1. INTRODUCTION

Sleep is essential in maintaining sound functions in the cerebrum and other areas and, as such, it assumes a role in improving quality of life. For a person to have a restful sleep, it is important that a good sleeping environment be provided. Of the factors affecting the sleeping environment, temperature / humidity, sound, and light are considered to be the three most important, with optimal values being assumed at 25˚C / 50% RH for temperature / humidity, 40 dB or below for sound, and 30 lux or below for luminous flux [1]. Thanks to scientific and technological progress, it is now possible to adjust these factors with relative ease. Another factor that affects the sleeping environment is bedding, which includes futons, bed mattresses, blankets, blankets made of toweling, sheets, pillows, and nightwear. Because bedding is used for many hours in direct contact with people, it is believed to exercise a significant impact on sleep; nonetheless there has until now been a dearth of research investigating the relationships between bedding and sleep.

One of the most important types of bedding is bed mattresses (hereinafter, “mattresses”), since they support a sleeping person’s body while ensuring comfortable sleep. Among the physical factors that mattresses are assumed to exert on people are their thermal properties (heat-retaining properties), contact properties (texture), and elastic properties (firmness). Based on the evaluation of mattresses by way of sensory testing, Ujiie concluded that feelings of firmness and sinking in affect the feel of bedding [2]. Since it is believed that the elasticity of mattresses has much to do with feelings of firmness and sinking in, this study investigates the impact that differences in mattresses’ degrees of elasticity might have on sleep by measuring both physiological and psychological responses. In order to conduct detailed analysis of the impact that physical properties of mattresses might have on sleeping conditions while a person is unconscious, the measurement of physiological responses such as cerebral activity is believed to be effective. The authors thus studied the possibility of evaluating the feel of mattresses through indices gained from physiological responses, and comparison of changes in moods after sleep with the results of physiological response measurements. In this study, the authors used polysomnography (PSG) testing, which diagnoses the condition of sleep, and Profile of Mood States (POMS) ratings, which examine moods and emotions, in order to evaluate the feel of mattresses, it is important to evaluate the psychological states of a person while he or she is awake both before and after sleep and the physiological states while unconscious during sleep. In this study, the authors used polysomnography (PSG) testing, which diagnoses the condition of sleep, and Profile of Mood States (POMS) ratings, which examine moods and emotions, in order to measure physiological and psychological conditions relating to the feel of bedding, and then verified the feel of mattresses accordingly. This report contains the evaluation results of mattresses based on depth of sleep indices as obtained through PSG testing, and evaluation results of...
the feel of mattresses based on mood differences before and after sleep as obtained using POMS rating.

When evaluating a person’s sleep conditions, the general method involves measuring brain waves to determine physiological changes during sleep [3]. In general, brain wave frequencies increase and register low amplitudes as the level of arousal rises. Conversely, brain wave frequencies decrease and register high amplitudes as the level of arousal declines. Since brain waves vary between deep and shallow sleep, the American Academy of Sleep Medicine (AASM) compiled an international sleep stage scoring system in 1968 [4]. Table 1 shows this sleep stage scoring. The scoring requires that the three indicators of brain waves, eye movement, and muscle potential in the jaw be measured simultaneously in a procedure known as polysonomography (PSG). PSG is determined at 20 or 30 second intervals. Periods are judged “Awake” if the \( \alpha \)-index is 50% or more and “Stage 1” if it is less than 50%. The development of \( \theta \) waves are not used to determine sleep stages. Instead, periods where sleep spindle and K-complex waves appear are judged to be “Stage 2.” If \( \delta \) waves with amplitude of 75 \( \mu \)V or more make up 20% or more of the evaluation period it is considered “Stage 3,” and if they make up 50% or more of the period it is judged “Stage 4.” Generally speaking, “Stage 1” and “Stage 2” are considered “light sleep,” while “Stage 3” and “Stage 4” are regarded as “deep sleep.”

Brain waves are in Stage 1 after approximately 1 hour of sleep, but as skeletal muscle tension decreases significantly the jaw muscle potential drops to its lowest level during the night. Rapid eye movement (REM) is observed sporadically during this period (REM sleep). In contrast to REM sleep, Stages 1-4 are referred to as “non-REM (NREM)” sleep. Those periods in which brain wave records indicate that muscle potential artifacts are mixed for 50% or more of the evaluation period are regarded as “Movement Time (MT).”

