Comparison of Sleep Quality and Thermal Comfort for Innovative Mattress Design

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Abstract

Sleep thermal comfort is one of the critical factors affecting sleep quality. In recent years, research not only investigates ways and products to improve whole body thermal comfort, but attaches great importance to local thermal comfort of peripheral skin. Healthy sleep containing cycle position change is considered to regulate body temperature. Mattress design contacted to human body provides direct impact on sleep comfort.

Twelve healthy participants had general level in BMI were recruited in 2-day sleep monitoring in simulated laboratory condition to evaluate two different design mattresses, one due to body segment location on the mattress, the other is according to position change during sleep. Sleep position, sleep quality data and skin temperature were examined. Through statistical analysis, this study deduced the relation between mattress design and all dependent variables of appraisement. All night sleep position change cycle and skin temperature in supine was slightly more stable was more regular and had less short phase body movement of the design due to sleep position change. Furthermore, the design due to position change contributed to reduction of sleep disturbance. Also, it promoted distal skin warming. The consequence indicated mattress design on the basis of posture change conformed particularly demands of local thermal comfort and enhanced sleep quality.

Keywords: mattress design, sleep position, thermal comfort, skin temperature, sleep quality

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1. Introduction

Sleep is one of the prime activities humans pursue [1]. The influence of mattress contacted to human body on physiology and subjective feeling contribute to good sleep quality, quantity, and mechanism [2]. In contrast with the knowledge of multiple factors of body needs on the sleep surface easy to quantify, like temperature and pressure, influencing sleep onset, there exists less probe of exile dynamic features, like sleep posture change and body temperature change [3]. A good bedding surface is universally accepted as one that provides comfortable support to the subject. The physical variables associated with comfort include spinal alignment (Lahm and Iaizzo, 2002; Ray, 1991), contact pressure or weight distribution, interface skin temperature, and vapor exchange between the subject and the bedding system (Rithalia and Kenney, 2000) achieve the local need of body sites [4]. Consumer mattress report of America expects temperature control mattress is one of the mattress trends in 2014. Both skin temperature and sensitivity to thermal stimulus differs from area to area on the body surface [5].

Factors influenced sleep is a field that is in a state of constant progress. One of the major preoccupations of sleep researchers in past few years has been investigating the relationship between circadian body temperatures and sleep quality. In physiology, thermoregulation composed of skin temperature and core body temperature (CBT) concerns sleep quality and is especially correlated to sleep onset latency, sleep maintenance (termination) and early morning awakening. Okamoto-Mizuno and Mizuno [6] infers that the most frequent reason healthy people without insomnia woke up from sleep or felt uncomfortable during their usual sleep was that they felt excessively high or low ambient temperature. Sleep thermal comfort is one of the critical factors affecting sleep quality. A comfortable thermal environment is essential for shorter sleep latency and sound sleep duration [7]. For the cold extremities, complaining frequently occurred of difficulties initiating sleep (DIS) from thermal discomfort [8]. An assessment of thermal comfort of four sleeping bags found that although the overall temperature is rising, but the temperature of the toes are showing stable or slightly decreased, besides, the research suggests that there needs a design for local foot thermal comfort of sleeping bag [4]. Overall, local thermal comfort is as important as whole body thermal comfort.

The previous studies addressed important claims regarding whether improvement of sleep propensity is due to distal skin warming or proximal skin warming before or during sleep. Most non-hairy distal skin is an explorer of heat exchange with environment compared to the rest of hairy skin [9]. To refrain alerting CBT, a mere increase (0.4°C) in skin temperature assists people have trouble initiating sleep or early morning awakening to accelerate sleep onset, decrease arousals, and increase slow wave sleep (SWS) [10-12]. Foot warming is a common method of distal skin warming. Most related studies were focused on warming distal skin to accelerate sleep onset, but the most efficient location of warming body is not clarified. In contrast, only few study like Raymann, Swaab [10] and Van Someren, Raymann [13] showed that warming proximal skin is relatively effective to distal skin for elevation of temperature and DPG to reduce in sleep-onset latency, but there’s a small but significant decrease in subjective comfort. It could explain why warming the proximal sites of the body is a more effective way of improving sleep than distal warming [14].

Healthy sleep contained cycle body movements is considered to regulate body temperature. Major movements such as changes in body position from lateral to supine [3], as well as movements to re-distribute load bring about a result of different bed temperature [1]. The effects on position change are considered to enhance blood circulation, avoid or decrease the pressure on certain areas of the body, and regulate body temperature [15]. Nakajima, Takamata [16] indicated that upright posture reduces thermogenesis and decrease CBT. The recent researches are mainly focus on different sleep position or body movement and its effects on certain sleep disorders, like restless legs syndrome [17], sudden infant death syndrome (SIDS) [18-20] and obstructive sleep apnea in the elderly and obesity. However, one scarcity with this area of research is that most studies weren’t investigated the influence of body movements corresponding to body temperature change during Sleep.

