STUDY ON RELATION BETWEEN SLEEPING COMFORT AND SLEEPING POSTURE

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ABSTRACT

In order to predict sleeping comfort based on sleeping posture on a simulation, we investigated relationship between sleeping posture and sleeping comfort. In previous studies, sleeping posture had a narrow variation with the result that mattress properties had a narrow variation. In order to vary sleeping postures variously, we customized a mattress which consisted of 3 different hardness and distribution; that is, 9 different types of mattresses for this study. Furthermore to simplify the estimation of sleeping posture (mattress sinkage), we measured the displacement of sticks by attached bed coils. Sleeping comfort was evaluated by the semantic differential (SD) method when subjects lay down on their back for five minutes. Subjects consisted of 20 healthy male students aged 20 to 22. The result showed that the back sinkage tended to be larger than the buttocks ones in the case of good sleeping comfort. On the other hand, the buttocks sinkages tended to be larger than the back one in the case of bad sleeping comfort. Consequently it was suggested that there was a good possibility of sleeping comfort prediction based on sleeping posture.

Keywords: *Sleeping comfort, Sleeping posture, SD method, Simulation*

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1. INTRODUCTION

Since it is said "Sleep is better than any medicine", it is an important factor for human being to remove physical and mental fatigue accumulated and to create energy for tomorrow. It becomes clear that the ratio of Japanese homes with bed reaches 60% by the westernized life style according the recent survey [1]. Against this backdrop, various kinds of bed mattress have been developed with excellent body pressure dispersion nowadays. However, sleeping comfort can never be guaranteed by any excellent mattress unless it is chosen to fit the body. The bed mattresses, for example, too soft or too hard for users may cause unusual sleeping posture and make the sleeping uncomfortable. So, ideally speaking, it is desirable to develop bed mattress suitable to each person. But it would take much cost and time in the repeated process of manufacturing sample product, evaluation by users and improvement in order to develop best suited mattress, which can be very inefficient. So it is found useful for both manufacturer and users to design bed mattress with computer simulation. Therefore, in order to design an efficient bed suitable to users, we are doing research on the predicted sleeping postures by simulation from the viewpoint of dynamics [2]. Using finite element method in the simulation to represent the human body in finite element model based on the body surface date obtained by 3D measurement, and solving the static contact problem with the mattress represented by the same finite element model to find out the static sleeping posture and the body pressure distribution when user lies on his back. We have confirmed, at the moment, that the sleeping posture can be predicted to an accuracy of 5mm, and the body pressure distribution to that of 2kPa, by entering each Young's modulus of human body and mattress as simulation parameters. However, the sleeping posture and the body pressure distribution are only prediction of dynamic behaviors, and the sleeping comfort of the mattress can not be judged by the simulation results, at the moment.

Generally, it is known that the quality of sleeping comfort is dependent on various factors, such as bedclothes, sleeping posture, humidity and temperature, sleeping time, surrounding lights, and sounds, etc [3]. With focus on the sleeping posture among all, we thought it is possible to predict the sleeping comfort through sleeping posture. If the sleeping comfort can be estimated by the sleeping posture, it is possible to predict the sleeping posture by simulation, and estimate further the sleeping comfort. Therefore, by using various mattresses with different hardness and distribution in this study to recreate various sleeping posture, and measuring the sleeping comfort at the time, we intended to clarify the relationship between them.

As for the relation between sleeping comfort and sleeping posture, various studies have been reported, such as the study in which sleeping comfort is estimated by neural network with sleeping posture and body pressure dispersion [4], the study in which investigated the sleeping comfort and body stability using the mattresses with different body pressure dispersion [5], the study in which the relation between initial sleeping posture, and posture during sleep and sleeping comfort[6], and the study in which the influence on sleeping posture by mattress elasticity and sleeping comfort. [7]. However, in those previous studies, there remain some issues; (1) variation of sleeping postures were limited because of the narrow variation in mattress patterns used, (2) many qualitative analyses resulting from the limited amount of data because of the time required to measure sleeping postures, and (3) no evaluation for sleeping comfort in details.

In consideration of those issues, we intended to clarify, in this paper, the relationship between sleeping posture and sleeping comfort, by means of (1) using 9 types of mattresses with different hardness and distribution to increase the variety of sleeping postures, (2) proposing a sleeping posture measuring method more simplified than before, and (3) using 21 different adjectives to measure the sleeping comfort. There are supine position, lateral position, and prone position in sleeping postures, and we conducted a survey in this paper only for the supine position (hereinafter, the term "sleeping posture" will refer to supine position).

