

# Quantitative effects of mattress types (comfortable vs. uncomfortable) on sleep quality through polysomnography and skin temperature

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## Abstract

Information concerning the stages of sleep is one of the most important clues for determining the quality of a particular mattress. The purpose of this study was to determine the effects of mattress type on sleep quality by measuring skin temperature, by using a subjective mattress rating system, and through the use of Polysomnogram. Polysomnography involved the recording of brain waves through electroencephalography (EEG) and the generation of a video graphic record of eye movement (EOG), chin movements (EMG) and heart rhythm (ECG). Sixteen subjects were used in this study, which was a test of mattress comfort. Subjects spent 6 days and nights in the laboratory. Data was recorded for a period of 7 h for each of 3 nights. It was found that mean skin temperature, deep sleep (stage III and stage IV), sleep efficiency, wake after sleep onset (WASO), stage 1 and subjective ratings of mattress comfort were significantly affected according to mattress type. When subjects slept on “comfortable” mattresses, mean skin temperature was higher than for “uncomfortable” mattresses. Lower body skin temperature, sleep efficiency and percentage of deep sleep were higher as well. The percentages of WASO and stage 1 were lower when subjects slept on “comfortable” mattresses. Subjective ratings of sleep quality paralleled recorded sleep data.

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## 1. Introduction

Although the use of western-style beds by Koreans has steadily increased, there exist few intensive studies on the comfort properties of the beds. Difficulties in the test of comfort properties arise from the fact that comfort in a bed is a complex phenomenon, consisted of subjective feeling and physical properties of the interface between a mattress and the human body.

We spend approximately one-third of our life in bed, and a synergy of psychological, physiological, and physical conditions affects the quality of sleep. Due to an insufficiently adapted sleep system (defined as mattress + support structure + head cushion) and/or incorrect sleeping posture, the human body, especially the vertebral column, is often insufficiently supported; insufficient back support

can cause low-back pain, which is one of the most compelling problems in the industrialized world (Hildebrandt, 1995). Polysomnographic measurements have been of critical importance in evaluating the interaction between sleep and physiological changes (Murali et al., 2003). Thanks to polysomnographic measurements, the effects of sleep can be objectively differentiated from the effects of rest and recumbency. The specific effects of sleep onset, sleep termination, and the effects of different sleep stages, can be assessed (Haex, 2004). When measuring sleep, subjective measures or self-evaluations are often used and are valuable, however show a high level of vulnerability to external and motivational factors (Curcio et al., 2001).

Body temperature rises with the increased catabolism of the waking day and falls to its lowest by night, falling to its lowest point during night of sleep, especially in comparison to a night spent awake (Mills et al., 1978). Bischof et al. (1993) found that two under-sheet temperatures (left and right) in the region of subject's pelvis for a night with low motor activity showed striking differences from those of a

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high motoric level. Laird and Miller (1930) showed differences in energy necessary for sleeping, according to mattress-spring type; their study also showed increased nervous response from subjects who slept without a mattress.

Other studies have investigated the sleep-improving qualities of various mattresses, e.g. how the curvature of the spine was supported and how the contour of the bed surface conforms to that of the body. Park et al. (2001) have reported that the comfort of a bed was more heavily influenced by secondary properties, such as spinal curvature and distribution of body pressure in Human-Bed system than the primary properties of the material of the mattress itself.

Although many people use beds there is little research concerning mattresses, however, Barder and Sten (2000) investigated the effect of mattress firmness on quality of sleep, and Peter and Avalino (1998) evaluated mattresses according to contact press, comfort and discomfort. These studies found no significant differences in effects of mattress firmness on sleep quality. Mattress comfort was evaluated by contact body pressure distribution, spinal curvature, and material of the mattress itself, such as firmness in previous studies. Previous studies have not provided evidence that sleep quality differs according to mattress comfort.

