaluated as a "bad touch feeling" before sitting, also improved 10 minutes later. Although the material properties of the seats were identical, the terms describing tactile sensations such as fit and touch improved. Therefore, we considered that the subjects' adaptation affected their somatic sense.

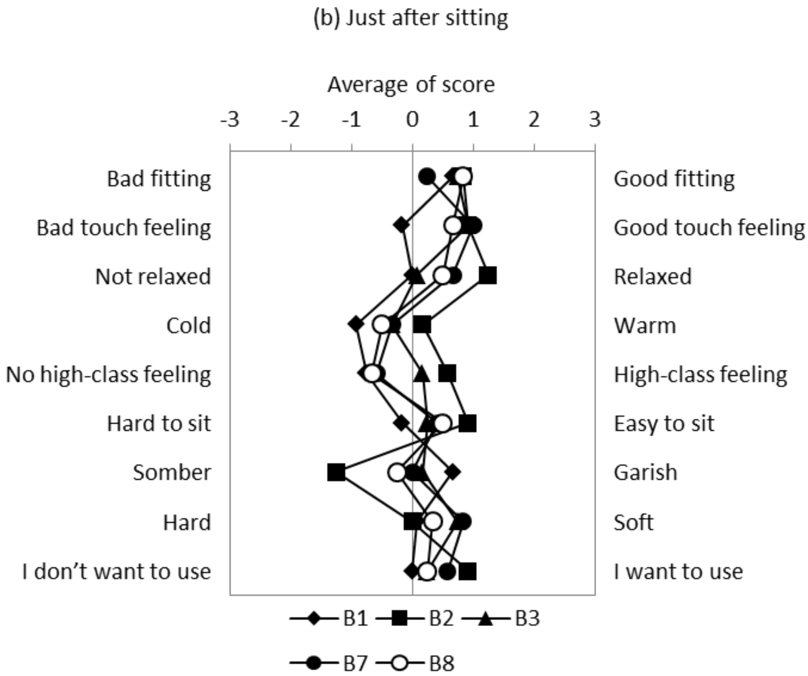
Based on the ANOVA results shown in Table 3-7, there was a main effect on the differences in colors without the pair of terms "Soft–Hard." Therefore, we considered that green colors were specifically evaluated with respect to differences in color, although green colors did not affect the feeling of softness. Additionally, there was a main effect on the difference in timing with the term “fitting,” and it corresponded to our previous consideration.

In the overall evaluation of green colors, the impression of tactile sensation improved as the subjects adapted to sitting, although green colors were specifically evaluated using the terms “I want to use.” That is, even the evaluation “I don’t want to use” improved on somatic sensation. Therefore, it is considered that green colors are “safe” colors.

3.5.4.3 Blue colors

Figure 3-13 (a–c) shows the SD profiles of the average scores for blue colors. Figure 3-13 (a–c) shows the results before sitting, just after sitting, and 10 minutes later. We also performed two-way ANOVA with the differences among the five colors and three time points (before sitting, just after sitting, and 10 minutes later) for each term, and the results are shown in Table 3-8.


(a) Before sitting
Average of score
-3
-2
-1
0
1
2
3
Bad fitting
Bad touch feeling
Not relaxed
Cold
No high-class feeling
Hard to sit
Somber
Hard
I don’t want to use
Good fitting
Good touch feeling
Relaxed
Warm
High-class feeling
Easy to sit
Garish
Soft
I want to use
B1
B2
B3
B7
B8


(b) Just after sitting
Average of score
-3
-2
-1
0
1
2
3
Bad fitting
Bad touch feeling
Not relaxed
Cold
No high-class feeling
Hard to sit
Somber
Hard
I don’t want to use
Good fitting
Good touch feeling
Relaxed
Warm
High-class feeling
Easy to sit
Garish
Soft
I want to use
B1
B2
B3
B7
B8

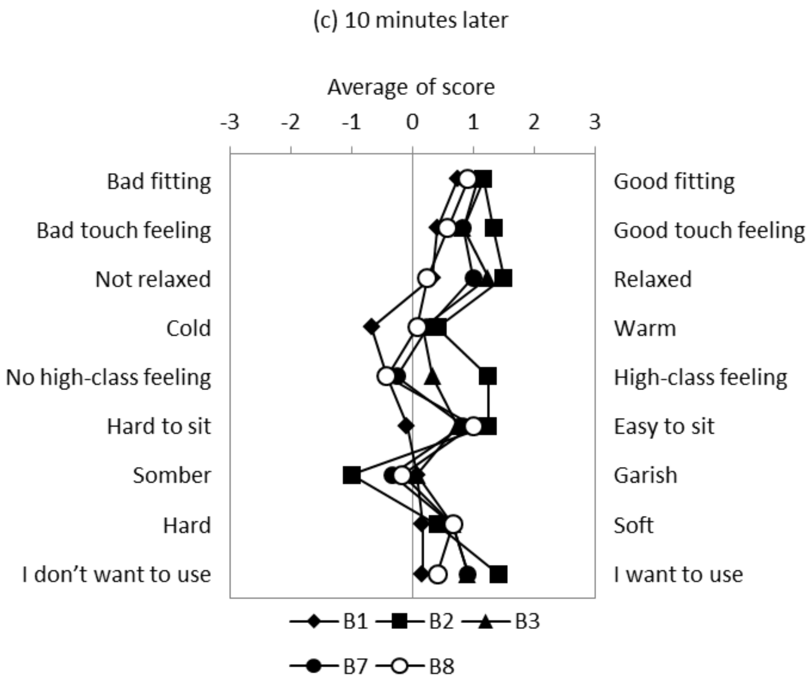


Figure 3-13. SD profiles of five blue colors

(a: Before sitting, b: Just after sitting, c: 10 minutes later)

Table 3-8. Results of ANOVA for blue colors in sitting experiment (*p < 0.05)

	Color	Timing	Interaction
Fitting		*	
Touch feeling	*	*	
Relaxed	*	*	
Warm	*	*	
High-class feeling	*		
Easy to sit	*	*	
Garish	*		
Soft	*		
I want to use	*	*	

The impressions of the blue colors were almost identical (Figure 3-13). B1, which had high saturation (Table 3-2), was felt to be garish, and this was evaluated as bad. However, B2, which had low brightness (Table 3-2), was felt to be somber, and this was evaluated as good. This tendency was also observed on the PC display (Figure 3-8).