2. EXPERIMENT

In order to clarify the relationship between sleeping posture and sleeping comfort, it is necessary to reproduce all the possible variation of sleeping postures. Since it is known empirically that sleeping posture varies with different bedclothes, we prepared for this paper a mattress variable in hardness and distribution to measure the sleeping posture and sleeping comfort by laying the subject on it. The details of the experiment are as follows.

2.1. Mattress Variable in Hardness

Mattresses available in the market are broadly grouped under foam mattresses, open coil mattresses, pocket coil mattresses, and water (air) mattresses. The pocket coil mattresses among them have a structure consisting of multiple pocket coils (springs) to support independently the surface, and it can vary in hardness partly by changing the coil diameter and volume (see Fig. 1).

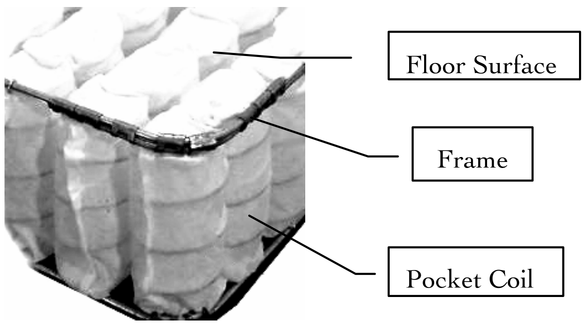


Figure 1: Structure of Pocket Coil Mattress

So, we divided the pocket coil mattress into 4 areas: head, chest, waist, and legs supporting areas, and changed the hardness and distribution of the mattress by applying 3 levels of spring harness (coil diameter: 1.6, 1.9 and 2.1mm) for the chest and waist areas. The coil diameter of 1.6mm are normally used for "soft" mattress, that of 1.9mm for "standard" one, and that of 2.1mm for "hard" mattress. We used fixed coil diameter of 1.9mm for head and legs part spring where relatively small sinkage are expected to avoid a massive combinations of experimental conditions, and applied 3 different levels of coil diameter only for chest and waist part springs. Consequently, we used 9 types of mattresses with different hardness in chest and waist parts for the experiment. Fig. 2 shows the overview of mattress, and table 1 shows characteristics of each sample. And we used semi-double sized mattresses (200cm long, 120cm width).

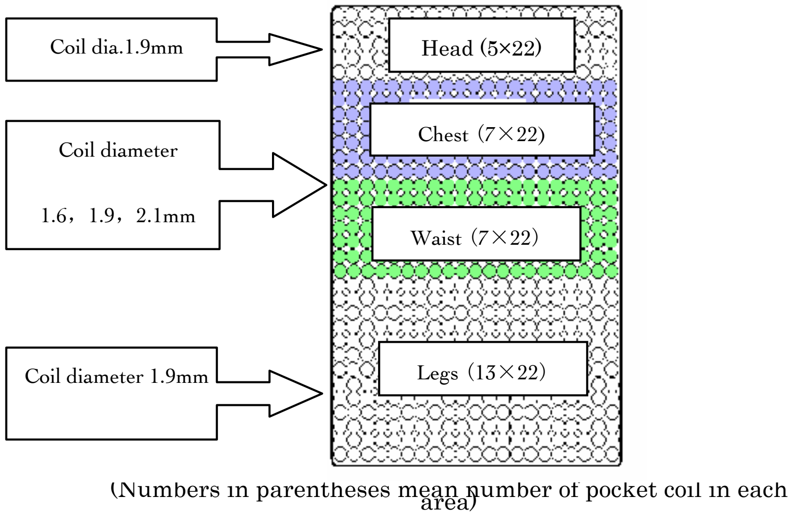


Figure 2: Overview of Hardness Variable Mattress

Table 1: Characteristics of Mattress Samples

Sample	Characteristics
(a) Chest 1.6mm, Waist 1.6mm	Soft in general
(b) Chest 1.6mm, Waist 1.9mm	Soft in Chest and Normal in Waist
(c) Chest 1.6mm, Waist 2.1mm	Soft in Chest and Hard in Waist
(d) Chest 1.9mm, Waist 1.6mm	Normal in Chest and Soft in Waist
(e) Chest 1.9mm, Waist 1.9mm	Normal in general
(f) Chest 1.9mm, Waist 2.1mm	Normal in Chest and Hard in Waist
(g) Chest 2.1mm, Waist 1.6mm	Hard in Chest and Soft in Waist
(h) Chest 2.1mm, Waist 1.9mm	Hard in Chest and Normal in Waist
(i) Chest 2.1mm, Waist 2.1mm	Hard in general

2.2. Measurement of Sleeping Posture

Plaster bandage [8] is known as a general method of measuring sleeping posture. However this method is not suitable to collect large numbers of data, since it requires the subjects to be strained and much time for the preparation. So, for this paper, we placed a stick in each pocket coil consisting mattress as shown in Fig. 3, and we estimated the sleeping posture by measuring the sinkage from the position change of the stick made by the compression of pocket coils. We measured the stick end position with 2 digital cameras

(Olympus SP-350 8mega pixel) in parallel stereo algorithm [9]. Since the measurement accuracy of the parallel stereo algorithm is 1.8mm, and the sinkage rate in chest and waist parts for supine position were measured about 20 – 80mm in preliminary experiment, we considered this accuracy as appropriate for this experiment. As the mattress used for the experiment consists of 704 pocket coils, and it would take much time to measure the entire sinkage rate, we measured the sinkage amount for the left side of the body on the presumption that sleeping posture is symmetric.