The objective of this study was to investigate the effects of mattress types (comfortable/uncomfortable mattress) on sleep quality. Polysomnogram, skin temperature and subjective sleep ratings were measured and analyzed to discern differences between comfortable and uncomfortable mattresses. Park's study (2001) investigated that comfortable mattress was evaluated as these methods included evaluation of spinal curvature, body pressure distribution, and subject ratings. Plaster cast was used to measure the spinal curvature in lying posture in each bed. Subject laid on it so that the spinal curvature on Scotch Cast could be seen from cervical 7 to coccyx. 3D measurement was done with the plaster cast that contained the spinal curvature in lying position to estimate the spinal curvature. Spinal curvature in standing position is measured by using the 3D measurement of Hyper Space co. They compared standing with lying curvature using a root mean square (RMS). Pressure at shoulder and hip part was measured using the pressure sensor matrix. This system can measure from shoulder to hip pressure distribution. In order to evaluate mattress comfort, subjects are asked to grade the level of comfort. The evaluation charts uses 7-point scales that are divided into two sections asking physical features and the level of satisfaction about physical features.

Significant correlation was found among comfort ratings, contact pressure at the shoulder and hip, and the value of RMS. Favored mattress by the subjective ratings was the mattress in which the spinal curvature in lying position was similar to that in standing position, in which the range of distribution of body pressure was narrow.

For purposes of this study, a comfortable mattress (Park et al., 2001) is defined as one that offers support sufficient to maintain spinal curvature in a manner more similar to that found while standing, that is the value of RMS was small between standing and lying position, and an uncomfortable mattress is one that offers support insufficient to maintain the aforementioned posture, that is the value of RMS was large between standing and lying position.

## 2. Method

### 2.1. Subjects

Subjects participated voluntarily, and were selected by the ability to adapt to the environs of the sleep laboratory. Subjects with a history or symptoms of sleep disorders, or of abnormal sleep habits were excluded. Subjects were asked to maintain their routine activities during daytime, not to drink any stimulating beverages, and avoid strenuous exercise. Subjects were asked not to drink any stimulating beverages prior to participating in the test. For polysomnogram and subjective ratings, sixteen healthy individuals (9 males, 7 females) ranging in age from 20 to 30 years old (yr.o.) participated in this experiment. Mean subject height and weight ( $\pm$ SD) were  $164.2 \pm 8.6$  cm (range 151–174 cm) and  $56.1 \pm 10.1$  kg (range 46–70 kg), respectively.

For the skin temperature experiment, six healthy individuals (4 males and 2 females) of the sixteen subjects ranging in age from 23 to 30 yr.o. participated in this experiment. This experiment processed at the same time with polysomnogram, and then subjects had to attach many sensors from forehead to foot. Therefore, we did experiment except for who moves around on the bed while asleep. As a result we collected data for the skin temperature from six subjects. The mean height of the subjects was 166 cm (SD 9.1 range 151–174 cm). Mean weight was 58.9 kg (SD 9.3, range 46–68 kg).

Subjects were instructed to wear long sleeved pajamas (100% cotton). The purposes and procedures of the study were explained to them in detail and they were required to sign a form signifying their consent in their participation.

### 2.2. Procedure

Polysomnographic data was measured continuously during 7 h (reported as the average time spent sleeping for Koreans, Lee and Hong, 2001). Subjects were required to sleep in the sleep laboratory for five or six nights to allow them to adapt sleep laboratory conditions; they were monitored over two or three consecutive nights. Each subject tested one comfortable and one uncomfortable mattress, one each on each of the two monitored nights. Mattresses ranged in comfort level from “most comfortable” to “least comfortable”, and mattresses used in the

two-night monitored test were randomly selected from among the eight used in this study. Polysomnogram and skin temperature were measured simultaneously. The following protocol (Fig. 1) was adopted for each subject.

### 2.3. Selection of beds

As in Park's study (2001), comfortable and uncomfortable beds were selected. Selection criteria included evaluation of firmness of mattress, anthropometric features, body pressure distribution, and spinal curvature. The comfort of eight mattresses was evaluated in terms of the distribution of the body pressure on the mattress and the difference in the spinal curvature between standing and lying position. In a comfortable bed, spinal curvature in a recumbent posture was maintained similar to that in standing, i.e. the value of RMS was small and range of distribution of body pressure was narrow. Mattresses where body pressure was evenly distributed were rated more comfortable.