The scores for both fit and touch 10 minutes after sitting were better than those just after sitting. The fit and touch scores for B1, which were evaluated as "bad fitting" and "bad touch feeling" before sitting, improved 10 minutes later; the fit score for B3, which was evaluated as "bad fitting" before sitting, also improved 10 minutes later. Although the material properties of the seats were identical among all seats, the terms regarding tactile sensation such as fit or touch improved. This tendency corresponded with the ANOVA results (Table 3-8) because there was a main effect on the difference in timing with their terms. Therefore, we considered that the subjects' adaptation affected their somatic sense. Additionally, only blue colors improved the subjects' impression of "Relaxed" and "I want to use" 10 minutes later. This tendency also corresponded with ANOVA results (Table 3-8) because there was a main effect on the difference in timing with their terms. We considered that blue colors are generally preferred according to previous reports [44-46]. Thus, we assumed that the subjects preferred blue colors and that blue colors affected their overall evaluation, such as "Relaxed" or "I want to use," in addition to adaptation.

3.6 Conclusion

In this chapter, we focused on the influence of seat color and examined the relationship between seat color and sitting comfort. We conducted two evaluations of seat color: on a PC display and by performing a sitting experiment. Based on our results, we conclude the following.

1) Seat color affects sitting comfort, and the impression is different for each hue. For instance, the evaluation scores for red exhibited wide variation, green was evaluated as a “safe” color, and blue was preferred by most of the subjects.
2) The evaluation scores on the PC display were similar to those in the sitting experiment; however, “vague” colors that were evaluated as “Neither” on the PC display were evaluated as bad colors on the real seat.
3) Terms regarding somatic sensation such as fit or touch improve with adaptation to sitting.

The findings of this study indicate that sitting comfort can be improved by changing seat colors and that the optimal train seat color can be approximately estimated on a PC before fabricating prototypes.

Chapter 4
Effect of footrest angle on decrement of leg swelling while sitting

4.1 Introduction

As already mentioned in section 1.1.3, leg swelling is a problem of daily life that must be addressed. It is generally believed that leg swelling is generated by an increase in leg volume secondary to an increase in extracellular interstitial fluid [27-33]. Leg swelling while sitting has several causes, including blood stagnation due to pressure on the thigh and diminution of the pumping effect of the gastrocnemius [33]. Many studies have examined the mechanism of increased leg swelling [25-31] and discussed how to restrain increasing leg swelling. However, to decrease leg swelling is more meaningful than to restrain increasing leg swelling as additional value for high-speed train. Nevertheless, few have investigated the mechanism of decreased leg swelling [32], and the overall mechanism of leg swelling remains unclear. In addition, the gravity effect secondary to lifting of the legs and the pumping effect secondary to the activity of the gastrocnemius effectively decrease leg swelling; however, it is difficult to perform such exercises in a limited space while sitting still. Therefore, we focused on footrests, particularly the footrest angle because raise legs is difficult in limited space such as in train seas although raising legs is known as effective way to decrease leg swelling. Therefore, the presence of a footrest or alteration of its angle is an alternative method by which to decrease leg swelling.

We studied the effect of the footrest angle on decreases in leg swelling using both a bioelectrical impedance method (BI method) [25,47-49] and near-infrared spectroscopy (NIRS) [5,51]. We used BI method because it can estimate leg swelling. In addition, we used NIRS to examine the hemodynamics because it is hypothesized that leg swelling is related to blood flow. There are some studies that investigate leg swelling but few studies that examine the relationship between leg swelling and blood flow.

4.2 Purpose

The purpose of this study was to investigate the effect of the footrest angle on decreases in leg swelling by measuring leg swelling and blood flow. Moreover, we examined the relationship between leg swelling and blood flow when leg swelling increased or decreased.

4.3 Methods

4.3.1 Outline

The sitting experiment performed in this study comprised three parts. First, the participants lay supine for 20 minutes to alleviate or decrease leg swelling before the experiment. Next, the participants sat on a high stool for 30 minutes to increase leg swelling. Finally, the participants sat on a trial chair with a footrest for 30 minutes to decrease leg swelling (Figure 4-1).

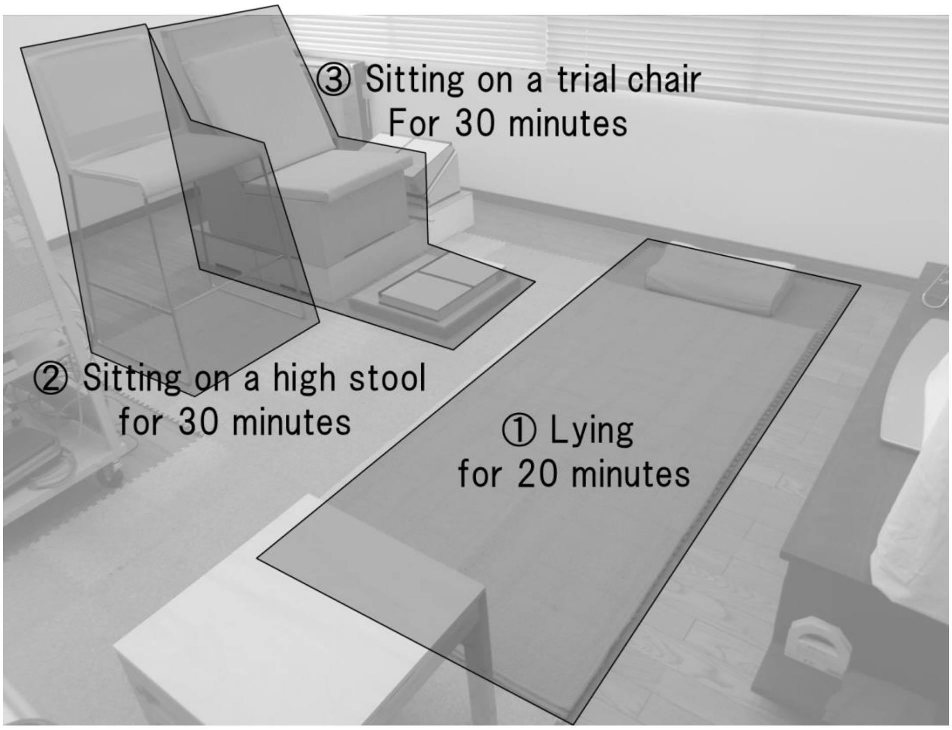


Figure 4-1 Experimental scene

This procedure was conducted once a day and was repeated three times (3 days) to research the differences among three footrest angles. The order of the footrest angles was randomized for each participant. Experiments were carried out in an experimental room that was adjusted to 22°C and 50% relative humidity. We utilized two measurements: leg swelling by the BI method and leg blood flow by NIRS.