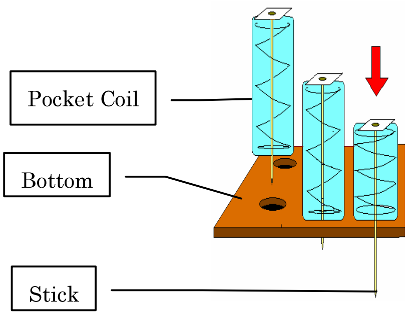


Figure 3: Measurement Algorithm of Mattress Sinkage

2.3. Measurement of Sleeping Comfort

Sleeping comfort was evaluated through the subjective test by semantic differential (SD) method when subjects laid down on their back for 5 minutes. The subjective test was conducted by using 21 kinds of adjectives for items on hardness (4 kinds), items on fitness (5 kinds), items on pain (4 kinds), items on sinkage (4 kinds), and other items (4 kinds), and the evaluation was made in 5 different levels. Table 2 shows adjectives used for the test.

Table 2: Adjectives used for Measurement of Sleeping Comfort

Items on Hardness	**Items on Fitness**	**Items on Pain**	**Items on Sinkage**	**Other Items**
hard – soft in Head	fit – unfit in Head	painful – not painful in Head	sunken – not sunken in Head	feel at ease – Ill at ease
hard – soft in Chest	fit – unfit in Chest	painful – not painful in Chest	sunken – not sunken in Chest	unstable - stable
hard – soft in Waist	fit – unfit in Waist	painful – not painful in Waist	sunken – not sunken in Waist	difficult – easy respiration
hard – soft In Heel	fit – unfit in Heels	painful – not painful in Heels	sunken – not sunken in Heels	don't like – like in general
	fit – unfit in Whole Body			

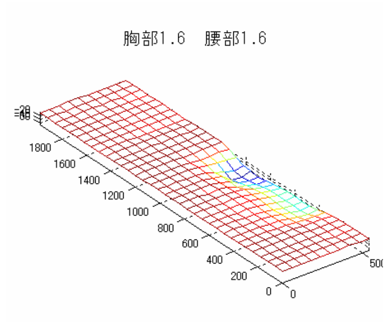
2.4. Body Type of Subject

We used BMI (Body Mass Index) to unify the body type, when choosing subjects. For this paper, we chose the standard body type with BMI of 18.5 – 20 [10]. And the subjects consisted of 20 healthy male students aged 19 to 23.

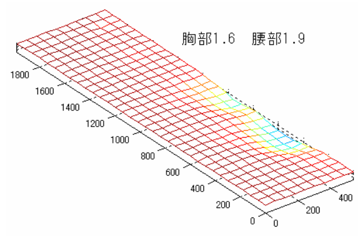
3. RESULT AND DISCUSSION

3.1. Sleeping Posture

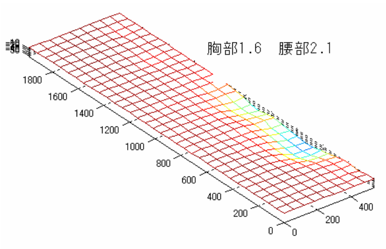
Fig. 4 shows the sleeping posture in left side of the body (sinkage distribution), when laid down on their back on 9 types of mattress with 9 different hardness and distribution. The sinkage amount in Fig. 4 is as indicated in the color bar, and the sinkage amount gets smaller when the color is more red, and larger when the color is more blue. And the subjects lay down on their back with their heads at the downside in the illustration. The figure shows the results of one subject, similar results was found also for other subjects.