NREM sleep and REM sleep alternate, and one cycle of NREM and REM sleep will last for about 90 minutes. This is known as a sleep cycle, and it is repeated 4-5 times in a sleeping period. Deep sleep (Stages 3 and 4) is concentrated in the first half of the sleep cycle, whereas Stage 2 and REM sleep frequently manifest in the latter half of the sleeping period. As described so far, the first sleep cycle is one of the keys to evaluating sleep, as it tends to be the deepest sleep of a given sleeping period.

2. EXPERIMENT

2.1 Experimental environment and samples

The experiment was conducted in a thermo-hygro static room where constant temperature and humidity of 25°C and 50 % RH were maintained. The laboratory was kept in a thermally comfortable condition.

In the mattresses used as samples for the experiment, rows of pocket coils were arranged where each metal spring was compressed and placed in its own sleeve of non-woven fabric. By changing the linear shape and how tightly the coils are wound (number of turns) it is possible to design mattresses with different degrees of elasticity. In this study, four types of commercially available mattresses with different degrees of elasticity were used for the experiment. Shown in Table 2 are the pocket coil specifications of each type of mattress. The spring constant was obtained through our experiment of elasticity. For the purposes of this research, the four types of mattresses with different degrees of elasticity are described as A140, B100, C088, and D072 in descending order according to their elasticity. Using this naming protocol, it is easy to differentiate the type of mattress used. The wire diameter and number of turns in the spring coil was not detailed in this paper. Therefore, the naming protocol was somewhat redundant. However, Table 2 details the samples used in this experiment. Other than mattresses, bed pads (outer fabric: 100% cotton, padding: 100% polyester), sheets and EMG records cannot be evaluated for 50% or more of the evaluation period.

Table 1: International Sleep Stage Scoring [4]

<table>
<thead>
<tr>
<th>Category</th>
<th>State</th>
<th>Brain waves, eye movement, muscle potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWAKE</td>
<td>Aroused</td>
<td>( \alpha )-waves and low voltage EEG of various frequencies are mixed. Weeks and high amplitudes trigger sustainable REM.</td>
</tr>
<tr>
<td>NON-REM (Non-REM Sleep)</td>
<td>STAGE 1 Sleep rests the cerebrum for recovery. Ranges from shallow (STAGE L) to deep sleep (STAGE D)</td>
<td>waves make up less than 50% of the total wave patterns, and various waves with relatively low voltages are mixed. Slow eye movements observed in the initial stage of sleep.</td>
</tr>
<tr>
<td></td>
<td>STAGE 2 Spindle waves lasting for 0.5 seconds or longer and K-complex waves 0.5 seconds or longer appear. High-voltage slow waves satisfying the definitions of STAGES 3 or 4 are not recognized.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STAGE 3 High-voltage slow waves of 2 Hz or more and amplitude of 75 ( \mu )V or more ( \delta )-waves make up more than 20% of the total wave patterns.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STAGE 4 High-voltage slow waves of 2 Hz or more and amplitude of 75 ( \mu )V or more ( \delta )-waves make up more than 50% of the total wave patterns.</td>
<td></td>
</tr>
<tr>
<td>REM (REM Sleep)</td>
<td>Wakes the cerebrum up from Non-REM sleep. The body is languid but the brain is near arousal.</td>
<td>Waves of relatively low voltage and in various frequencies are mixed and rapid eye movements occur. Skeletal muscle tension decreases significantly and jaw muscle potential drops to its lowest level.</td>
</tr>
<tr>
<td>MT (Movement Time)</td>
<td>Body movements shifting sleeping posture (turning over, etc.) are observed.</td>
<td>Muscle tension accompanied by body motions and artifacts prevent evaluation of waves and EMG records cannot be evaluated for 50% or more of the evaluation period.</td>
</tr>
</tbody>
</table>

Table 2: Pocket coil specifications of each mattress

<table>
<thead>
<tr>
<th>Sample</th>
<th>Spring constant (kgf/mm)</th>
<th>Wire diameter</th>
<th>Turns</th>
<th>Coil diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A140</td>
<td>0.0140</td>
<td>2.1</td>
<td>5</td>
<td>59</td>
</tr>
<tr>
<td>B100</td>
<td>0.0100</td>
<td>1.9</td>
<td>5</td>
<td>59</td>
</tr>
<tr>
<td>C088</td>
<td>0.0088</td>
<td>1.7</td>
<td>4</td>
<td>59</td>
</tr>
<tr>
<td>D072</td>
<td>0.0072</td>
<td>1.6</td>
<td>5</td>
<td>59</td>
</tr>
</tbody>
</table>
(100% cotton), blankets made of toweling (100% cotton), and pillows (outer fabric: 75% cotton, 25% polyester, padding: 100% polyester) were used.