### 2.4. Measurements of physiological variables

Subjects slept in the sleep laboratory ( $20.4 \pm 1^\circ\text{C}$ ,  $50 \pm 2\%$  relative humidity) and electroencephalographic (EEG), electromyographic (EMG), electrooculographic (EOG) and electrocardiographic (ECG) data were recorded. Four electrodes (labeled  $C_3$ ,  $C_4$ ,  $A_2$  and  $O_1$ ) and one ground electrode were placed around the cranium to record neuroelectrical activity. Five electrodes were used on each subject in order to limit electrode-associated discomfort. These leads were used to determine the stage of sleep the subject was in during any given period of the night. Two channels were used for EOG, one electrode was placed above and to the outside of the right eye, and another electrode was placed below and to the outside of the left eye. These leads recorded the eye movement during sleep and served to help determine sleep stages. Two leads were placed on the chin (EMG). These leads served to monitor muscle movement during sleep; this was helpful in classifying a movement as a waking period, an arousal, or a spastic movement. Surface chest electrodes were used for recordings of ECG. Polysomnographic data was recorded using the BRAIN QUICK SYSTEM 2, Italy micromed.

To estimate body movements on comfortable and uncomfortable mattresses, the change of skin temperature of the normal sleep condition whereby subjects were covered with blanket and naturally occurring body movements were measured. Skin temperatures of forehead, abdomen, hand, forearm, thigh, calf and foot were recorded at intervals of 20 s. Sensors used included the BOITE No45 20 CAPTEURS Type H6100, Analog World 20H6100, and the CORECI. Mean skin temperature was calculated by Hardy and DuBois's Seven-Point Method (1938). Mean skin temperature ( $T_{sk}$ ) was calculated using the following formula.

$$T_{sk} = 0.07A + 0.35B + 0.14C + 0.05D + 0.19E + 0.13F + 0.07G,$$

$A$  = forehead,  $B$  = abdomen,  $C$  = forearm,  $D$  = hand,  $E$  = thigh,  $F$  = calf,  $G$  = foot

Upon awakening subjects answered questions about sleepiness, maintenance of sound sleep, anxiety level, overall sleep quality and easy of entry into a sleep state (Oguri et al., 1985). The questionnaire was based on a six-point scale consisting of semantic differential method.

### 2.5. Analysis

Overnight parameters (e.g., total time in bed, total sleep time) were collected. The overnight recording was divided into epochs by 30 s. The standard EEG, EMG and EOG recordings were evaluated and the predominant stage of sleep (according to the manual of Rechtschaffen and Kales, 1968) was assigned to the entire epoch. The first night's record was not use (Agnew et al., 1966).

Sleep quality was assessed using sleep stages, skin temperature and subjective estimates of sleep quality. To compare sleep quality between two different mattresses (comfortable and uncomfortable mat.), the  $t$ -test for each pair of variables from all the recorded nights for the two mattresses conditions was used. Differences of  $p < 0.05$  were considered significant for all statistical analyses.

## 3. Results

Classical sleep EEG parameters according to the criteria of Rechtschaffen and Kales (1968) were within the normal

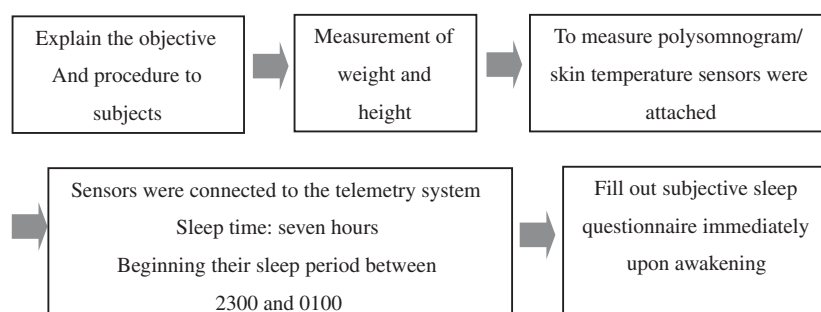


Fig. 1. Diagram of experimental settings.