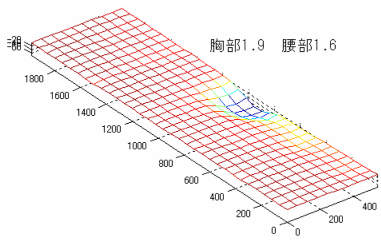
(a) chest:1.6mm, waist:1.6mm



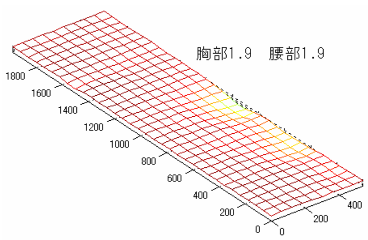
(b) chest:1.6mm, waist:1.9mm

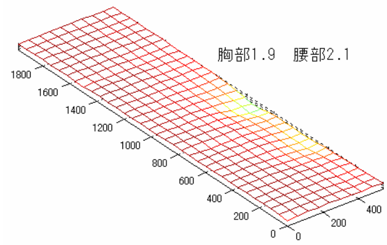


(c) chest:1.6mm, waist:2.1mm

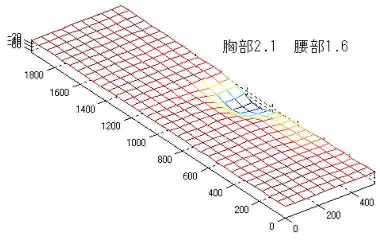


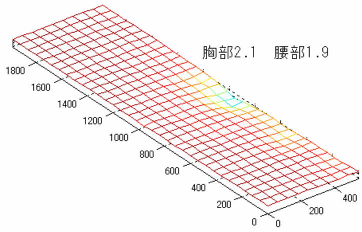
(d) chest:1.9mm, waist:1.6mm



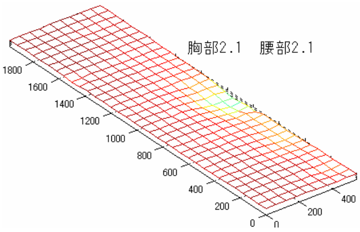


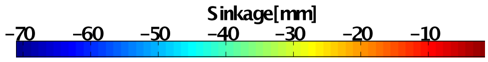
(e) chest:1.9mm, waist:1.9mm (f) chest:1.9mm, waist:2.1mm

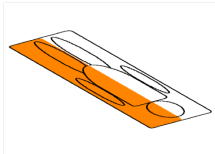




(g) chest:2.1mm, waist:1.6mm (h) chest:2.1mm, waist:1.9mm



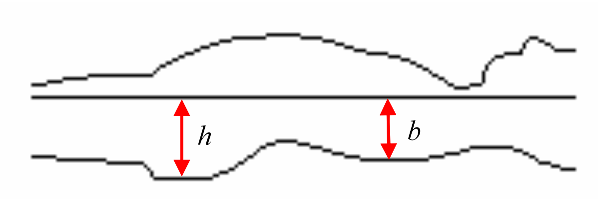




(i) chest:2.1mm, waist:2.1mm

Figure 4: Birds-Eye-View of Mattress Sinkage Distribution (Left Side of the Body Only)

It can be observed in Fig. 4 that the sinkage distribution changes according the combination of mattress spring diameters. In order to classify the sinkage distribution quantitatively, we measured the maximum sinkage amount in chest and waist part and calculated the proportion (Maximum Sinkage in Chest/Maximum Sinkage in Waist) as shown in Fig. 5 (See Table 3). When conducted two-way analysis of variance (repeated-measures) using both chest spring diameter and waist spring diameter as cause factors, an interaction was observed at a significant level of 5%, and significant difference was also found in the order of sample (d), (g) < (a), (e), (f), (h), (i) < (b), (c) as a result of multiple comparison. It is suggested by this result that the sinkage distribution in this experiment can be grouped broadly under 3 different categories. In the first case of sinkage ratio at 0.55 to 0.8, the waist part is more sunken by a factor of 1.3 to 1.8 than chest part. This distribution can be observed mainly when the same spring diameter is used for chest and waist, and the waist part is sunken more than chest because of the mass ratio of chest and waist in human body (chest : waist = 33% : 44%) [11] (see Fig.4 (a), (e), (f), (h), (i)).This distribution (sleeping posture) is named "Waist Part Type I" taxonomically here. In the second case of sinkage ratio of 1, the chest part is sunken more than waist part. This distribution can be found when the spring diameter is 1.6mm, and the sinkage amount in the chest part is larger than wait part because of the soft spring in chest part (see Fig. 4 (b), (c)).This distribution is named "Chest Part Type" in this papaer. In the third case of the sinkage ratio at 0.4 and below, the waist part is sunken more at a factor of 2.5 than the chest part. This distribution can be recognized mainly when the spring diameter is 1.6mm, and the waist part is sunken locally (so called "dog-leg" posture), because of the little sinkage in the waist part in relation with the above mentioned mass ratio in addition to the soft spring in the waist part (see Fig. 4 (d), (g)). Here this distribution is named "Waist Part Type II".



$$ratio = b / h \qquad (1)$$

Figure 5: Classification of Sinkage Distribution

Table 3: Sinkage Ratio at Chest/Waist of Each sample (n=20)