2.2 Subjects

It is expected that the feel humans will receive from a mattress differs depending on their gender, age, and physique. It was therefore decided to limit the subjects of this research to male individuals with a standard physique, whose Body Mass Index (BMI) as computed by weight/height² fell within the range of 18.5 – 25. The subjects were 13 male undergraduate and graduate students who were both mentally and physically sound and had no sleep disorders. Table 3 shows data on their physiques. The subjects were instructed beforehand not to consume any coffee, alcohol, etc. or do any excessive exercise prior to the experiment. They were also asked to wear the same clothing that they would normally wear while sleeping. Before the day of the experiment, the subjects submitted a written agreement on their participation in the experiment and use of the experimental data for subsequent investigations.

2.3 Physiological response measurement

PSG was used in order to conduct subjective and qualitative evaluation of the impact that mattresses with different degrees of elasticity might have on sleep. PSG records human sleep-related biophysiological phenomena to monitor the depth and development of sleep over time, and necessitates simultaneous recording of multiple physiological indices (brain wave recording, electrooculography, and electromyography).

In accordance with the international ten-twenty electrode system, the electroencephalogram (EEG) was recorded by using a monopolar lead method with C3, C4, and A1 and A2 (left and right ear lobes) being standard attachment areas. For the electrooculogram (EOG), eye movements on both sides were recorded by installing electrodes at an area 1 cm obliquely upward from the outer canthus of the left eye and at an area 1 cm obliquely downward from the outer canthus of the right eye, and by using a monopolar lead method, in which the lobe of ear (A1) served as standard attachment areas. To record the electromyogram (EMG), two electrodes were attached 3-4 cm apart from each other above the jaw muscle and a recording was made using a bipolar lead method. Grounding of the body was made in the region near the collarbone. Figure 1 illustrates where the electrodes were attached. The electrodes used for this experiment were dish-type biological electrodes (ACT biological electrodes AC-P102, Digitex Lab. Co., Ltd.), to which paste for measuring biological signals was applied. To prevent the electrodes from peeling off, elastic surgical tape was attached over the electrodes. The biological signals were amplified using a bioamplifier (Polymate AP1132, TEAC Corporation) and then converted from analog to digital at a sampling frequency of 500 Hz before being recorded on a computer.

Sleep stages, which indicate the depth of sleep, were determined from the PSG data gathered. It is believed that REM sleep and NREM sleep alternate in a cycle of roughly 90 minutes during adult sleep. Analysis was made for a period up to two hours after the experiment began, since it is assumed that sleep can be deepest during the very first cycle and so variances among different subjects would be small, and that the condition of sleep during the initial stage from going to bed to falling asleep can most significantly affect the resting period.

The depth of sleep can be determined in a comprehensive manner based on the occurrence ratio of different brain waves, amplitudes, eye movements, and jaw muscle activity. Sleep stages were recorded every 30 seconds using sleep brain wave analysis software (Sleep Sign Ver2, Kissei Comtec Co., Ltd.) and determined in accordance with the international scoring system of Rechtschaffen and Kales. Sleep stages were determined according to the six grades of Stage W (including MT), Stage R, and Stages 1 through 4. Sleep efficiency and occurrence ratios of each sleep stage during the respective analysis periods were then computed based on the results. Also, sleep conditions were compared among different samples by calculating the average sleep depth.

For chronological data of sleep stages (indicating sleep depth) appearing in a given analysis period, a score of 0 was assigned to Stage W (including MT), with 0.5 assigned to Stage REM, 1 to Stage 1, 2 to Stage 2, 3 to Stage 3, and 4 to Stage 4. Here, in this experiment, a semi-awake state of REM sleep has been assumed. It was given a weighting of 0.5, since the brain is almost in a fully awake state while the body was considered to be in a resting state[5]. The

<table>
<thead>
<tr>
<th>Table 3: Subject physique data</th>
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<tbody>
<tr>
<td>Number of subjects</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BMI</td>
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</tbody>
</table>

Figure 1: Electrode attachment areas
average sleep depth S could then be obtained using the following formula, where \( n \) = the total number of data in a given analysis period and \( x_j \) is the sleep stage that has appeared.

\[
S = \frac{1}{n} \sum_{j=1}^{n} x_j
\]

The occurrence ratio of each sleep stage is defined as the ratio of data that was judged as, for example, Stage 3 during a given analysis period to the total data. The occurrence ratios of other sleep stages were computed in a similar manner.

