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SLEEPING COMFORT EVALUATION OF BED MATTRESSES BASED ON POLYSOMNOGRAPHY (PSG) AND MOTION ANALYSIS DURING SLEEP

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ABSTRACT

The purpose of this study is to create an evaluation index for the quality of sleep according to the elastic properties of bed mattresses, by measuring physiological and psychological responses and the motion of turning over in bed while sleeping. Four different bed mattresses with different elasticity moduli were used. All of the mattresses featured a pocket coil system.

In order to monitor the depth of sleep – an important indicator of the quality of sleep – the polysomnography (PSG) results of subjects sleeping on each bed mattress were measured using a bio-amplifier. PSG is a comprehensive recording of the biophysiological changes which occur during sleep. Additionally, the subjects' body motions during sleep were measured with an actigraph (accelerometer) by calculating how many times each subject turned over in bed.

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The PSG-based evaluation revealed that the depth of sleep was greater for bed mattresses with higher elastic moduli. With regard to turning over during sleep, the motion of the legs was less than the motion of the arms for bed mattresses with lower elasticity moduli. This was presumably because the subjects on bed mattresses with lower elasticity moduli slept more lightly, since it was not easy for them to turn over as the area from the lumbar to the gluteal region sank deeper into bed mattresses with lower elasticity moduli. It was therefore concluded that the frequency of turning over in bed is as useful as PSG when used as an indicator by which to infer quality of sleep.

Keywords: *Sleep, Bed Mattress, Comfort, Polysomnography (PSG), Actigraph*

1. INTRODUCTION

Sleep plays an important role in relieving the fatigue of the brain and body. Recently, there has been growing social concern about the relationship between sleep and health. A survey by the Ministry of Health, Labour and Welfare of Japan showed that one in every five Japanese people has some kind of concern regarding sleep[1]. Another survey by the NHK Broadcasting Culture Research Institute revealed that the hours of sleep for Japanese people have been on the decline since 1970[2]. The issue of sleep and health can become even more urgent, as people stay up later and the population ages rapidly. Thus, there is a need for measures to improve technologies which can support healthy sleeping habits.

In order to lead a lifestyle with healthy sleeping habits, it is necessary to create an environment for comfortable sleep, which in turn requires high quality of bedding, as well as temperature and humidity, luminosity, and ambient sound. Since bedding is used for many hours in direct contact with the human body, it can have a significant influence on sleep. Recent years have seen the development of bedding which helps to improve sleep, but there have been few scientific observations on how to select bedding that suits individual needs.

In this study, the elastic properties of bed mattresses were noted. The influence on sleep of bed mattresses with different elasticity moduli was verified by PSG and the frequency of turning over in bed, thus evaluating the sleeping comfort of bed mattresses. The purpose of this study is to create an evaluation index for the quality of sleep according to elastic properties of bed mattresses, by measuring physiological and psychological responses and the motion of turning over in bed while sleeping.

2. METHODS

2.1. Bed Mattresses

For this experiment, four types of bed mattresses with different elasticity moduli were used (A140, B100, C088, and D072). All of the mattresses featured a pocket coil system. The spring constants of the coils in the mattresses were 0.0140kgf/mm, 0.0100kgf/mm, 0.0088kgf/mm, and 0.0072kgf/mm, respectively. Figure 1 shows the relationship between the load and displacement for the pocket coils of each bed mattress.

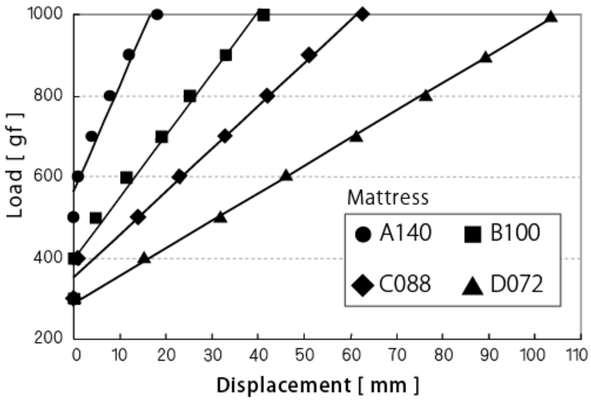

Figure 1: Load-displacement relationship of pocket coils for each bed mattress

2.2. Relationship between bed mattresses and sleeping posture

How the difference in elastic moduli can influence the sleeping posture was investigated by using a slide gauge to measure the back posture of the subjects while lying on the bed mattress (Fig 2). The subjects were seven male college students of standard physique, i.e., 168.0±5.0 cm in height and 60.8±6.0 kg in weight. The bed mattresses with lower elastic moduli sank more significantly (larger displacement).