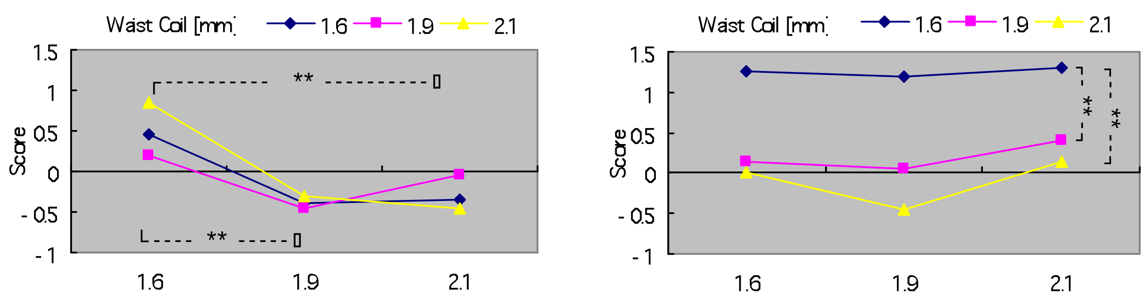
Sample	Sinkage Ratio at Chest/Waist
(a) Chest 1.6mm, Waist 1.6mm	0.71±0.22
(b) Chest 1.6mm, Waist 1.9mm	1.44±0.36
(c) Chest 1.6mm, Waist 2.1mm	1.45±0.33
(d) Chest 1.9mm, Waist 1.6mm	0.38±0.08
(e) Chest 1.9mm, Waist 1.9mm	0.76±0.23
(f) Chest 1.9mm, Waist 2.1mm	0.80±0.22
(g) Chest 2.1mm, Waist 1.6mm	0.35±0.08
(h) Chest 2.1mm, Waist 1.9mm	0.56±0.18
(i) Chest 2.1mm, Waist 2.1mm	0.66±0.21

3.2. Sleeping Comfort

Two-way analysis of variance by chest spring diameter (3 levels) and waist spring diameter (3 levels) of the mattress was conducted for the subjective test of 20 subjects on the sleeping comfort. Fig. 6 to 11 show the test result on each item.

3.2.1. Items on Sense of Hardness

Fig. 6 indicates the results of question on hardness at chest part and waist part among 4 adjectives on hardness. The higher rating in Fig. 6 shows the softer assessment declared by the subject. As a result of the test, we found that the subjects feel softer than any other diameter if the spring diameter is 1.6mm both in chest and waist part, and it became clear there is no significant difference in sense of hardness between the spring diameter of 1.9mm



and that of 2.1mm. Fig. 6 indicates that there is no influence of waist (chest) spring diameter but only chest (waist) diameter on the chest (waist) hardness, which lead to the result reflected by the characteristics pocket coil mattress consisting of independent springs. As for the sense of hardness in head and heels part, there is no significant difference among 9 different samples in head part, while in heels part there found an influence of waist spring diameter.

(a) Sense of Hardness in Chest Part (b) Sense of Hardness in Waist Part

Figure 6: Sense of Hardness in Chest Part and Waist Part

3.2.2. Items on Sense of Fitness

Fig. 7 shows the result on the sense of fitness in whole body among 5 adjectives relating to the sense of fitness. The higher rating in Fig. 7 shows higher fitness assessment declared by the subject. As a result of the test, we found main effect of chest spring diameter, the sense of fitness is significantly higher for the spring diameter of 1.6mm than any other diameter, and it became clear that there is no difference in sense of fitness between diameter of 1.9mm and that of 2.1mm. As proven from the result of sleeping posture (sinkage amount), the sinkage amount for spring diameter of 1.6mm is larger than any other diameter, and it is predictable that the mattress has deformed to fit the back shape. It is assumed that this leads to the sense of fitness.

Further observation on the sense of fitness by region, led to a finding that the sense of fitness in chest part has an association with the chest spring diameter just like the fitness in whole body. As for other regions, there is no difference in sense of fitness nor association with the spring diameter.

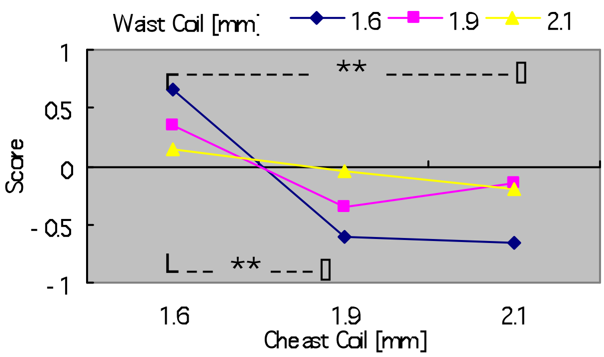


Figure 7: Sense of Fitness in Whole Body

3.2.3. Items on Pain

Fig.8 shows subjective test result on the pain in waist part among 4 different adjectives on pain. The lower rating in Fig. 8 shows the more pain experienced by the subjects. As a result of the test, we found main effect of waist spring diameter in waist part, the sense of more pain is recognized at the spring diameter of 1.6mm than any other diameter, and it became clear there is no significant difference in sense of hardness between the spring diameter of 1.9mm and that of 2.1mm. No significant difference in sense of pain was found in any other region, head, chest, or heels, and no association with the spring diameter was recognized.