4.3.2 Chairs and sitting postures

When the participants sat on the high stool (height, 690 mm; seat, 410 mm [depth] × 470 mm [width]) for 30 minutes, they were instructed to sit back, touch the backrest, and let their legs hang down. (Figure 4-2)

We manufactured a trial chair made of wood frames and cloth-covered urethane cushions, which was assumed to be a relaxation chair. Figure 4-3 shows the detailed dimensions of the trial chair. The trial chair had three types of footrests, and the top board angle differed among them (0°, 15°, and 30°). The height of the front side edge (50 mm) and dimensions of the top board (300 mm [depth] × 450 mm [width]) were identical among all three footrests.

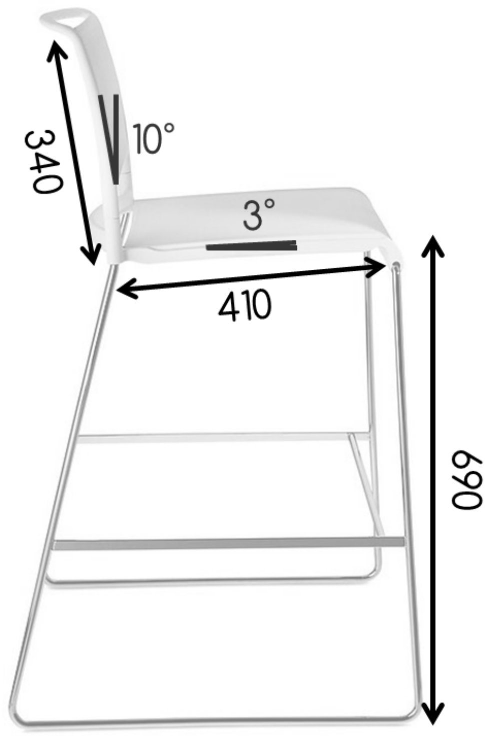


Figure 4-2 Detailed dimensions of the high-stool [mm]

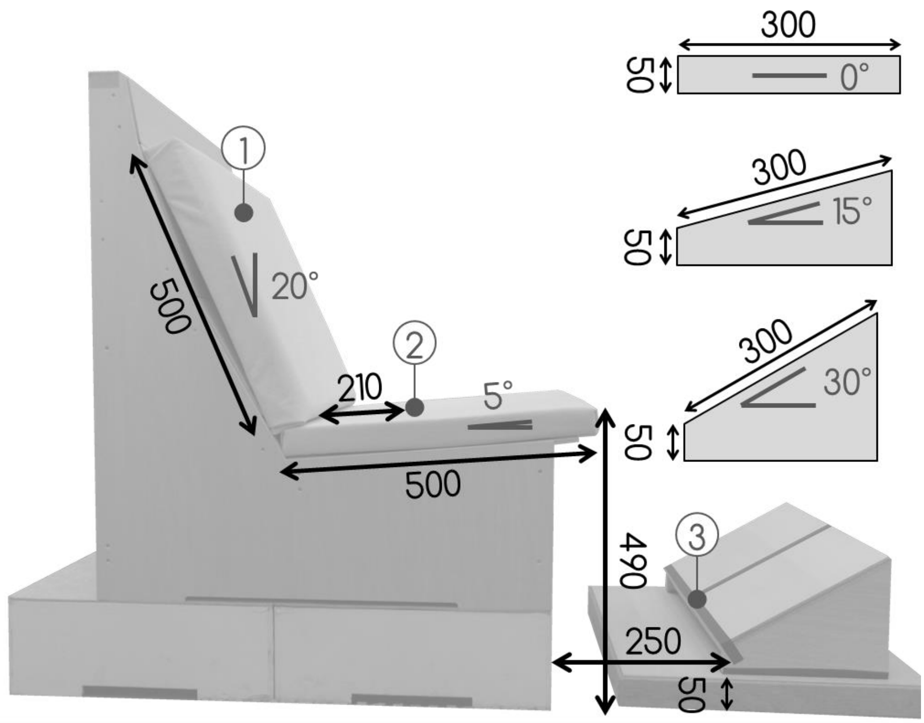


Figure 4-3 Detailed dimensions of the manufactured trial chair [mm]

When the participants sat on the trial chair, the sitting posture from the side view was established as follows; (1) the scapula touched the back of the cushion, (2) the ischium was placed 210 mm from the distal aspect of the seat cushion, and (3) the heel was in contact with the proximal aspect of the top board of the footrest.

4.3.3 Measurement of leg swelling

The BI method is a technique that estimates water volume within the human body by measuring changes in impedance (or resistance) while a multifrequency electrical current flows. Several previous studies have measured leg swelling using the BI method [25,47-49]. According to Seo [47], the shape of the lower leg is assumed to be a cylinder (radius of the base = r), and swelling occurs equally at any position in the leg. The value r then changes according to the level of swelling. The resistance or impedance is expressed by the following equations:

$$R = \rho l \pi r^2 \quad (4.1)$$

$$\therefore \; V = \pi r^2 l = \rho l^2 / R = C \times 1/R \quad (4.2)$$

R: resistance (impedance)　ρ: resistance rate (constant)

l: length of the leg (constant)　πr^2: sectional area of leg

V: volume　C: constant numbers

Therefore, the change in water volume leading to leg swelling is inversely proportional to change in resistance or impedance. In addition, a high-frequency electrical current flows inside cells, and a low-frequency electrical current flows through extracellular interstitial fluid. It is hypothesized that the water volume in the extracellular region increases because of the increase in leg swelling and because a low-frequency current flows easily; thus, impedance decreases. In this study, we defined R0 as resistance at zero frequency, and determined BI to be the index of leg swelling by calculating the reciprocal of R0. If BI increases, leg swelling increases:

$$\mathrm{BI} = 1/\mathrm{R_0} \qquad (4.3)$$

R0 was measured using MLT-50 and MLT-30 (Sekisui Medical Co., Ltd., Tokyo). These two devices have the same specifications. Four electrodes (Eslode ER-240P: Sekisui Medical Co., Ltd., Tokyo) were placed on the shin regions of both legs according to the anatomical features (Figure 2). BI was obtained every 5 minutes while sitting on the high stool and trial chair.