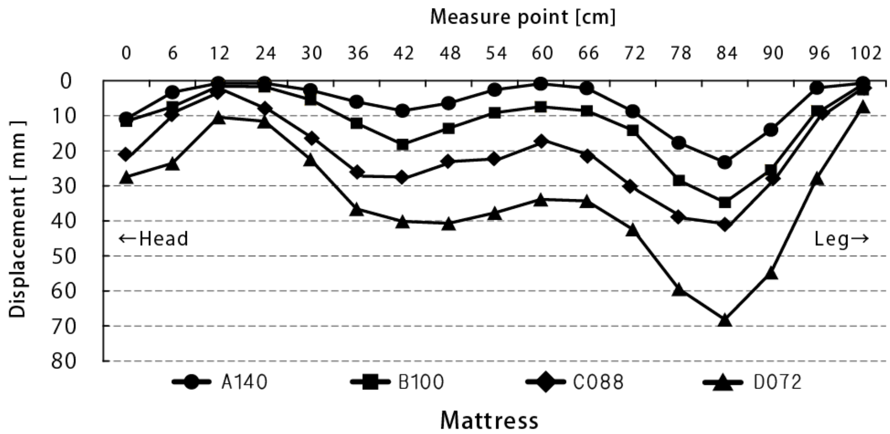

Figure 2: Displacement of sleep posture for each bed mattress (Mean of seven subjects)

2.3. Experiment 1: Sleeping comfort evaluation by PSG

PSG was measured for the subjects using a bio-amplifier while sleeping on each bed mattress, so that the depth of sleep – an indicator of the quality of sleep – could be estimated. PSG is a method of comprehensively recording the biophysiological changes that occur during sleep.

2.3.1. Subjects

The subjects were 10 male college students of standard physique, i.e., 170.6±5.0 cm in height and 60.8±4.6 kg in weight, with a 20.9±1.4 body mass index.

2.3.2. Experimental environment

The experiment room was controlled at an operative temperature of 25.0℃ and a relative humidity of 50%.

In addition to the bed mattresses, a bedpad, sheet, towel blanket, and pillow were used for the experiment. Subjects wore the same clothes as they would normally sleep in.

2.3.3. Procedure

This experiment was conducted according to the usual bedtime of the subjects. The subjects entered the experiment room one hour before going to bed, wore electrodes for PSG, and had their general feelings evaluated before sleeping. Then, the subjects were asked to lie on the bed mattress, and the electrode's lead wire was connected to the measuring device before beginning the experiment. The experiment was finished by evaluating their feelings after sleeping when they had awoken. This experiment was conducted twice for each subject using one kind of mattress, with the four kinds of mattresses being used randomly among the subjects.

2.3.4. Measuring and analysis method

For PSG, electroencephalograms (EEG), electrooculograms (EOG), and electromyograms (EMG) were recorded at a sampling frequency of 500 Hz. Figure 3 illustrates the locations of the electrodes.

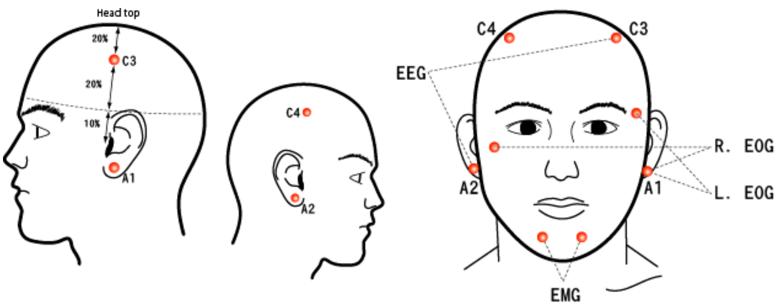

Figure 3: Location of electrodes

Based on the data recorded using PSG, the depth of sleep of the subjects was analyzed. Human brain waves are classified into □ wave (- 4 Hz), □ wave (4 Hz - 8 Hz), □ wave (8 Hz - 13 Hz), and □ wave (13 Hz -) patterns. The depth of sleep was judged overall by taking into account the frequency of each brain wave's appearance, the amplitude of the brain waves, ocular motility, and muscle activity. The depth of sleep was judged using sleep brain wave analysis software (Sleep Sign ver.2.0, Kissei Comtec Co., Ltd., Japan) every 30 seconds in accordance with the international judgment standard of Rechtshaffen & Kales[3]. Depth of sleep was categorized into six stages, comprised of stages 1-4, stage W, and stage R.