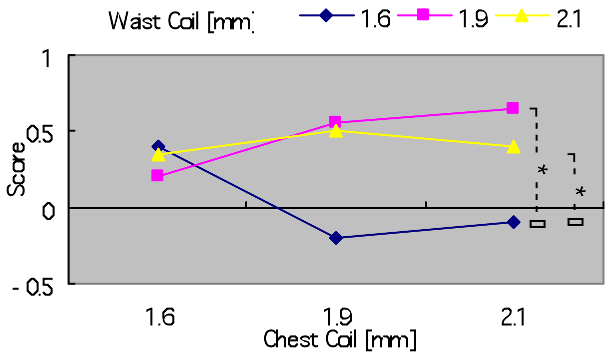
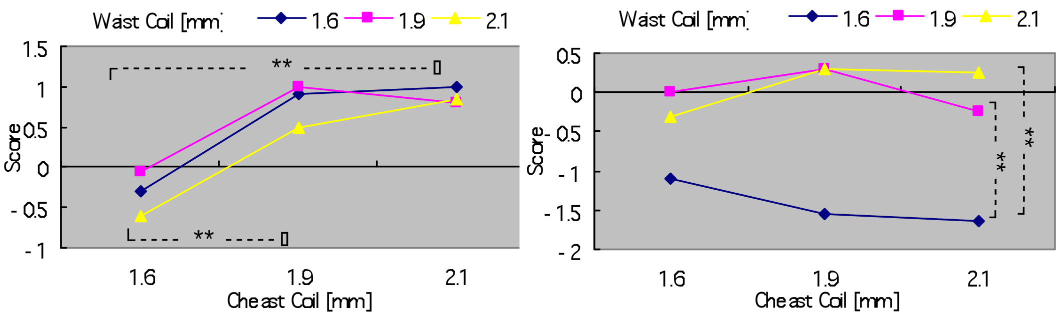


Figure 8: Pain in Waist Part

3.2.4. Items on Sense of Sinkage

Fig. 9 shows the result of sense of sinkage in chest and waist part among 4 adjectives on sinkage. The lower is rated in Fig. 9, the more sense of sinkage the subjects feel. As a result of the test, we found that the subjects feel more sense of sinkage than any other diameter if the spring diameter is 1.6mm both in chest and waist part, and it became clear there is no significant difference in sense of sinkage between the spring diameter of 1.9mm and that of 2.1mm. Since the sinkage has an association with the spring diameter (hardness), the same result was obtained as the sense of hardness on the mattress. No significant difference was found on the sinkage in head and heels parts, and no association with spring diameter was recognized.



(a) Sense of Sinkage in Chest Part (b) Sense of Sinkage in Waist Part

Figure 9: Sense of Sinkage in Chest and Waist Parts

3.2.5. Other Items

(1) Sense of Ease

Fig. 10 shows the result for sense of ease. The higher is rated in Fig. 10, the more sense of ease is declared by the subjects. As a result of the subjective test, the main effect of chest and waist spring diameters were recognized, and we found that there were more sense of ease in chest spring diameter of 1.6mm than any other diameter, while there were less sense of ease in waist spring diameter of 1.6mm than any other diameter. And it became clear that no significant difference in sense of ease between coil diameter of 1.9mm and that of 2.1mm both for chest and waist.

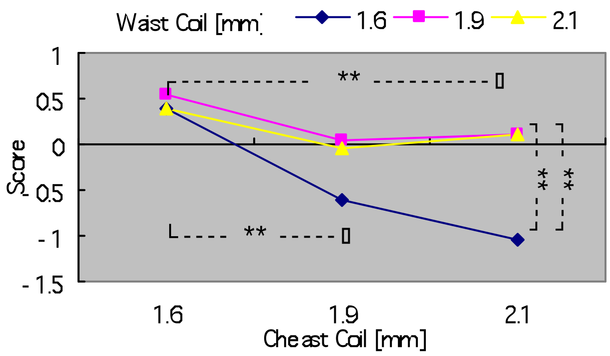


Figure 10: Sense of Ease

(2) Sense of Stability

The sense of stability was defined, in this paper, as the capacity to retain sleeping posture against vibration of mattress. As a result of the subjective test for the sense of stability, the main effect of chest and waist spring diameters was recognized just as is the case of above mentioned result for the sense of ease, and we found that there were more sense of stability in chest spring diameter of 1.6mm than any other diameter, while there were less sense of stability in waist spring diameter of 1.6mm than any other diameter. And it became clear that no significant difference in sense of stability is found between coil diameter of 1.9mm and that of 2.1mm both for chest and waist.

