Biomechanical Determinants of Sitting Posture

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Abstract Regarding the increase of seating comfort research, the authors indicated that the researches about the human mechanism of seating comfort are needed by a systematic analysis of seating research literature using the framework of the Multispace design model. Seating comfort is influenced not only by the chair but also by sitting posture. It seems that when we sit down, we determine the sitting posture by optimizing the inherent posture determinants among the possible postures under the given conditions. Generally, a good posture is considered to be in low body loads that can continue to sit comfortably for a long time. The aim of this study is to extract the determinants from the biomechanical loads. In this study, the musculoskeletal loads on the sitting posture estimated from the measured data of skeletal posture and chair reaction forces using the 2-dimensional musculoskeletal model. The results showed the average value of chair reaction forces, the concentration of reaction forces and shear reaction forces effected on the posture as contact loads. And, lumbar shear forces, back and leg muscle stress and intra-abdominal pressure effected as biomechanical loads as the determinants of sitting posture.

Keywords: Seating comfort, Sitting posture, Musculoskeletal loads, Contact loads, Biomechanical model.

1 Introduction

A person has spent most of the day in a sitting posture. Therefore, many kinds of research had been done for seating comfort. The authors had done a systematic analysis of seating research literature using the framework of the Multispace design model for extracting the elements considered in the research. The study indicated that the researches about the human mechanism of seating comfort are needed [1].

Seating comfort is influenced not only by the chair or seat but also by sitting posture. In a normal chair design, it was assumed that the chair was seated deeply with the trunk in contact with the backrest, but in reality, there are also many sitting postures observed where the buttocks are moved forward [2]. This sitting posture is considered to be determined by the physical characteristics of the human body under the sitting conditions of the chair properties, such as the dimensions and hardness, and the sitting purpose such as ease or work. In other words, it seems that when we sit down, we determine the sitting posture by optimizing the inherent determinants among the possible postures under the given conditions. Generally, a good posture is considered to be in low body loads that can continue to sit comfortably for a long time. Therefore, in this study, we considered that the inherent determinants are existing in the biomechanical loads.

The biomechanical loads in sitting include contact loads by compression of soft tissue and blood vessels on the body surface and musculoskeletal loads such as muscle and joint loads. Although these biomechanical loads are often analyzed by physiological measurements such as electromyography or surface blood flow, the range of non-invasive measurements is limited. Therefore, it is an effective approach that uses a biomechanical model for estimating internal loads.

Reed et al. [3] used a myoelectric measurement of erector spinae muscles and model analysis of four rigid links from head to lumbar. And, he mentioned the loads on the back and neck muscles and spinal flexion are related to the determination of driving posture in the automobile seats [2]. Goosens et al. [4] indicated the chair design guideline to reduce the shear reaction forces acting on the body from the viewpoint of preventing pressure sores from the analysis of a couch using a four-link full-body model. However, these models have low biomimetic properties, and it is difficult to consider individual differences, and there is a limit to the estimation accuracy of internal loads.

The authors developed a detailed musculoskeletal model for estimating the musculoskeletal loads in sitting from the measured skeletal posture and reaction forces [5]. Using this model, we have shown that the musculoskeletal loads and the contact loads those are smaller in the posture with less physical fatigue for long-term driving, which was determined by experiment [6].

In this study, we investigated factors that are optimized in natural seating posture for musculoskeletal loads and contact loads using the model and extracted biomechanical determinants of sitting posture.

2 Analysis methods

2.1 Methods of internal loads estimation

A musculo-skeletal model shown in Figure 1 was constructed in a sagittal plane for estimating muscle forces and spinal loads on sitting posture [5]. The model consists of 13 rigid segments and 63 muscles. Spinal segments were connected with passive elastic elements representing intervertebral discs and ligaments. The abdominal area was modeled as a balloon. Intra-abdominal pressure was calculated geometrically in proportion to the cross-sectional area of the abdominal balloon. Anatomical parameters were decided based on the literature.