Table 1  
Average percent sleep stage composition and the standard deviations of 16 subjects on comfortable and uncomfortable mattresses

Parameter	Mean (S.D.)	
	Comfortable mattress	Uncomfortable mattress
Sleep latency (%)	2.5 (4.5)	3.1 (4.7)
Sleep efficiency (%)**	96.7 (4.9)	95.1 (4.7)
Wake after sleep onset (WASO)**	2.1 (1.2)	2.8 (1.3)
Stage 1 (% of sleep period time)**	10.9 (6.7)	16.8 (7.3)
Stage 2 (% of sleep period time)	41.0 (9.9)	39.2 (8.4)
Stage 3 (% of sleep period time)	10.5 (4.9)	9.4 (4.5)
Stage 4 (% of sleep period time)**	9.7 (4.0)	6.8 (4.6)
REM (%)	21.4 (3.1)	23.1 (5.3)
S3 + S4 (% of sleep period time)**	20.3 (4.0)	16.2 (4.3)
NREM	72.2 (8.8)	72.2 (6.6)

SD: variability across 16 subjects' mean scores.

Paired sample *t*-test performed.

\* $p < 0.05$  \*\* $p < 0.01$ .

range for healthy young subjects (stage 1,  $11.9 \pm 4.2$  min; stage 2,  $192.0 \pm 34.5$  min; stage 3,  $54.8 \pm 23.3$  min; stage 4,  $59.0 \pm 24.7$  min; REM,  $113.3 \pm 22.6$  min).

Average sleep stage composition (%) and the standard deviations of the sixteen subjects on comfortable and uncomfortable mattresses are shown in Table 1. Average total time in bed (TIB)/total sleep time (TST) were 418.4 (22.8) min/403.8 (28.0) min on comfortable mattresses, 435.7 (36.6) min/414.3 (47.1) min on uncomfortable mattresses.

Significant differences were found between the two kinds of mattresses. When subjects slept on comfortable mattresses, percentages of deep sleep (S3 + S4) ( $M = 20.3\%$ ,  $SD = 4.0/M = 16.2\%$ ,  $SD = 4.3$ ,  $t_{15} = 6.08$ ,  $p < 0.000$ ) and sleep efficiency ( $M = 96.7\%$ ,  $SD = 4.9/M = 95.1\%$ ,  $SD = 4.7$ ,  $t_{15} = 3.06$ ,  $p < 0.01$ ) were higher than those for uncomfortable mattresses. Sleep efficiency is the ratio of total sleep time to time spent in bed, multiplied by 100%. High sleep efficiency signifies that a subject fell asleep quickly, and did not often awaken prior to being roused at the conclusion of the test period. Wake after sleep on set (WASO) ( $M = 2.1\%$ ,  $SD = 1.2/M = 2.8\%$ ,  $SD = 1.3$ ,  $t_{15} = -3.04$ ,  $p < 0.01$ ) showed a tendency to be longer with uncomfortable mattresses as compared to comfortable mattresses. Comparison of sleep parameters by gender, Stage 2 ( $F = 4.6$ ,  $p < 0.05$ ) displayed statistically significant differences across gender. Males' average percentages of stage 2 (44.7% (7.6)) were 9.8% higher than those for females (34.9% (10.9)) on comfortable mattresses. On uncomfortable mattresses, females' average percentages of REM (27.1% (5.1)) were 7.6% higher than those for males (20.7% (3.9),  $F = 8.2$ ,  $p < 0.05$ ), and males' average percentages of NREM (76.3% (3.7)) were 10.8% higher than those for females (65.5% (4.3),  $F = 28.8$ ,  $p < 0.000$ ).

Percentages of deep sleep (S3 + S4) in the sixteen subjects on comfortable and uncomfortable mattresses are shown in Fig. 2. All subjects showed lower percentages of deep sleep on uncomfortable mattresses than on comfortable mattresses.