(3) Ease of Respiration

Fig. 11 shows the result regarding ease of respiration in supine position. The higher is rated in Fig. 11, the easier respiration is declared by the subjects. As a result of the subjective test, the main effect was found only for chest spring diameter, the chest spring diameter of 1.6mm allowed easier respiration than any other diameter, and it became clear that there is no difference in ease of respiration between diameter of 1.9mm and that of 2.1mm.

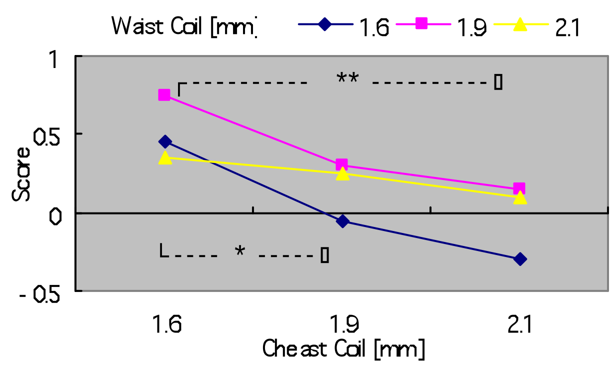


Figure 11: Ease of Respiration

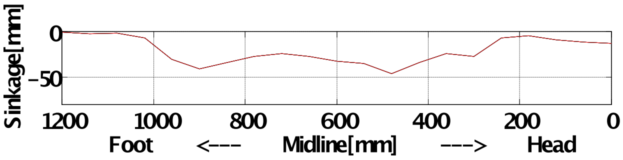
(4) Taste

As a result of the taste for the mattress in supine position, the main effect was recognized for chest and waist spring diameters just as is the case of above mentioned result for the sense of ease and sense of stability and we found that the chest spring diameter of 1.6mm was preferred rather than any other diameter, while the waist spring diameter of 1.6mm was ill-preferred rather than any other diameter. And it became clear that no significant difference in impression between coil diameter of 1.9mm and that of 2.1mm both for chest and waist.

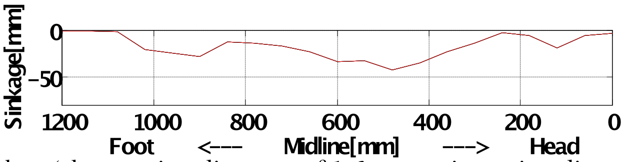
3.3. Relationship between Sleeping Posture and Sleeping Comfort

The sample proved broadly to provide sleeping comfort at subjective test in previous section, had chest spring diameter of 1.6mm and waist spring diameter of 1.9mm or 2.1mm .(see sample b & c) The sample proved to provide an ill sleeping comfort, had chest spring diameter of 1.9mm or 2.1mm and waist spring diameter of 1.6mm (see samples d & g). So we discuss the relationship between sleeping posture and sleeping comfort by comparing the sleeping postures when laid down on these samples.

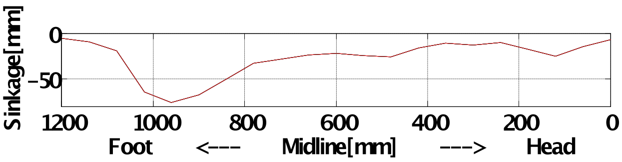
From the result of chest/waist sinkage amount ratio (see table 3), the sleeping posture would be "Chest Part Type", in which the chest part is sunken more than waist part, when the subject laid on their back on the samples (b & c), and this can be observed at the cross section view of sleeping posture (midline sinkage) (see Fig. 12 (a), (b)). Meanwhile, when the subjects laid down on their back on the samples with bad evaluation of sleeping comfort, the sleeping posture would be "Waist Part Type II" in which waist part is sunken more than chest part (see Fig. 12 (c), (d)). Therefore, from these results, it became clear that the sleeping comfort is good when the sleeping posture is "chest part type" in supine posture, while bad when the sleeping posture is "waist part type II".