Skeletal postures of the model segments were determined using input data of measured geometrical locations and interpolated lumbar curve. Following forces were acted on each segment; segment weight, seat reaction forces, joint reaction forces, ligament forces, moments of intra-abdominal pressure and intervertebral disc spring. Joint torque for maintain sitting posture were calculated by measured skeletal posture and seat reaction forces under the equilibriums of moment equations around each joint. Using joint torque, muscle forces and joint forces were estimated under the condition of minimum muscle fatigue [7].

Chair reaction forces and acting point coordinates were measured using cushion-adjustable chair shown in Figure 2 that can adjust shape, angles and cushion properties with force plate. Sitting postures were measured at body landmarks using 3D-digitizer (Kosaka Lab., VECTRON VSC-27). Example of measured data (sitting posture and reaction forces) is shown in Figure 3.

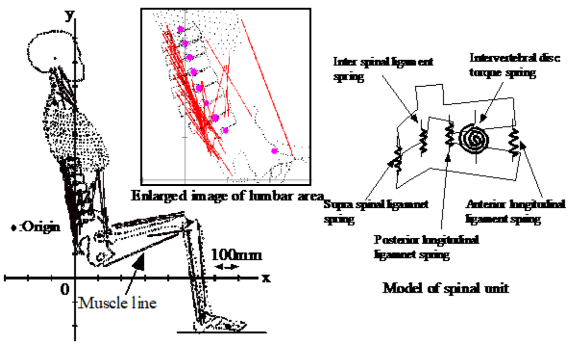


Fig. 1. Musculo-skeletal model.

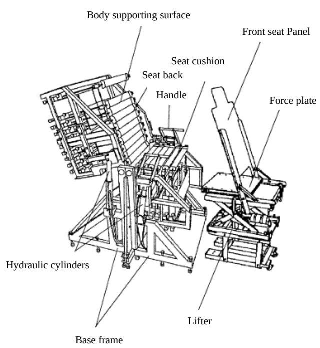


Fig. 2. Cushion-adjustable chair.

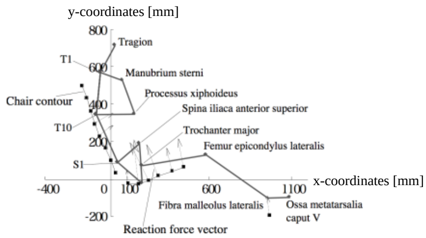


Fig. 3. Example of measured data.

2.2 Experiment conditions

In this study, we focused on automotive seats where it is easy to observe individual preference of their sitting posture in order to maintain a constant posture for a long time. Seat dimensions and cushion properties were set on cushion-adjustable chair for driver's seat condition of M class sedan shown in Figure 4 and rear seat condition of L class sedan shown in Figure 5.

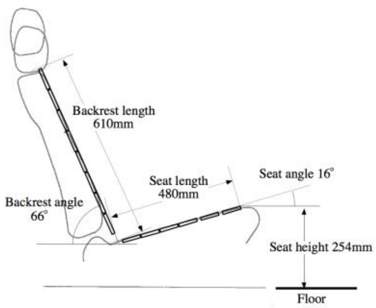


Fig. 4. Driver's seat conditions.

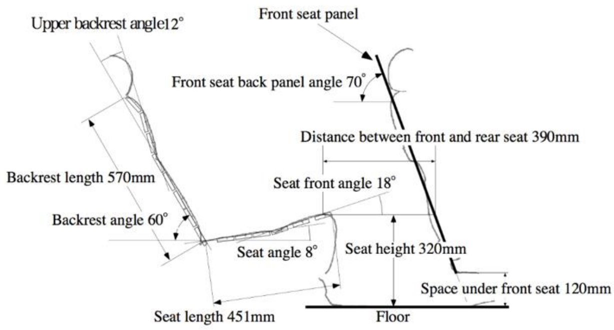


Fig. 5. Rear seat conditions.

The experiment conditions are shown in Table 1. In the driver's seat condition, the subject was instructed that "gaze forward assuming driving, the hands are placed on the thigh". However, no pedals were provided to remove the influence of the driving operation system for posture determination. Also, in the rear seat conditions, a panel equivalent to the back of the front seat was provided, instructed that "gaze assuming looking forward and take a comfortable posture". The sitting postures measured are the following four types, and the sitting duration is about 15 minutes per posture.