2.3.5. Sensory evaluation

Then, the Profile of Mood States (POMS) was used to survey the subjects' feelings. The POMS is a 65-item, self-administered scale developed specifically to investigate subjects' feelings and emotions at a certain time, and is a useful tool for intervention research. This assessment measures the six factors of Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor, Fatigue, and Confusion. POMS assessment was conducted immediately before and after sleep in order to monitor how the feelings and emotions of the subjects changed.

2.4. Experiment 2: Sleeping comfort evaluation using motion analysis while sleeping

In order to investigate the kind of influence a difference in elastic moduli of bed mattresses has on the subjects' motion while sleeping, the number of body motions while sleeping was calculated using an accelerometer. The bed mattress and experimental environment for this experiment were similar to those used in Experiment 1 (Section 2.3.).

2.4.1. Subjects

The subjects were four male college and graduate school students of standard physique, i.e., 174.0±2.2 cm in height and 61.3±3.4 kg in weight, with a 20.2±0.8 body mass index.

2.4.2. Procedure

The experiment was performed using a procedure similar to that described in Section 2.3.3. above. An accelerometer was attached to the non-dominant arm and non-dominant leg of each of the subjects. The four kinds of bed mattresses were used randomly among the subjects.

2.4.3. Measuring method

An actigraph (Micro-Mini Actigraph) by AMI Inc. of the USA was used in the experiment. The actigraph is a measuring device widely used for research and clinical evaluation of sleep[4][5]. The output of the actigraph was obtained using the zero-crossing mode (ZCM) and time above threshold mode (TATM).

3. RESULTS AND DISCUSSION

3.1. Influence on depth of sleep

The mean depth of sleep for each bed mattress is shown in Figure 4. Sleep was observed to be deepest for the A140 bed mattress with the highest elastic modulus, followed by the B100, C088, and D072. Sleep tended to be deeper for bed mattresses with higher elastic moduli.

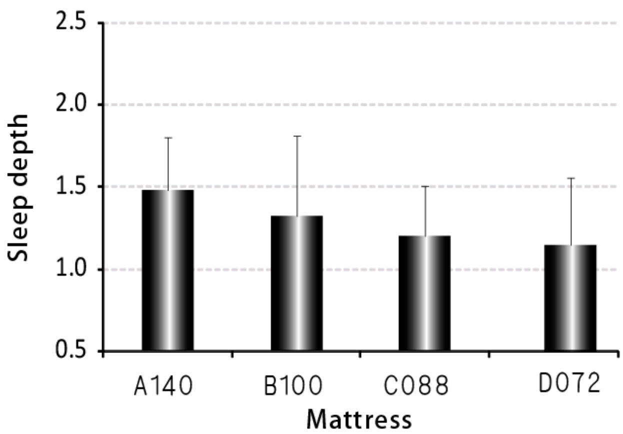

Figure 4: Depth of sleep for each bed mattress (mean of ten subjects)

Shown in Figure 5 is the incidence of deep sleep for each bed mattress. The incidence of Stage 1 and Stage 2 showed little difference. However, the incidence of "Deep Sleep (Stage 3 and Stage 4)" was greater for bed mattresses with higher elastic moduli.