2.4 Psychological reaction measurement

In order to evaluate each sample, the moods of subjects after sleeping on a mattress with a given degree of elasticity were investigated based on changes in POMS results taken before and after sleep. POMS is a type of testing using a questionnaire method, in which subjects are requested to respond using one of 5 grades (scores of 0 – 4) to 65 questions developed to investigate the temporary moods and emotions of subjects [6]. POMS rating is also applied in the psychological and psychosomatic medicine fields to understand the state of diseases and evaluate therapeutic effects, and its effectiveness has been verified [7, 8]. Using the POMS system, 6 factors that concern human moods and emotions (tension, depression, anger, vigor, fatigue, and confusion) can be measured. In order to analyze the data, scores of each constituent item were totaled for each scale in order to calculate raw scores for every question except for dummy questions. The raw scores were then converted into standardized ones (T scores) to calculate the scores for each item. As an index for indicating complete mood conditions, total mood disturbance (TMD) was calculated. The TMD was computed using Schacham’s method [9], where a score for vigor (positive factor) was deducted from the total scores of the five negative factors (those other than vigor), to which a value of 100 was added. Based on differences in the moods of subjects before and after sleep, the effect of sleep in improving mood was verified and comparison was made among different samples.

2.5 Experimental procedure

The experiment was performed according to the subjects’ usual times for going to bed and waking up whenever possible. Subjects entered the laboratory one hour before their bedtime. After being briefed on the experiment, electrodes for recording polygraphs were installed, pre-sleep surveys were conducted, and POMS rating was performed to check their moods prior to sleep. They were then asked to assume a supine position on a mattress, and the electrodes’ lead wire was connected to the measuring instrument. Consideration was given to keep the resistance of electrodes below 5 kΩ. The recording condition of each physiological index was then checked [10].

After checking the recording conditions, the experiment was started by turning off the lights. The experiment was assumed to have ended when the lights of the room were turned on and the subjects had woken up and risen from the mattress. Then, electrodes were removed and post-waking surveys and POMS ratings immediately after sleep were performed.

The subjects slept on 4 different mattresses randomly, and for each subject 2 experiments using 1 type of mattress each (total 8) were conducted. Although the procedure was conducted 26 times, twice the electrodes came off the test subjects while sleeping, and so data was only successfully collected on 24 occasions. Similarly, the successful collection of data from POMS failed once, resulting in data for 25 procedures.

3. RESULTS AND DISCUSSION

3.1 Differences in sleeping posture due to varying elasticity of bed mattresses

Mattresses used for this research had different degrees of elasticity. Variances in elastic properties can affect sleeping postures, which presumably cause differences in the feel of mattresses. It is therefore important to monitor subjects’ sleeping postures when evaluating the feel of mattresses.

Because the most common posture at the time of falling asleep and during sleep is a supine position [11], the shape along the median line on the back side of a human body lying in such a position (sleeping posture curve) was measured for each sample to determine differences in sleeping postures among different samples. Shown in Figure 2 are the sleeping posture curves observed when subjects were lying supine on each of the four types of mattresses with different degrees of elasticity. The values given below are the averages of the seven subjects (height:

Figure 2: Sleeping postures in a supine position for each sample
168 ± 5 cm, weight 60.8 ± 6.0 kg). It was confirmed that the sleeping posture curves varied among different samples. The amount of sinking in was large for mattresses with a low degree of elasticity, and displacement was greater for the area from the waist to the hip.

3.2 Evaluation of sleep based on physiological reactions

Using the data on determined sleep stages, the average sleep depth two hours after the experiment began was calculated. Shown in Figures 3 and 4 are the sleep efficiency and average sleep depth for each sample. For sleep efficiency, A140 and B100, whose degrees of elasticity were higher, recorded higher efficiency than the other two. Average sleep depth was also deeper in the order of A140, B100, C088, and D072, displaying a trend toward deeper sleep as the samples’ degree of elasticity increased. Variance analysis and multiple comparisons using the Tukey method did not show any statistically significant disparities among different samples.

Using the data on determined sleep stages, the occurrence ratios of each sleep stage within two hours after the experiment began were calculated. Shown in Figure 5 are the occurrence ratios of each sleep stage for the samples. The occurrence ratios of Stage W, Stage R, Stage 1, and Stage 2 did not vary much among samples, but those of Stage 3, Stage 4, and Deep Sleep (Stage 3 and Stage 4 combined) were highest in A140 and decreased steadily in B100, C088, and then D072, indicating the trend that, as with average sleep depth, the occurrence ratio of deep sleep stages was higher for samples whose degrees of elasticity were higher. The occurrence ratios of each sleep stage did not show any statistically significant differences either.