Rearward sitting posture: deeply sitting with maximum efforts (instructed).

Forward sitting posture: sitting posture with 120 mm forward at ischial tuberosity from rearward sitting posture (instructed).

Natural sitting posture: naturally sitting posture (no instruction).

Optimal sitting posture: sitting posture after adjustment cushion hardness for maximum comfort from natural sitting posture (no instruction).

Thirty-seven subjects (age: 21 to 30) were examined (height: 171.3±5.2 cm, weight:66.1±7.1kg).

Table 1. Experiment conditions.

	Experiment.1	Experiment.2	Experiment.3	Experiment.4
Chair condition	Driver's seat	Driver's seat	Rear seat	Rear seat
Cushion hardness : backrest [N/mm]	6	12	6	12
Cushion hardness : seat [N/mm]	6	6	6	6
Number of subjects	10	12	12	37
Measured postures	Backward sitting Natural sitting Forward sitting	Natural sitting Optimal sitting	Backward sitting Natural sitting	Natural sitting Optimal sitting

3 Results

3.1 Differences of sitting postures between experiments

Sitting posture and reaction forces on driver's seat (experiment 1) were shown in Figure 6. Following tendency were observed. Pelvis rotated with forward movements of ischial tuberosity. Reaction forces concentrated to around T10 and ischial tuberosity by reducing pelvic support with forward movements of ischial tuberosity.

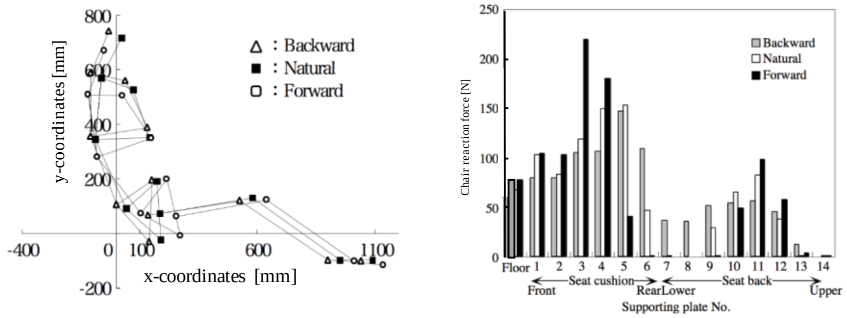


Fig. 6. Differences of sitting posture and seat reaction forces between ischial positions.

Measurement examples of natural and comfort sitting posture on driver's seat (experiment 2) were shown in Figure 7. Thus, differences of both postures were small, seat reaction forces were distributed, and peak position of back reaction forces were changed after cushion adjustment. It seems that contact loads were optimized by cushion hardness adjustments.

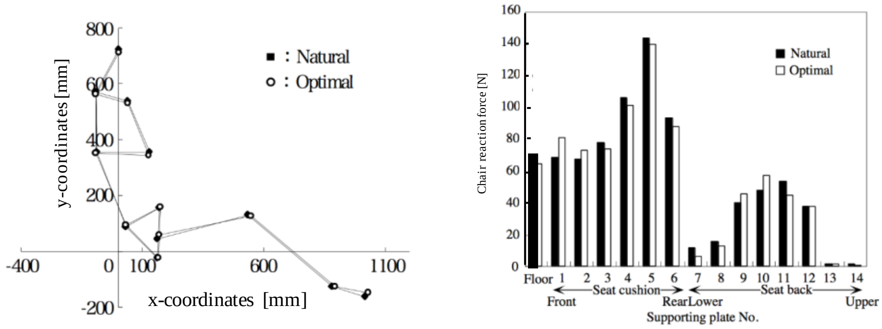


Fig. 7. Differences of sitting posture and seat reaction forces between sitting conditions.

Natural sitting posture on driver's seat (experiment 1) and rear seat (experiment 3) of same participant are shown in Figure 8. Following tendency observed on rear seat that has large reclining angle. Torso were reclined on seat back and pelvis rotated to rearward. And, foot moved to nearside for pelvis by flexion of knee. This was caused by restriction of space by front seat and prevention of pelvis sliding forward. As a result, distribution of reaction forces become same as forward sitting posture.