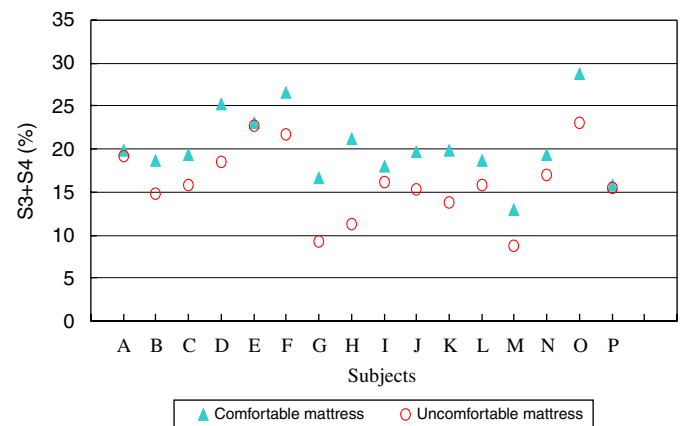


Fig. 2. Comparison of mean percent-stage of slow-wave activity (S3 + S4) on comfortable and uncomfortable mattresses in 16 test subjects, each represented by a letter-code (ex: 'A, B, C,' etc.).

On comfortable mattresses, subjects had higher mean skin temperatures than on uncomfortable ones (Fig. 3). There were significant differences in mean skin temperature in subjects on comfortable and uncomfortable mattresses. These differences were statistically significant at six of hour points. Mean skin temperature showed a tendency to rise after going to bed; mean skin temperature fell after 3 h. Fig. 4 shows the changes in calf temperature while sleeping.

There were significant differences in skin temperature by gender.

Comparing comfortable mattress to uncomfortable one, there were significant differences in subjective sleep ratings scores (Table 2). The main effect of the subject ratings on paired sample *t*-tests was significant in five factors: sleepiness in the morning ( $t_{15} = 3.643$ ,  $p < 0.005$ ), maintenance of sound sleep ( $t_{15} = 2.164$ ,  $p < 0.05$ ), anxiety level ( $t_{15} = 3.324$ ,  $p < 0.005$ ), overall and sleep quality ( $t_{15} = 2.160$ ,  $p < 0.05$ ) and ease of entry into the sleep state ( $t_{15} = 2.253$ ,  $p < 0.05$ ). All subjects demonstrated a deeper sleep state on comfortable mattresses than on uncomfortable mattresses.

One dimension showed a significant difference in subjective ratings scores by gender, on comfortable mattresses, the score of anxiety level in males (158.2 (18.4)) were higher than those for females (129.7 (28.5)).

Polysomnogram data and subjective ratings of sleep quality were used to determine sleep quality variation by mattress type. When subjects slept on comfortable mattresses, percentages of deep sleep and sleep efficiency were higher than those for uncomfortable mattresses. WASO

showed a tendency to be longer with uncomfortable mattresses in comparison with comfortable mattresses. On comfortable mattresses, subjects had higher mean skin temperatures and calf temperatures than on uncomfortable ones. Comparing comfortable to uncomfortable mattresses, there were significant differences in the scores for subjective sleep ratings. These results were showed in a graphing (Fig. 5), z-score was used because each unit was different.

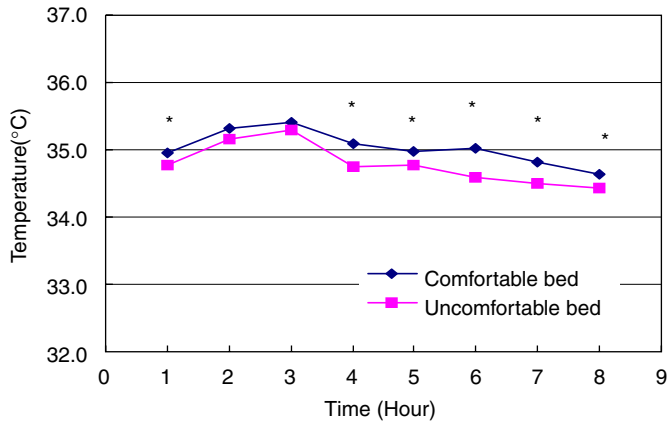


Fig. 3. Changes in mean skin temperature during sleep. \* $p < 0.05$  for correlated  $t$ -test between matched pairs.