We calculated the ratio of the change in BI (BI%) every 5 minutes while sitting according to the following equation:

$$\mathrm{BI\%} = \mathrm{BI_i}/\mathrm{BI_0} \times 100 \qquad (4.4)$$

$\mathrm{BI_i}$: measured BI at every 5 min ($\mathrm{i} = 1,2,\cdots,6$)

$\mathrm{BI_0}$: measured BI just after sitting

4.3.4 Measurement of blood flow

NIRS is a technique that measures the quantity of oxygenated hemoglobin (OXY-Hb) and deoxygenated hemoglobin (deOXY-Hb) based on their different light absorption characteristics when irradiating near-infrared light with various frequencies. According to Hosoi [5] and Oyama [51], deOXY-Hb is assumed to be associated with outflow of venous blood for internal respiration in a body organ such as the lower leg. In addition, we interpreted OXY-Hb is assumed to be associated with inflow of arterial blood. In this study, we measured blood flow (OXY-Hb and deOXY-Hb) at a depth of 13 to 30 mm from the surface of the skin using BOM-L1TRW (OMEGAWAVE, Inc., Tokyo). Sensor probes were attached to the points of maximum lower leg depth [37] for each leg (Figure 3). The sampling rate was 10 Hz while sitting on both the high stool and the trial chair.

We analyzed three indices at an average interval of 1 minute: OXY-Hb, deOXY-Hb, and Total Hb (OXY-Hb + deOXY-Hb) for noise processing. To exclude individual differences, we calculated the rate of change in each index (OXH%, deOXY%, and Total%) by dividing the average value by the initial value; that is, we performed standardization. Moreover, to study the relationship between blood flow and BI, we also calculated three indices at an average interval of 5 minutes to compare them with the BI every 5 minutes.

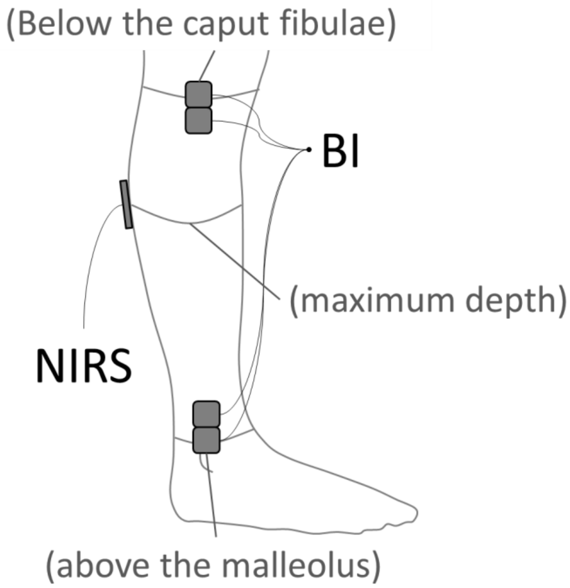


Figure 4-4 Positions of electrodes for BI and sensor probes for NIRS

4.3.5 Participants

We recruited six volunteers as participants (three males and three females). Personal data are shown in Table 4-1. We measured the leg swelling and blood flow of each leg for all 6 participants and obtained 12 data parameters.

Table 4-1 Participants' personal data (M = male, F = female)

	P1 (M)	P2 (F)	P3 (M)	P4 (F)	P5 (M)	P6 (F)	**Ave. ± S.D.**
Age	37	38	29	32	41	31	**34.7 ± 4.3**
BMI	24	22	19	18	25	17	**20.9 ± 3.0**
Height [cm]	179	157	170	156	166	162	**165 ± 7.9**
Weight [kg]	76.8	53	56	43	70	45	**57.3 ± 12.4**

4.4 Results and discussion

4.4.1 Leg swelling

Figure 4-5 shows BI% as obtained by the BI method while sitting on the high stool for 30 minutes. These data were averaged among all of the data (n = 36 = 6 participants × 3 days × 2 legs).

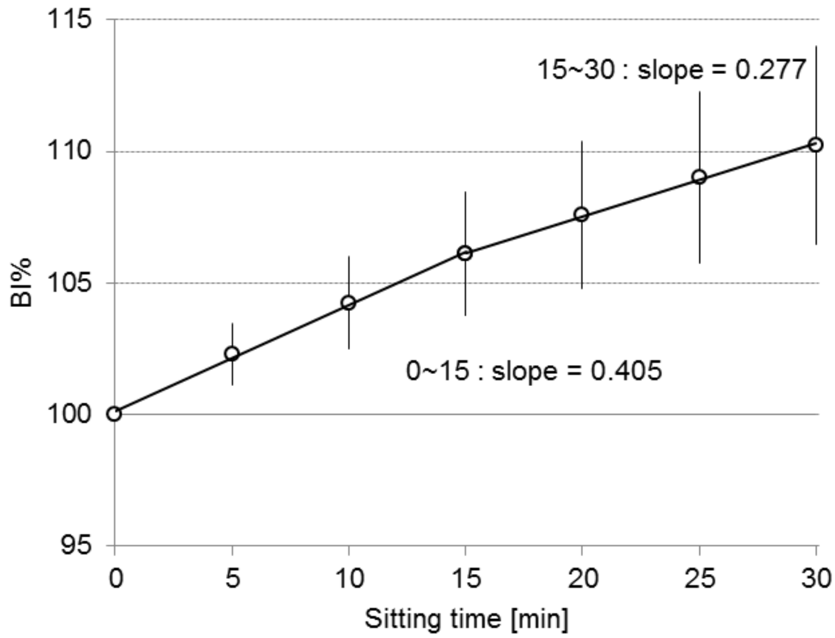


Figure 4-5 Results of BI% while sitting on the high stool

These results show that BI% increased with time while sitting on the high stool and increased by an average of about 10% with 30 minutes of sitting. BI% of male subjects was significantly larger than that of female subjects from 5 to 30 minutes (t-test, $p < 0.05$). Although it was anticipated that leg swelling would be saturated, our results did not show this tendency for 30 minutes of sitting. However, because the curve gradient slightly changed at about 15 minutes, there is a possibility that the swelling increased gradually. In addition, because BI% increased with time for all subjects, it is considered that sitting on a high stool generated leg swelling. This is because the backside of the thigh was under pressure due to the legs hanging down while sitting on the high stool. The leg swelling increased in steady increments because the backrest restrained the body motion and there were thus few variations among subjects.