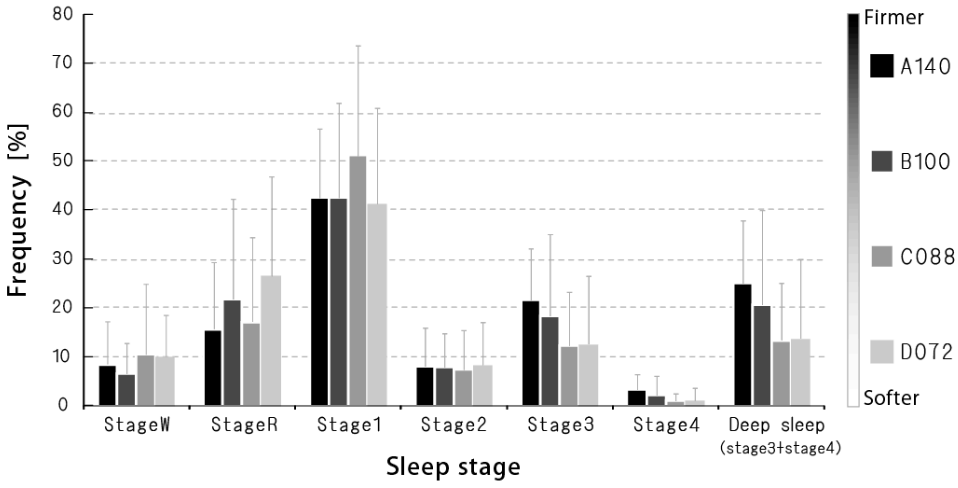

Figure 5: Incidence of sleep stages for each bed mattress (Mean of ten subjects)

Differences in POMS score before and after sleep for different factors are shown in Figure 6. Bed mattresses with higher elastic moduli exhibited a higher score for improvement of Vigor (V) and reduction of Fatigue (F) after sleep.

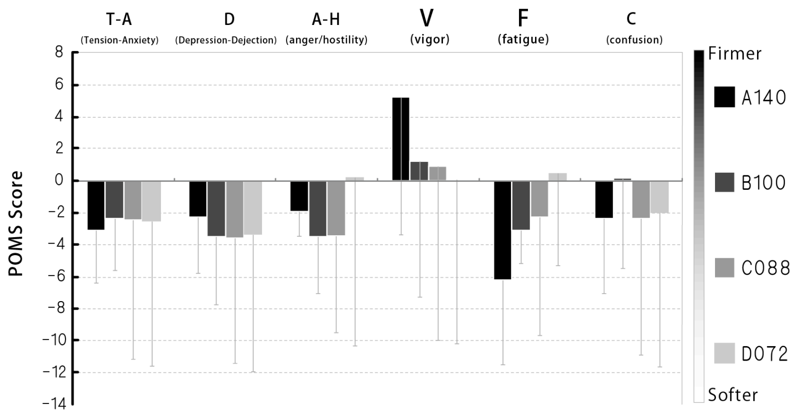

Figure 6: Difference of POMS scores before and after sleep by factor (Mean of seven subjects)

The experiment revealed a tendency toward deeper sleep among bed mattresses with higher elastic moduli (A140, B100). It was therefore assumed that the bed mattresses with higher elastic moduli were able to better maintain deep sleep when compared with those having lower elastic moduli. Likewise, POMS scores were higher for bed mattresses with high elastic moduli. It was thus deduced that displacement of the sleeping posture influenced the quality of sleep on each bed mattress. It was suspected that bed mattresses with lower elastic moduli sank too deeply, resulting in the subjects' sleeping postures being maintained in an improper position, and thereby disturbing their sleep.

3.2. Influence on turning over in bed

The activity counts of one subject's arm and leg over the course of one night are shown in Figure 7 (a-d). The activity of the leg was slightly less for bed mattresses with lower elastic moduli (C088 and D072) than for those with higher elastic moduli (A140 and B100).

The ratio of mean leg activity to mean arm activity for each bed mattress is shown in Table 1. For mattresses with lower elastic moduli, the ratio was observed to be smaller for all of the subjects. Sumi et al. reported that there are nineteen movement patterns when a person turns over in bed, and that many of those movements begin from the pelvic girdle[6]. Meanwhile, Tanaka et al. analyzed the spinal axial rotation and integrated electromyography (IEMG) of the muscle that is used during rolling for three different patterns of turning over. The three patterns observed were: 1. rolling which starts at the pelvic girdle, 2. rolling which starts at the shoulder girdle, both of which are usually observed in healthy individuals, and 3. rolling only by swinging the upper extremities, which is observed in individuals with a damaged cervical cord[7]. They reported that Pattern 3 exhibited a significant rise in the IEMG of both sides of the greater pectoral muscle when compared with the other two patterns. From these reports, it may be deduced that the majority of patterns of turning over in bed are initiated in the lower half of the body, and that doing so is efficient in terms of the dynamics of the human body. It therefore becomes difficult to turn over in bed when the movement of the lower half of the body is inhibited, resulting in the possibility of disturbed sleep. The bed mattresses with lower elastic moduli sank especially deeply from the lumbar to the gluteal region (Fig. 2). It was thus inferred that the decreased activity of the legs was the result of obstructed lower body movement.