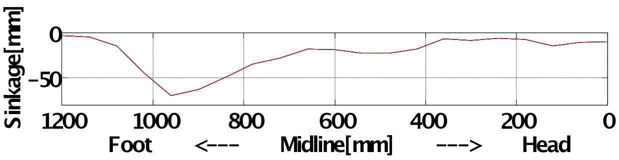
(a) sample b (chest spring diameter of 1.6mm, waist spring diameter of 1.9mm)



(b) sample c (chest spring diameter of 1.6mm, waist spring diameter of 2.1mm)



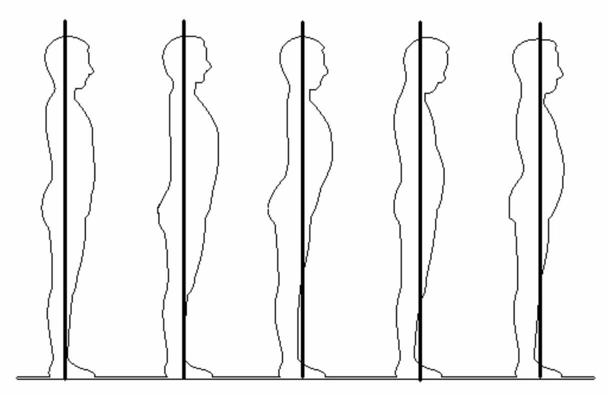
(c) sample d (chest spring diameter of 1.9mm, waist spring diameter of 1.6mm)



(d) sample g (chest spring diameter of 2.1mm, waist spring diameter of 1.6mm)

Figure 12: Sinkage Distribution in Supine Position on the Sample with Good Sleeping Comfort (b,c) and that with Bad Sleeping Comfort (d,g)

Then what is the reason why the sleeping comfort is better in the sleeping posture of "chest part type" and worse in the sleeping posture of "waist part type II"? Fig. 13 shows Staffel's 5 Classifications [12], known as the method of classification for standing postures. Among these classifications, S-shaped type is a posture requiring less burden to the body with natural curve on the spine, while in other postures, the spine turn into less natural shape, and it would be difficult to retain the same posture for a long time [13]. Although it is a matter of speculation, when compared Fig. 12 with Fig. 13, the spine is curved in natural shape for "chest part type" recognized in this paper just as is the case of S-shaped type, and this has something to do with the good sleeping comfort. Meanwhile, in case of "waist part type II", the spine becomes in linear shape as is the case of flat back or concave back type, and it is speculated that this could lead to a result of bad sleeping comfort. As for the relation between standing posture and sleeping posture, it is necessary to collect sufficient quantity of samples for a statistic evaluation, and we need to conduct a detailed study again.



S-Shaped, Flat Back, Concave Back, Round Back, Concave round

Figure 13: Staffel's 5 Classifications (Standing Posture)

When summarized, sleeping posture is one of the most important factors to determine the sleeping comfort, and it is implicated that the chest part is sunken more than waist in the sleeping posture when sleeping comfort is good, while the waist part is sunken more than chest when sleeping comfort is bad. Consequently, we think it is effective for sleeping comfort improvement, to make the chest spring softer and the waist spring harder to ease formation of "chest part type" sleeping posture when designing bedclothes.

4. CONCLUSION

In this paper, we reported the relationship between sleeping posture and sleeping comfort with a view to application by simulation for an estimation of sleeping comfort, and we make clear the following. (1) The sleeping posture varies according the hardness of mattress, and turns into the sinkage distribution for "chest part type" where the chest portion is sunken more than waist portion in case of mattress with soft chest part and hard waist part, while it turns into "waist part type II" where the waist part is notably sunken in case of mattress with hard chest part and soft waist part. (2) Sleeping comfort is improved in case of mattress with soft chest portion and hard waist portion. In contrast, the sleeping comfort becomes bad in case of mattress with hard chest portion and soft waist portion. (3) Sleeping comfort becomes better when sleeping posture (sinkage distribution) turns into "chest part type" and worse when sleeping posture turns into "waist part type II".

These conclusions suggest a capability to presume the sleeping comfort by the sleeping posture, and an estimation of sleeping comfort is expected by simulation in future. However, the knowledge obtained in this paper is what was found when laid down on the bed for a short time, and the association is not clear yet with the comfort in real sleep where sleeping posture varies intermittently by roll-over. Furthermore, we could not report the tendency variation by body type and the association with neck posture under influence of pillows, since we chose only young male adult with standard body type for the subjects, and measured the sleeping posture (sinkage amount) only for the chest portion and waist portion. So our future research issue is to broaden attributes of the subject, conduct some similar experiment in the state of resting and sleeping, and verify detailed association with time variation of sleeping posture and body pressure distribution.

ACKNOWLEDGMENTS

This experiment was conducted as a collaborative study with Simmons Co., Ltd., for which we like to express our sincere appreciation. Also we like to tender our deep gratitude to our former student, Mr. Tetsunobu Sato, who spent much time to help our data analyses.

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