Figure 4-6 shows BI% while sitting on the trial chair using the three footrest angles for 30 minutes. The obtained data were averaged among all subjects (n = 12).

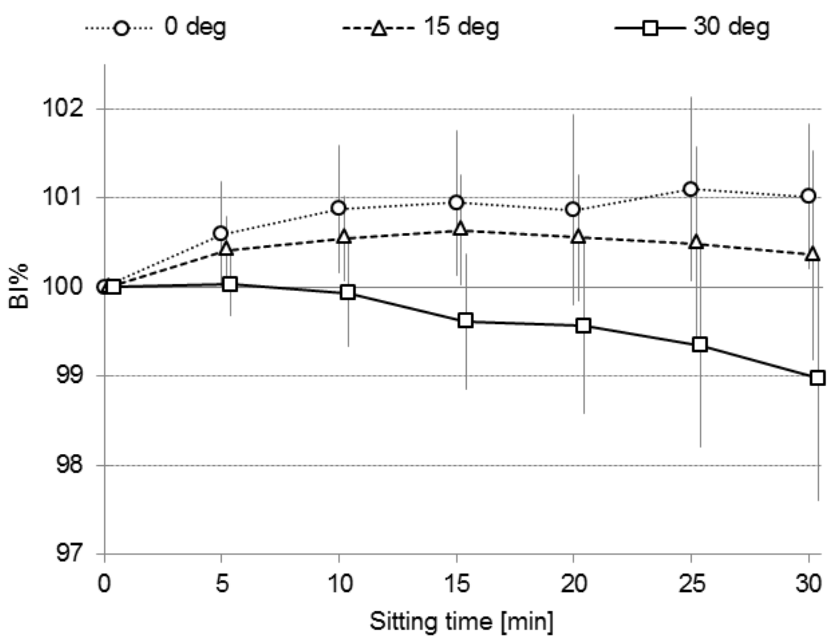


Figure 4-6 Results of BI% while sitting on the trial chair at each footrest angle

The results show the difference in BI%; that is, the differences in leg swelling among the footrest angles. BI% moderately increased at 0°, remained flat at 15°, and slightly decreased at 30°. We performed two-way ANOVA with the time course and footrest angle from 5 to 30 minutes, and only the footrest angle had a main effect ($p<0.01$). Therefore, it is considered that differences in the footrest angle affected the occurrence of leg swelling. Moreover, a footrest angle of 30° was the best condition under which to reduce leg swelling in this study. However, the rate of decrease was about 1%, and the reduction effect was smaller than the gain effect (10% increment) while sitting on a high stool.

4.4.2 Blood flow

Figure 4-7 shows the rate of change in the hemoglobin levels (OXY%, deOXY%, and Total%) while sitting on the high stool. These data were averaged among all subjects, excluding one whose data widely varied over time ($n = 35$).

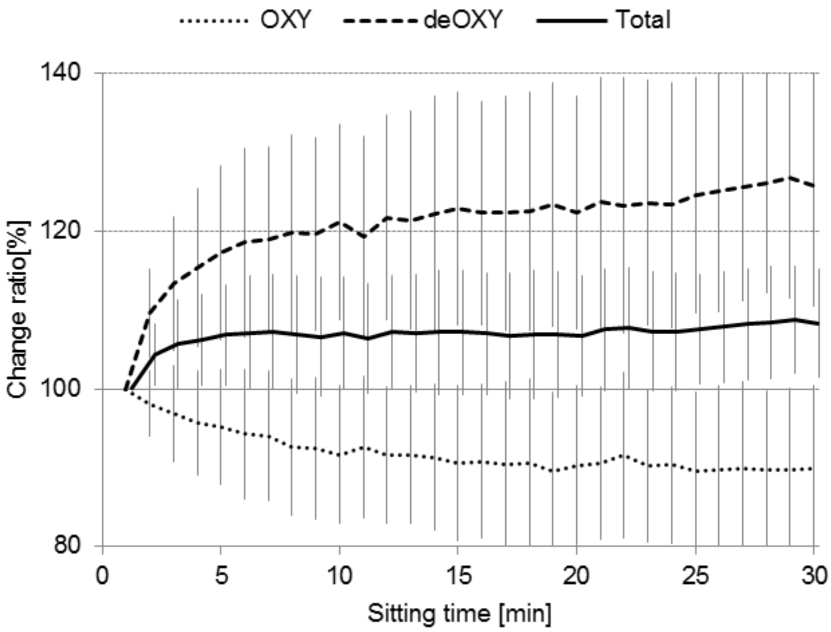
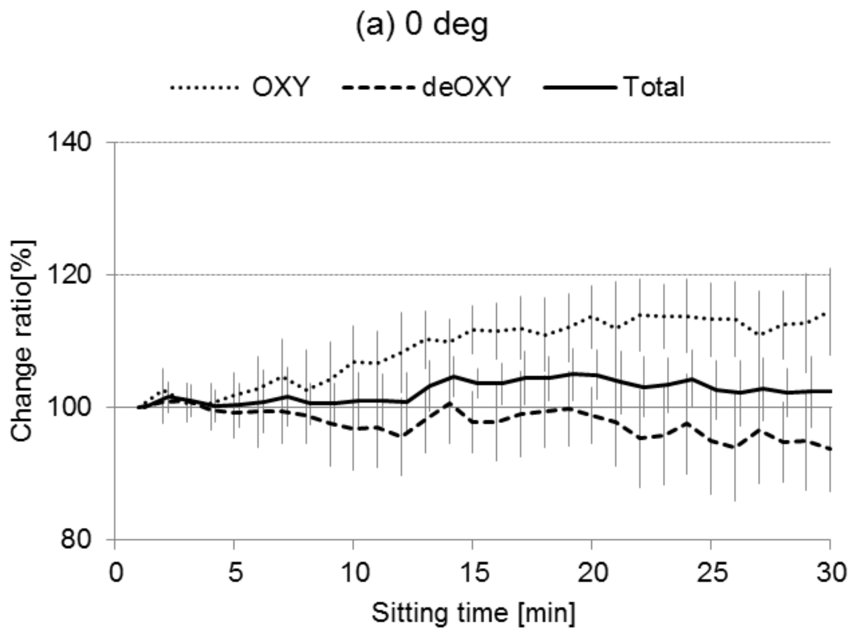
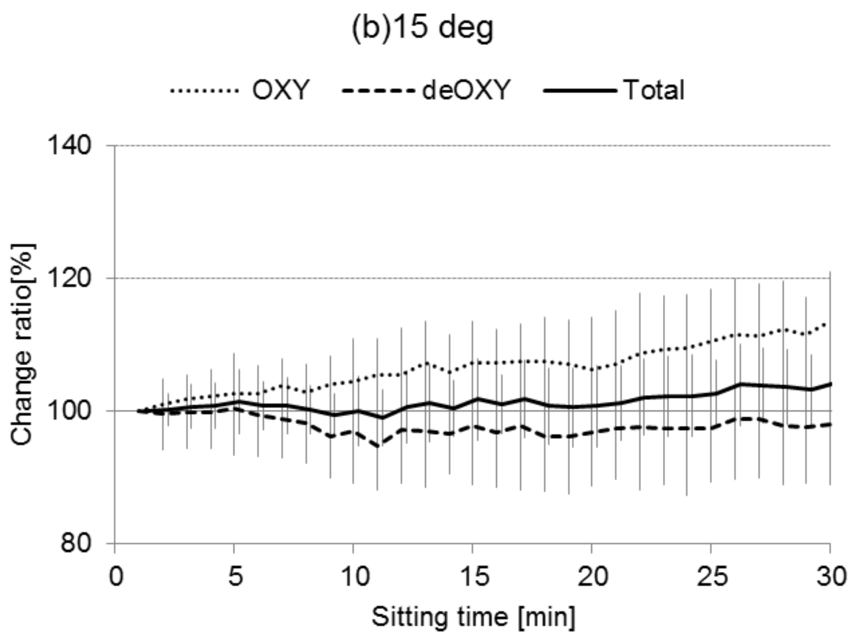