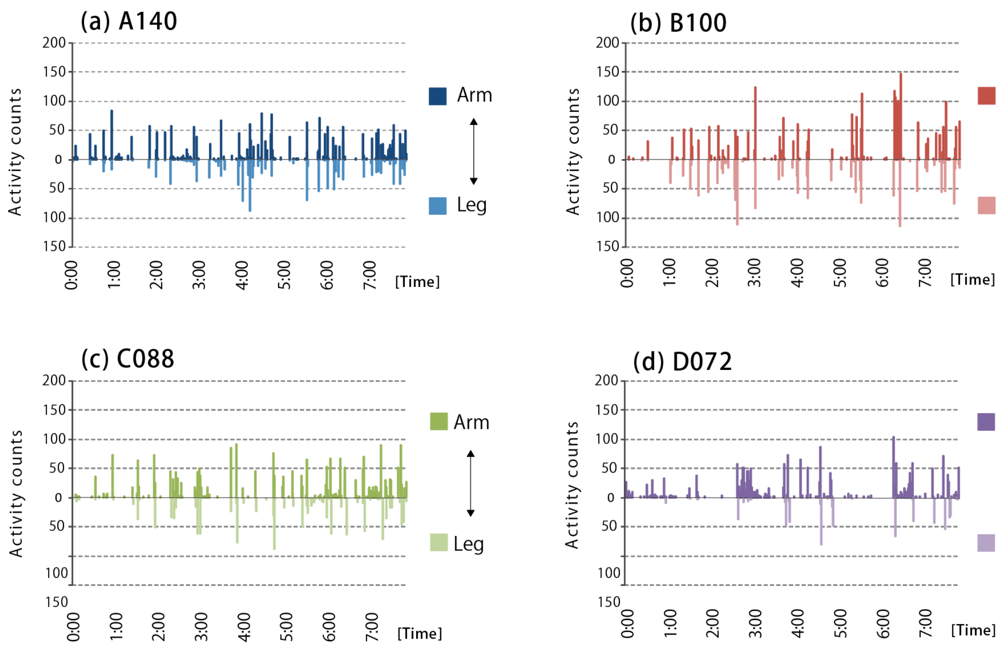

Figure 7: Activity counts for one subject's arm and leg for each bed mattress (a-d)

Table 1: Ratio of leg activity to arm activity for each mattress

	A140	B100	C088	D072
Subject A	0.55	0.67	0.55	0.52
Subject B	0.52	0.59	0.53	0.29
Subject C	0.61	0.58	0.52	0.56
Subject D	0.75	0.85	0.50	0.66

Firmer ⟷ Softer

4. CONCLUSION

The PSG of subjects sleeping on each bed mattress was measured using a bio-amplifier in order to monitor depth of sleep – an important indicator of the quality of sleep. The subjects' body motions during sleep were also measured with the actigraph (accelerometer) by counting how many times each subject turned over in bed. The results showed that sleep tended to be deeper when a bed mattress with a higher elastic modulus was used. Likewise, bed mattresses with higher elastic moduli produced higher POMS scores. It was believed that bed mattresses with lower elastic moduli disturbed sleep because they sank too deeply.

With regard to turning over during sleep, the motion of the legs was less than the motion of the arms for bed mattresses with lower elasticity moduli. It was concluded that, because the lumbar to the gluteal region sinks deeply on such bed mattresses, the motion of the lower half of the body was inhibited and thus leg motion was decreased, with lighter sleep occurring as a result.

The authors have concluded that it is possible to estimate the quality of sleep through the motions of turning over in bed with as much efficiency as PSG. Since the number of subjects for this experiment was not large, however, it is considered necessary to conduct the experiment once more with a larger number of subjects. This experiment was conducted for subjects with a standard physique. Going forward, we aim to establish criteria for selecting of bedding suited to each individual by conducting experiments with a more diverse range of subjects.

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