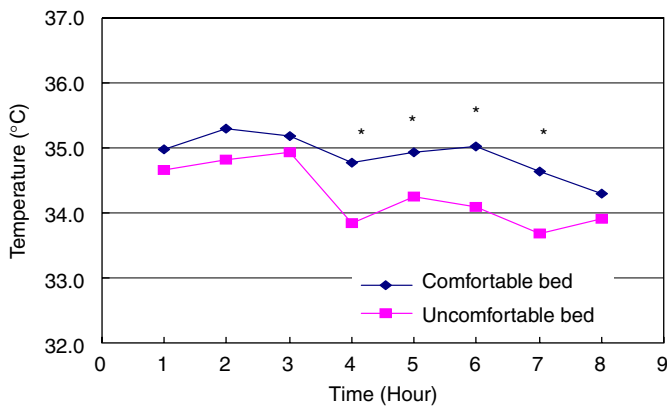


Fig. 4. Changes in calf temperature during sleep. \* $p < 0.05$  for correlated  $t$ -test between matched pairs.

Table 2  
Sum of subjective sleep rating scores given by participants in the sleep study

Dimension	Mean (S.D.)	
	Comfortable mattress	Uncomfortable mattress
Sleepiness in the morning**	351.0 (59.3)	283.3 (65.7)
Maintenance of sound sleep*	144.6 (20.8)	127.6 (40.1)
Anxiety level**	145.8 (26.8)	128.3 (25.0)
Overall sleep quality*	81.1 (17.6)	69.1 (14.1)
Ease of entry into the sleep state*	88.1 (14.1)	78.4 (18.3)

SD: Variability across 16 subjects' mean scores.

Paired sample  $t$ -test performed.

\* $p < 0.05$  \*\* $p < 0.01$ .

#### 4. Discussion

The purpose of this study was to determine the effects of mattress type on sleep quality by measuring skin temperature, by using a subjective mattress rating system, and through use of Polysomnography.

The percentage of deep sleep and sleep efficiency were high when subjects slept on comfortable mattresses. On uncomfortable mattresses, the percentages of WASO and stage 1 sleep were higher than comfortable mattresses.

Suckling et al. (1957) studied physiological parameters of subjects sleeping on hard, medium and soft supporting surfaces (hard mattress) and Bader and Engdal (2000) studied the relationship between sleep quality and bed surface firmness. Rosekind et al. (1976) investigated the effects of waterbed surfaces on sleep and Okamoto et al. (1997) studied about air mattress on sleep.

If subjects were studied on an individual basis and research focused on firmness rather than comfort, changes in sleep quality related to comfort of mattress were observed. Previous studies have not provided evidence that sleep quality differs according to mattress comfort. Comfortable mattresses seemed to differ according to firmness, but the comfort of a mattress was heavily influenced by secondary properties such as spinal curvature and distribution of body pressure in the human-bed system rather than the primary properties of the material of the mattress itself.

Our study investigated differences between comfort and discomfort. We measured difference between comfortable and uncomfortable mattresses selected according to physical differences of a test subjects. According to our results,