Figure 4-7 Blood flow while sitting on the high stool

During 30 minutes of sitting on the high stool, OXY-Hb decreased and deOXY-Hb increased (Figure 4-7). In particular, because of the change in posture, deOXY-Hb dramatically changed until the 5-minute time point was reached, and total-Hb drastically increased until 5 minutes secondary to the influence of deOXY-Hb. Because the participants lay supine before sitting on the high stool and raising the body, the blood flowed into the lower extremities secondary to the gravity effect, and the total blood flow in the lower leg thus increased. Under the interpretation of deOXY-Hb as outflow of venous blood [5,51] in internal respiration, the outflow of deOXY-Hb was impeded.

Figure 4-8 (a)(b)(c) shows the results of blood flow at a footrest angle of 0°, 15°, and 30° while sitting on the trial chair. These data were averaged among all subjects (n = 12).





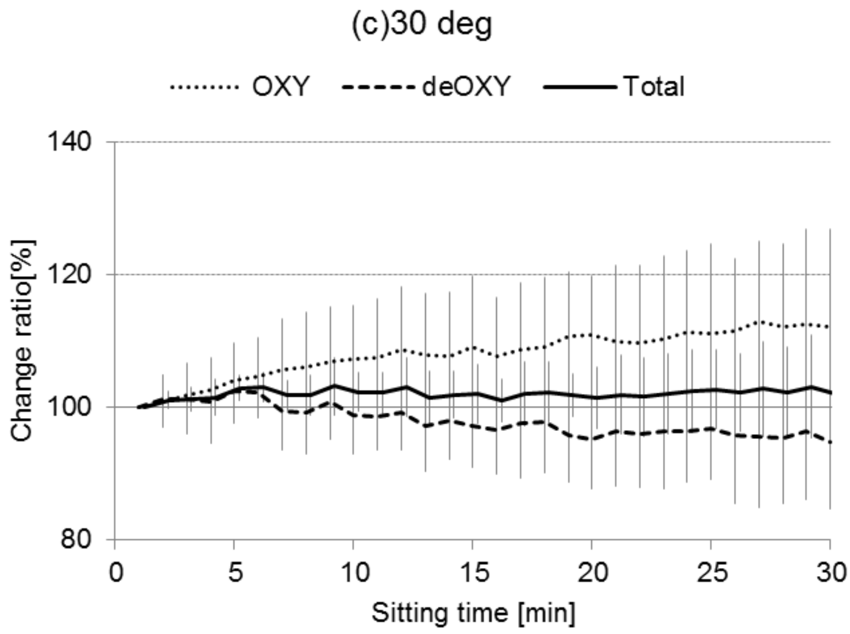


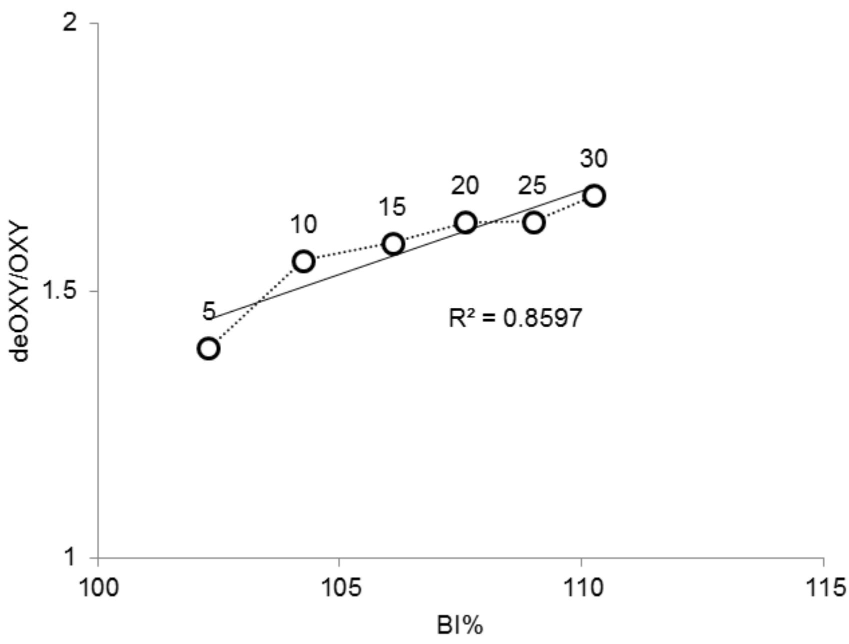
Figure 4-8 Blood flow while sitting on the trial chair (a: 0°, b: 15°, c: 30°)