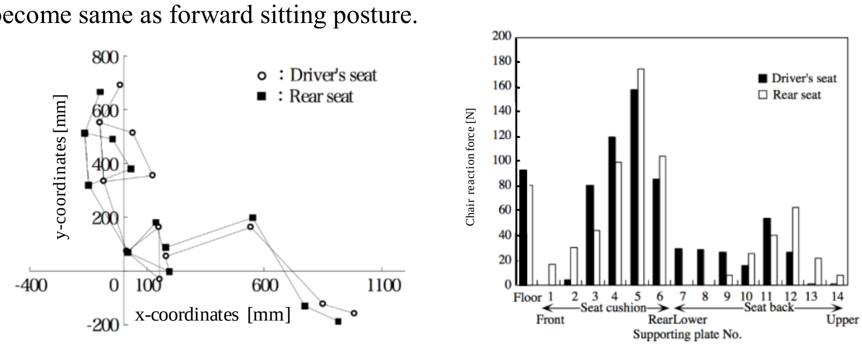


Fig. 8. Differences of sitting posture and seat reaction forces between seat conditions

3.2 Analysis of biomechanical determinants of sitting posture

We analyzed measured reaction forces as contact loads and internal loads calculated from measured postures and reaction forces as musculoskeletal loads. Parameters that minimized at natural or optimal sitting posture were defined as candidate of biomechanical determinants. In this chapter, the in biomechanical loads index value of each subject is compared between posture conditions, and a case where a significant difference of 5% or more is found in the change between postures by the sign rank test of Wilcoxson in the Figure.

3.2.1 Contact loads

Using the reaction force of each supporting surface measured by the cushion-adjustable chair, the following two indices were defined for each of the seat cushion and seat back.

· Reaction force concentration ratio = Reaction force standard deviation/reaction force average value of seat cushion or back

· Average value of reaction force on seat cushion or back

As shown in Figure 9, reaction force concentration ratio of seat and back were minimized (12 out of 10 subjects) at rear seat condition (experiment 3, 4). Average reaction force of seat and reaction force concentration ratio seems to be candidates of determinants. As shown in Figure 10 and 11, Sum of shear forces were minimized on driver's seat condition (experiment 1, seat 6 and back 7 out of 10 subjects). Therefore, shear reaction forces seem candidate of determinants.

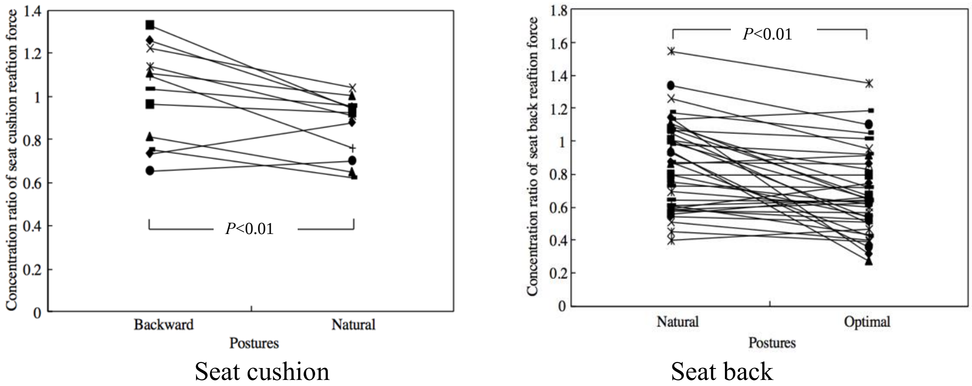
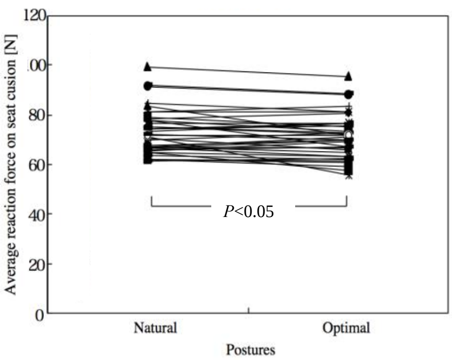