3.3 Mood surveys

Figure 6 shows differences in the POMS results of each sample before and after sleep. Scores for the factors of tension, vigor, and fatigue were seen to either increase or decrease in the order of A140, B100, C088, and D072. Variance analysis and multiple comparisons using the Tukey method revealed significant differences in fatigue factors between samples A140 and D072, and between samples B100 and D072.

Figure 7 shows the TMD scores for each sample before and after sleep. Also shown on Figure 6 are the POMS

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Figure 3: Sleep efficiency of mattresses (N = 24)

Figure 4: Average sleep depth of mattresses (N = 24)

Figure 5: Occurrence ratios of each sleep stage for the samples (N = 24)

Figure 6: Differences in T scores for each sample before and after sleep (N = 25)

Figure 7: TMD scores for each sample before and after sleep (N = 25)
results for each sample before and after sleep. To evaluate the differences, the Wilcoxon test was used. For samples A140 and B100, TMD scores after sleep lowered compared to those before sleep, and significant differences were observed.

4. CONCLUSION

In all three indices for evaluating the quality of sleep, namely, sleep efficiency, average sleep depth, and sleep stage occurrence ratios, mattresses with higher degrees of elasticity were seen to allow good sleep. In particular, the results of average sleep depth and sleep stage occurrence ratios confirmed that average sleep was deeper and the occurrence ratios of deeper sleep stages were higher in order of samples with higher degrees of elasticity (A140 > B100 > C088 > D072). It can therefore be safely inferred that the subjects entered into deeper sleeping conditions when sleeping on samples with higher degrees of elasticity.

POMS results showed that for each sample the scores of negative factors lowered after sleep compared to before. This shows that both the mind and body of the subjects recovered after resting, which made them feel good after the sleeping period. Comparison among samples revealed that, for samples A140 and B100, scores of negative factors for many items showed a significant decrease after sleep compared to before, while scores for vigor (positive factor) increased. Furthermore, with regard to TMD scores, which indicate the general mood of the subject, scores for samples A140 and B100 lowered after sleep. This suggests that sleeping on samples A140 and B100 prompted further improvement of feeling. Also, differences in scores before and after sleep confirmed that fatigue lowered but vigor rose after sleep in order of samples with higher degrees of elasticity (A140 > B100 > C088 > D072). It may thus be concluded that the higher the elasticity of a sample was, the better the subjects felt after sleep, which brought about major improvements in their moods.

From the above information, it may be determined that, so long as male subjects with a standard physique are used, the sleeping conditions are favorable for mattresses with higher degrees of elasticity, and the effects of improvement in the moods after sleeping on such mattresses are greater.

It has been reported that NREM sleep works to delete or reduce the intensity of unnecessary memories, such as those involving anxiety and stress experienced in daily life. For mattresses with high degrees of elasticity, there were high occurrence ratios of deep sleeping stages, during which NREM sleep is experienced. It may therefore be assumed that, because NREM sleep was able to fulfill its function to eliminate memories of anxiety and stress during daily life, the POMS scores for negative factors were lowered. For mattresses with low degrees of elasticity, on the other hand, it would seem that the effects of NREM sleep were insufficient. It appears that this has something to do with the factor of sinking in among sleeping postures as shown in Figure 2. It must be particularly noted that sinking in at the waist affected the subjects’ movement, such as turning over, and thus had an impact on the quality of sleep. From these results, it may be suggested that movement can affect the quality of sleep.

It has been confirmed that the feel of mattresses with different degrees of elasticity can affect the depth of sleep and the moods after sleep, and that mattresses with higher degrees of elasticity were evaluated favorably. The technique used for this research, namely, evaluating psychological states during the aroused condition before and after sleep and physiological conditions while unconscious during sleep, makes it possible to conduct subjective evaluation of the feel of mattresses. Also, because mattresses’ physical properties when altering their degrees of elasticity in stages have been identified, it is now possible to numerically express the firmness of comfortable mattresses.

In this research, however, the subjects of the experiments were all male university students with a standard physique. It is believed that variances in the physique, gender, and age of subjects may result in different effects from mattresses. For example, obese subjects would be expected to experience greater sinking into the mattress than subjects with a standard physique, and the results of experiments would thus differ from those conducted on subjects with a standard physique.

The authors wish to conduct experiments using a broader subject profile and, by combining other evaluation methods such as simulations, hope to continue with their studies to predict and evaluate mattresses that are comfortable for each individual.

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REFERENCES


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