We found that OXY-Hb increased, deOXY-Hb decreased, and Total Hb slightly increased while sitting on the trial chair. This is because the pressure on the backside of the thigh while sitting on the trial chair was smaller than that while sitting on the high stool. The blood circulation was restored because of the increases in OXY-Hb and deOXY-Hb secondary to sitting on the high stool flew out because of decrease of deOXY-Hb. However, there were no significant differences among the three footrest angles because these results showed a wide variation.

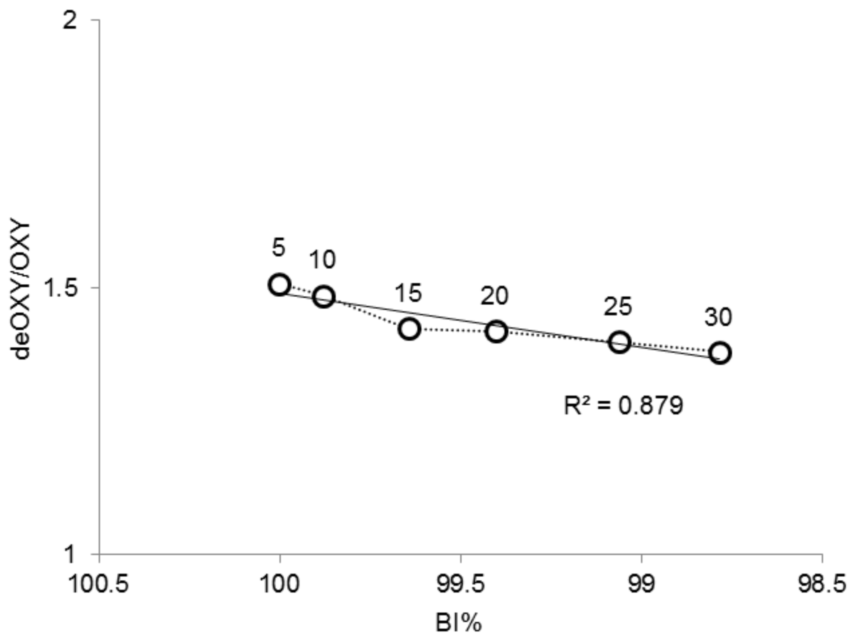
4.4.3 Comparison between leg swelling and blood flow

To investigate the relationship between leg swelling and blood flow, and especially to examine the difference between increased and decreased leg swelling, we assigned all 36 subjects with an increase in BI% while sitting on the high stool to the increased swelling group (Group A), 14 subjects with a decrease in BI% while sitting on the trial chair as the decreased swelling group (Group B), and the remaining 22 subjects with no change in BI% while sitting on the trial chair as the unchanged swelling group (Group C).

We calculated the correlation coefficient between BI% (leg swelling) and the ratio of deOXY-Hb/OXY-Hb (blood flow) for each subject in Groups A and B using all measurement values at an average interval of 5 minutes from 5 to 30 minutes. In Figure 4-9(a)(b), the horizontal axis indicates BI%, the vertical axis indicates deOXY-Hb/ OXY-Hb, and the plotted data were averaged. The circle marks in Figure 4-9(a)(b) represent the measurement values every 5 minutes while sitting.



(a) Results of group A as increase of swelling



(b) Results of group B as decrease of swelling

Figure 4-9 Blood flow while sitting on the high stool

Both Groups A and B showed a strong correlation. In Group A, the data for 31 of 36 subjects had a positive correlation, and the data for 27 of them showed a strong correlation (r>0.6). BI% increased according to the increase in deOXY-Hb because deOXY-Hb increased while sitting on the high stool based on the blood flow as shown in Figure 4-7. If deOXY-Hb is interpreted as outflow of internal respiration, it is considered that outflow of deOXY-Hb was restrained by sitting on the high stool, and leg swelling consequently occurred.

In Group B, the data for 12 of 14 subjects had a positive correlation, and the data for 9 of them showed a strong correlation (r > 0.6). Figure 4-10 shows the OXY-Hb blood flow at an average interval of 1 minute for Groups B and C. The results show their averages.