The purpose of this study is to evaluate the sleep quality and thermal comfort of innovative mattress design and to recommend dynamic and continuous physiological information to enhance the efficacy and quality of the mattress design. The link between sleep mechanism and sleep surface which causes exile dynamic features assists an adjustable sleep surface design.
2. Methods

2.1. Sleep monitoring and observation

Sleep monitoring for whole night is a direct method to observe and analyze sleep position change. Using a video footage, common equipment, for sleep recording helps diagnose sleep problems by observing slight body movement and position shift [21]. The comprehensive equipment for studying sleep is polysomnography (PSG) which records the multi-parametric physiological changes occur during sleep. Objective sleep quality can be detected by a non-invasive equipment, actigraphy, a body movement detector, and this is the one used in this study. Activity data were automatically scored after pressing the event marker [1]. A general method to investigate participants’ whole body comfort and local thermal comfort is to affix thermistors on certain body sites interested to comprehend [4, 5, 22]. By means of sleep monitoring data analysis, specific sleep positions of body segments corresponding to mattress were obtained. Sleep positions were divided into major movement and minor movement among individuals. The aim of the experiment was to observe the dynamic and continuous features of all-night sleep positions. Design of mattressI was due to body segment location on the mattress, and design of mattressX was according to position change during sleep.

2.2. Experiment environment and procedure

Twelve healthy participants (women, n = 6; men, n = 6) without sleep disorders and aged between 20 and 30 years were recruited in this study. All the participants had general level in BMI and were noticed to suspend medicine taking and caffeine or alcohol consuming during the experiment to exclude the external factors influencing normal sleep mechanism. Sleep monitoring executed in simulated laboratory (Fig. 1) condition with explicit control of environmental variables. Digital Video was set up just above each mattress for all night sleep position recording. Before experiment day, all participants were informed to conduct one week adaptation night to adjust their sleep time. During 2-day experiment, all participants had a regular eight-hour sleep form 00:00 pm to the alarm clock went off at 8 am for two different design mattresses random evaluation. Diagram of experiment setting is presented in Fig. 2. Sleep quality data were recorded by wearing an actigraphy around the dominant arm, and participants fitted with thermistors on seven sites of dominant side, forehead, abdomen, thigh, calf, forearm, hand, foot, for proximal and distal skin temperature measurement. Skin temperature was recorded by a computerized system (Arduino) in 30-sec intervals.

Fig. 1. Laboratory experimental environment.
3. Result and discussion

3.1. Thermal Comfort analysis

3.1.1 Statistical analysis and calculation of skin temperature

The mean skin temperature (MST) was calculated according to Hardy and Dubios’ 7-point prediction equation [23-25]. The average of all participants’ mean skin temperature for two mattress, 33.54°C for mattress X and 33.56°C for mattress I, are close. Individual differences were excluded when each part of skin temperature divided by mean skin temperature. According to quotient closed to 1, skin temperature of lower limb represented mean skin temperature. For mattress X abdomen temperature expressed core temperature is lower and foot temperature indicated extremity temperature is higher. The result showed temperature diffusion was better for mattress. However, hand temperature, also distal skin temperature, is higher than abdomen temperature for both mattress and with little difference. It can be figured out according to position recording that the hands were well protected due to their close position to core body during the experiments.

Skin temperature was analyzed by repeated measures ANOVA. Mauchly’s test of sphericity indicates that these data violated the sphericity assumption. Therefore, the degrees of freedom were adjusted using the Greenhouse-Geisser approach. The results indicate a significant effect for body part, \( F(6,6) = 31.030, p < 0.05 \). When least significance difference (LSD) was applied for comparison, significant differences were identified for abdomen and foot \( p < 0.05 \), and no differences were identified for thigh and abdomen \( p = 0.012 > 0.01 \), because these parts were core body. However, no significant effect for mattress \( F = 1.667, P = 0.223 \) and no interaction effect between body part and mattress \( F = 0.963, P = 0.413 \) were found.

\[
MST = 0.07 T_{\text{forehead}} + 0.35 T_{\text{abdomen}} + 0.14 T_{\text{forearm}} + 0.05 T_{\text{hand}} + 0.19 T_{\text{thigh}} + 0.13 T_{\text{calf}} + 0.07 T_{\text{foot}}
\]
3.1.2. Specific sleep position correlated to local skin temperature