Fig. 9. Reaction force concentration ratio between sitting condition



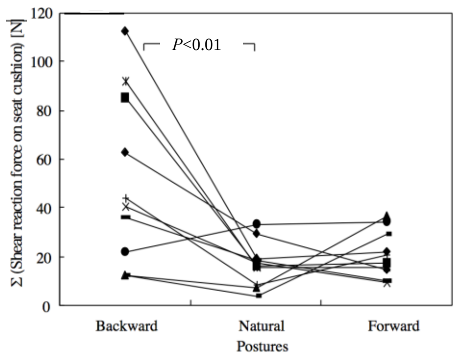


Fig. 10. Average reaction force on seat cushion. **Fig. 11.** Shear forces of seat cushion (Driver's seat).

3.2.2 Joint loads

As shown in Figure 12, sum of lumbar shear forces was minimized at natural sitting posture on driver's seat condition (experiment 1, 8 out of 10 subjects). Sum of lumbar compression forces did not have clear tendency. Therefore, lumbar shear force seems to be candidate of determinants.

3.2.3 Muscle loads

Sum of back muscle stress on driver's seat condition (experiment 1) were shown in Figure 13. Back muscle loads were minimized at natural sitting posture (6 out of 10 subjects). Although differences were relatively small compared with back muscles, leg muscle forces were also minimized on driver's seat condition (experiment 2, 7 out of 12 subjects) shown in Figure 14. As shown in Figure 15, neck muscle loads were minimized only on rear seat condition (experiment 4, 7 out of 12 subjects). This tendency seems to be caused by differences of conditions between driver's and rear seat. No tendency was observed for abdominal muscle forces.

3.2.4 Other internal loads

As shown in Figure 16, intra-abdominal pressure was minimized at natural sitting posture on driver's seat condition (experiment 1). No tendency observed on rear seat condition.

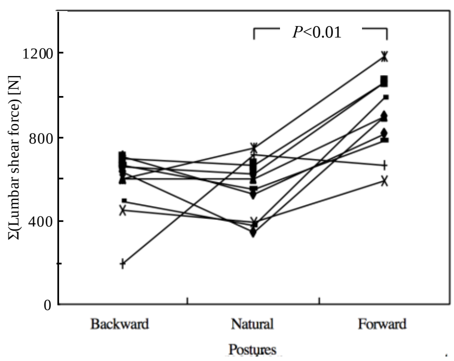


Fig. 12. Lumbar shear forces (Driver's seat).

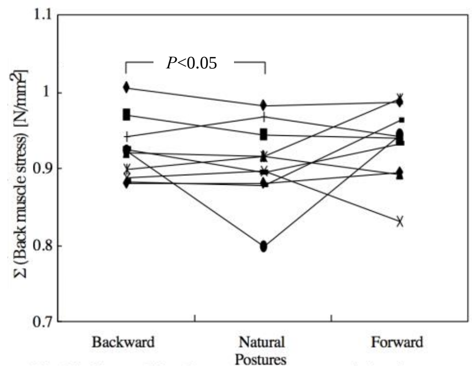


Fig. 13. Back muscle stress (Driver's seat).

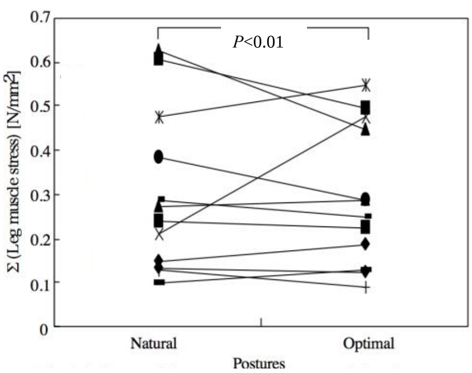


Fig. 14. Leg muscle stress (Driver's seat).

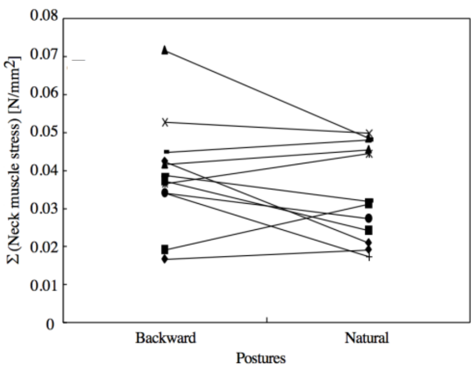


Fig. 15. Neck muscle stress (Rear seat).