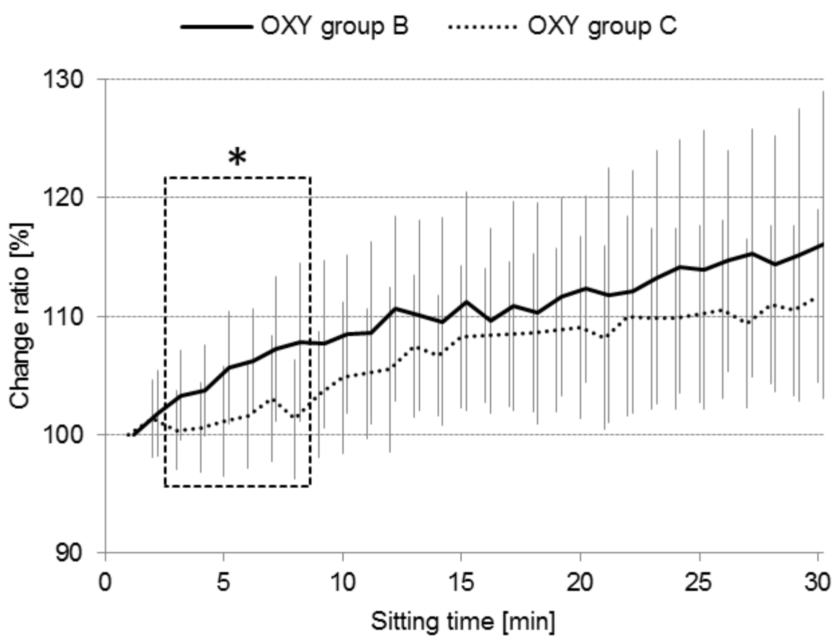


Figure 4-10 Comparison of OXY-Hb blood flow between Groups B and C

The OXY-Hb blood flow showed a significant difference from 3 to 8 minutes (t-test, $p<0.05$). This indicates that BI% decreased according to increase in OXY-Hb, and leg swelling consequently decreased. It is presumed that inflow of blood was recovered due to the decline in pressure at the back of the thigh by sitting on the trial chair, and OXY-Hb flow was stimulated because of adequate leg muscle activity with use of the footrest. Therefore, it is considered that deOXY-Hb for outflow affects the occurrence of leg swelling and that increase of OXY-Hb for inflow influences the reduction of leg swelling.

There are some limitations in this study. It is necessary to investigate the reason why the leg swelling decreased with a 30° footrest, and there are two possibilities. First, the dorsal extension of the ankle joint at a 30° footrest enables the muscle activity of the gastrocnemius to increase, and it is assumed that a muscular pumping effect is generated because of this activity. Second, the pressure on the backside of the thigh diminishes because the footrest allows for changes in not only the ankle joint angle, but also body posture parameters such as the knee angle and lumbar angle. In the future, it will be important to measure or the electromyography of the gastrocnemius the pressure distribution on the thigh to investigate these two hypotheses.

4.5 Conclusion

This chapter demonstrated the fact that leg swelling decreases only by using a footrest, and there was a relationship between the blood flow of the lower leg and fluctuations in leg swelling. If it is clarified that swelling can only be reduced by using a footrest, the sitting comfort of chairs, such as home-use relaxation chairs or vehicle seats, can be improved by adding a footrest.

In this study, we measured leg swelling by the BI method and blood flow by NIRS while sitting on a high stool or trial chair with a footrest. Within the scope of this study, it can be concluded that;

1) BI% increased by about 10% by sitting on the high stool, and BI% decreased by about 1% by sitting on the trial chair with a 30° footrest.
2) deOXY-Hb increased by sitting on the high stool, and OXY-Hb increased by sitting on the trial chair.
3) Comparison of swelling and blood flow revealed strong correlations between BI% and deOXY-Hb/ OXY-Hb in both the increased swelling and decreased swelling groups.
4) Increases in deOXY-Hb influences gains in leg swelling, and increases in OXY-Hb influences reductions in leg swelling.

Chapter 5
Conclusions

In this thesis, we investigated sitting comfort. Because sitting comfort includes many factors, we focused on three main topics. 1) The first topic (Chapter 2) was the internal stress around the intervertebral disks as analyzed by FEM analysis. 2) The second topic (Chapter 3) was the visual influence of seat colors on sitting comfort. 3) The third topic (Chapter 4) was the angle of the footrest that best reduces leg swelling.

Based on the results of the FEM analysis, we can conclude the following.

1-1) We categorized generally used sitting postures on train seats into three main postures (working, reading, and resting) and found that these postures are influenced by the resting level of each.

1-2) We constructed a human-seat FEM model for each posture and observed that the three FEM models had high validity for reproduction of the sitting posture.

1-3) Comparison between internal stress and subjective evaluation indicated that a high level of stress in the lumbar region results in lumbar pain after 30 minutes of sitting and that the stress distribution is important for long-term sitting.

It is possible that lumbar pain can be estimated by FEM analysis. In addition to previously obtained physiological measurements, the internal stress distribution during sitting is valuable information. FEM analysis can be applied to seat design and can estimate sitting comfort using PC simulation before fabrication of a prototype.

Based on the results of our study on the visual influence of seat colors, we can conclude the following.

2-1) Seat color affects sitting comfort, and the impression differs among hues. For instance, the evaluation scores for red exhibited wide variation, green was evaluated as a “safe” color, and blue was preferred by most of the subjects.

2-2) Evaluation scores on the PC display were similar to those obtained in the sitting experiment; however, “vague” colors that were evaluated as “Neither” on the PC display were evaluated as bad colors on a real seat.

2-3) Terms regarding somatic sensation, such as fit or touch, improve with adaptation to sitting.

We found that seat color affects sitting comfort. Changing seat colors is easier than redesigning the structure of a seat. It is possible that seat colors improve sitting comfort; if so, this would help to design more effective and economical seats.

Based on the results of the investigation of leg swelling, we can conclude the following.

3-1) Leg swelling increased by sitting on the high stool and decreased by sitting on the trial chair with a 30° footrest.

3-2) The deOXY-Hb level increased by sitting on the high stool, and the OXY-Hb level increased by sitting on the trial chair.

3-3) Comparison of swelling and blood flow revealed strong correlations between BI% and deOXY-Hb/OXY-Hb in both the increased swelling and decreased swelling groups.

3-4) Increases in the deOXY-Hb level influenced gains in leg swelling, and increases in the OXY-Hb level influenced reductions in leg swelling.

We found that the use of a 30° footrest can reduce leg swelling, and this fact is novel information in terms of evaluation of sitting comfort. The purpose of many previous studies was to create “tireless chairs”; i.e., chairs in which we can sit for a long period of time. In addition to creation of such functional chairs, it is important to increase sitting comfort. Reduction in leg swelling is one example of improvement in sitting comfort.

Finally, this thesis aimed to propose a design guide for the development of train seats through multiple investigations. The following important factors for designing seats were elucidated in this study.

1) Sitting posture is important, and it is advisable to determine the envisaged posture of the developing seat because internal deformation or stress distribution differs in each sitting posture.
2) Some factors, such as internal stress and color preference, can be approximately estimated before fabrication of the prototype. Thus, it is important to investigate the target customer before fabrication of the prototype to narrow down the specifications such as size and color.
3) It is possible to improve existing seats by simple measures such as adding a footrest and changing the color.
4) A footrest is effective not only in terms of inhibition of increases in leg swelling, but also in terms of reduction in leg swelling. Footrests not only contribute to the development of tireless seats, but also add comfort to the seat. Thus, it is important to consider values in addition to functionality.

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