Distinct sleep positions reveal signals of body condition. Major movements such as position changed from lateral to supine [3] re-distributed load as a result of different bed temperature [1], and regulate body temperature [15]. The result of this study obtained cycle sleep position change phenomenon. The changes of sleep posture were categorized as supine, lateral and semi-lateral and prone according to the direction and angle of their torsos to the mattress. The characteristic of minor movement was the consideration of the posture of the extremities out of the torso which was constantly ignored in sleep position analysis. Video footage in concert with skin temperature record of body sites indicated local thermal comfort. Images of whole night sleep showed that hand is usual near trunk, or core body, and the position lead to relatively stable hand temperature and a little higher than mean skin temperature. There was also a conjunction between position and temperature change, with no sexual differences. Nakajima, Y., et al indicated that upright posture reduces thermogenesis and decrease core body temperature [16]. In this study, two obvious foot temperature diversifications were at about 4 and 5am, respectively rising and dropped temperature. Most lateral with lower limbs folded and more minor body movement followed higher and rising foot temperature, in contrast, most supine with straight legs then foot temperature reduced (Fig. 4). The alternative change showed sleep position change cycle coordinate with temperature change rhythm and sleep cycle.

![Fig. 4. Sleep positions comparison of skin temperature change. (a) temperature rising (b) temperature dropping](image)

3.2. Sleep quality influenced by thermal comfort

3.2.1 Sleep quality comparison of two mattress

Sleep quality data were analyzed by PC based MotionWare Software. In composed of 11 data each mattress, with one missing data, the results indicated the relationships among sleep quality and mattress design were what was expected for female participants (Fig. 5), that is, mattressX enhanced sleep quality. Exclude two outliners, M1 and M2’s data showed great difference evenly in most situation, the remains’ result was also expected (Table. 1). Reduce of sleep latency and wake time during sleep are correlated to thermal comfort enhance. The results of four representative index, sleep efficiency, sleep latency, actual wake and mean activity, were showed as following. Besides sleep latency, other index illustrated the sleep quality of mattressX was better. There were more sleep disturbance and body movement of mattressI, which represent participants needed to change their position because of discomfort. It can be figured out that the mattress design due to sleep position change was contributed to enhance sleep quality during sleep, but not accelerate sleep.

| Sample          | Actual wake (%) | Sleep efficiency (%) | Sleep latency | Mean activity /epoch |
|-----------------|-----------------|----------------------|---------------|----------------------|
| Original (n=11) | 0.255           | -2.1                 | 00:06         | 0.037                |
| Modified (n=9)  | -0.756          | 0.233                | 00:03         | -0.246               |
| Male (n=5)      | 0.06            | -0.4                 | 00:02         | -0.038               |
3.3. Correlation between sleep position and sleep quality

The video footage presented participants spent more percentage of time on lateral than supine of both mattresses. Compared to mattressI, all night sleep position change cycle was more regular and had less short phase body movement of mattressX. Furthermore, both design contributed to reduction of sleep disturbance. The covered sleeping surface of the males was larger than the females. As the males had the higher average heights, they usually bent their bodies to match the size of the mattress, especially their foot. Compare to higher foot temperature of mattressX for all participant, no promotion in sleep quality of mattressX for male can point that mattress size and design should suit various figure.

To reduce sleep latency, according to literature, distal skin warming was a suggest method instead of thermal insulation. Both mattress design were short of external warming devices, and it may be the reason that no distinct decrease in sleep latency. Yousefi, Ostadabbas [26] developed an algorithm which can accurate predict participants’ sleep position by image processing. The advantage of this classification method increased categories of lateral to foetus and yearner. Most female sleep in foetus in contrast of male sleep in supine or yearner before fell asleep. Two outliner were found more supine during their sleep, and it may infer to the mattress design due to position change provided less or no support for user who is accustomed to supine. For poor sleepers, J. De Koninck [27] observed that they use the back position, so-called supine, frequently for long periods of sleep time.

4. Conclusion

Exile investigation of continuous sleep position change information provided a benefit resource to valid sleep surface comfort with other physiological message. The images of sleep monitoring attempts to account for most of particular temperature change and sleep quality affected by body movement. Sleep quality For male, higher foot temperature but no promotion in sleep quality of mattressX should be interpreted in relation to mattress size and unsuitable design location to figure. Such findings indicated that the mattress design due to sleep position change was contributed to enhance sleep quality during sleep, but not accelerate sleep for female. Both mattress designs were short of external warming device, and it is one explanation for no distinct decrease in sleep latency. Mattress
design due to position change provided less or no support for those who are accustomed to supine. The relationship between sleep position, skin temperature and sleep quality needs further exploration. This study presents preliminary results of a pilot experiment that will be further analyzed and expanded.

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