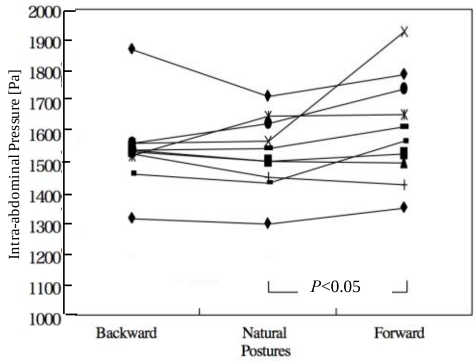


Fig. 16. Intra-abdominal pressure (Rear seat).

4 Discussion

Percentage of subjects and internal loads parameters were shown in Table 2. As a result, following parameters were extracted as biomechanical determinants of sitting posture.

Contact loads: concentration ratio of seat and back, average of seat reaction forces, sum of shear reaction forces of seat and back.

Musculoskeletal loads: sum of lumbar shear forces, sum of back muscle stress, sum of leg muscle stress, intra-abdominal pressure.

Table 2. Percentages of subjects for optimized internal loads in experiments [%]

Load parameters (Sum)	Experiment.1	Experiment.2	Experiment.3	Experiment.4
Concentration ratio of seat cushion reaction force	20	42	**83**	**68**
Concentration ratio of seat back reaction force	20	50	17	**81**
Average reaction force on seat cushion	0	25	25	**68**
Shear reaction force on seat cushion	20	**58**	0	8
Shear reaction force on seat cushion	40	**75**	42	49
Lumbar shear force	**80**	**67**	17	49
Back muscle stress	50	**58**	**67**	46
Leg muscle stress	30	**58**	**58**	**51**
Neck muscle stress	0	33	**58**	49
Intra-abdominal pressure	**80**	25	**58**	41

As for the contact loads, it is indicated that the absolute value of the compression force is important in order to prevent the blood flow inhibition due to the soft tissue compression, and it is better to distribute. This is close to the knowledge [9] about the good pressure distribution conventionally used for chair evaluation. Also, the shear forces agree with the view of Goosens et al. [4]. In addition, the tendency of the reaction force is more prominent in the rear seat condition because the reaction force is bigger due to the trunk reclined backward.

For lumbar intervertebral disc loads, it is considered reasonable to be sensitive to shear forces, as the intervertebral discs are considered to be strong in the compressive component and weak in the shear component. The muscle loads are also consistent with the conclusion of Reed [1], where the spinal muscles are dominant. In addition, the lower leg muscle loads are due to the influence of the bi-articular muscle connecting the pelvis and lower leg such as Hamstrings on the torso posture. The intra-abdominal pressure is particularly observed at the driver's seat conditions because the angle between the seat back and the seat cushion is narrower than at the rear seat.

The tendency in the neck muscle loads was observed in the rear seat condition only. It is considered to be appeared remarkably for maintaining the posture of the head for gazing the front due to the backrest angle. However, in this experiment, since the experiment is not performed including changes of the backrest angle, validations of the layout dependency will be a future subject.

5 Conclusions

In this study, the biomechanical determinants of sitting posture were discussed. The concentration of reaction forces, an average of seat reaction forces, a sum of shear reaction forces of seat and back were extracted as contact loads. Sum of lumbar shear forces, a sum of back muscle stress, a sum of leg muscle stress, intra-abdominal pressure were extracted as musculoskeletal loads.

However, the weight of each index is unclear, and it will be a future task to determine this. If sitting posture is simulated as to optimize these physical load indices, it is possible to evaluate the posture virtually. In addition, if measurements of skeletal posture and chair reaction forces can be obtained, it may be effective to use them directly as sitting posture comfort indices. Identification of the weight for the indices and develop it into a sitting posture simulation in further study.

In conducting all the experiments of this research, the informed consent for an experiment involving human subjects was obtained from the experiment participants with in advance explanations of the experiment.

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