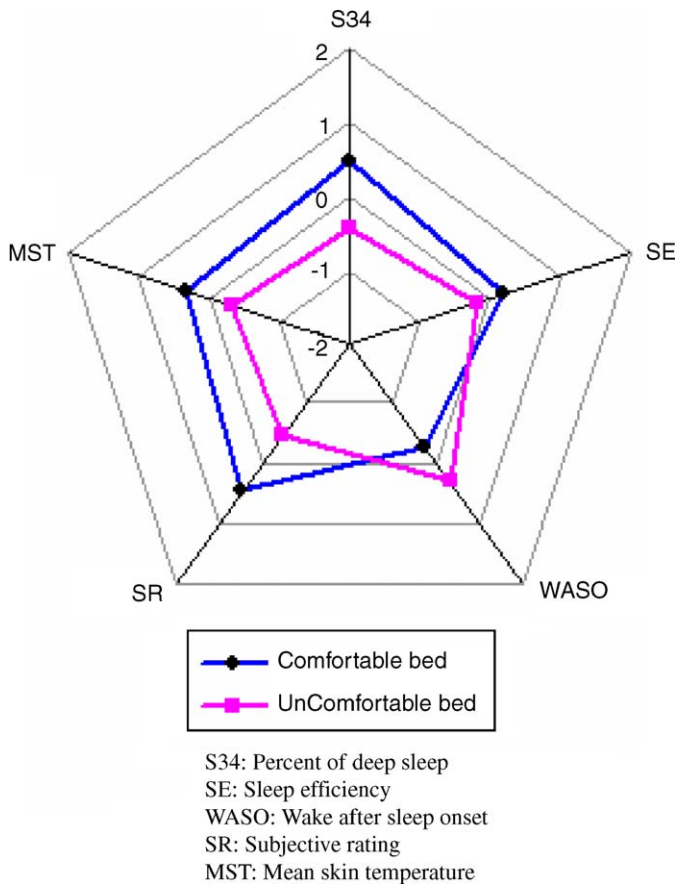


Fig. 5. Overall performance patterns between comfortable and uncomfortable mattresses.

mattress was an influencing factor; we found that subjects could sleep deeply and efficiently on comfortable mattress.

Skin temperature changed during sleep as a result of body movement related their exposure of the surface area and subjects maintained bed climate comfortably through more or less exposure of surface area (McCullough et al., 1987; Bischof et al., 1993; Kawabata and Tokura, 1995). Body movements have been found to be distributed differently through the sleep stages, with occurrence of fewest in deep sleep, and increasing toward the end of the slow-wave sleep periods. Increased motility reflecting sleep disturbance observed with most sleep complaints, e.g. in heavy snorers, even without apnea, may reflect micro arousals (Polo, 1992) and sustained periods of immobility distinguish good from poor sleepers (Hyyppä and Kronholm, 1987).

We found that skin temperature was higher for subjects sleeping on comfortable mattresses than for subjects sleeping on uncomfortable mattresses. Lower body skin temperatures were notably higher on comfortable mattresses. This phenomenon might evidence increased more body movement and exposure of the surface area of a body.

According to our results subjective ratings correspond to the physical signal data. A study of subjective estimates of sleep quality agreed with the other objective variables

(Okamoto et al., 1997). According to Kim et al.'s study (1997a, b), bed type affected not only sleep quality but also subjective sleep ratings. Therefore, an optimal mattress should facilitate higher sleep quality, and should consider individual differences (reflecting spinal curvature, body pressure distribution, subjective ratings) in order to facilitate deep sleep. The percentages of deep sleep and sleep efficiency were high when subjects slept on comfortable mattresses, while on an uncomfortable mattress, the percentage of WASO was high. One of sleep environments was mattress types affected not only sleep quality but also subjective sleep ratings.

Comparison of sleep parameters by gender, female has a higher percentages of REM and lower percentages of NREM on uncomfortable mattresses than males. According to Vagiakisa's study (2006), female with the "obstructive sleep apnea syndrome" has a higher apnea-hypopnea index in REM than NREM, sleep quality was worse in female than in male patients (Ohayon, 1996). Apnea tend to appear in REM sleep (O'Connor et al., 2000), if that time gets longer, subject is likely to have more sleep problems. As a result the mattresses type was an influence to females' REM sleep percentages. Subjective ratings "score of anxiety" level in males were higher than those for females on comfortable mattresses, which mean male subjects demonstrated a better sleep quality on comfortable mattresses than on uncomfortable mattresses.

## 5. Conclusions

These results showed the difference of sleep quality and skin temperature between comfortable mattresses and uncomfortable mattresses. Uncomfortable mattresses do not provide enough support for the body, causing people have trouble in getting to deep sleep and made more body movements. Comfortable mattress are necessary to support the spine curvature naturally and to delete unnecessary body movements, therefore a comfortable mattress should facilitate higher sleep quality. Further investigations are required with body movements, temperature and humidity inside blankets and outside. There are lots external factors to influence sleep, such as temperature, humidity, mattress firmness, pillow, blanket, nightgown and body movements. The majority of studies, including this study investigated about comfortable mattress that has two or three factors although sleep quality is influenced by complex environments. The impact on sleep quality through complex measurements should be studied. To find out comfort in mattress, we have to consider that comfort in mattress is a complex phenomenon based upon subjective feeling and physical properties of the interface between the mattress and human body.

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