An Innovative Mattress Design to Improve Sleep Quality and Thermal Comfort

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Abstract. Different body segments have different thermal characteristics and sleeping postures change unconsciously during the night. Thus, the movements of the extremities should be taken into consideration in a bedding system design. The design guidelines propose in this study is enhance pressure balance, the physiological balance of microclimate, and improvement of distal skin blood circulation. An innovative mattress design has been developed in this study. The proposed mattress has a five-layer sandwiched structure. Twelve healthy participants had general level in BMI were recruited in 3-day sleep monitoring including one habit adjustment night in simulated laboratory condition to evaluate the original and design mattresses. The consequence indicated mattress design considered thermal comfort efficiently on the basis of position change improved sleep efficient, loss sleep disturbance by loss mean activity and arousal time.

Keywords: Sleep position · Thermal comfort · Sleep quality · Mattress design

1 Introduction

The thermoregulation system composed of core body temperature (CBT) and skin temperature [1] acts as a signal of both sleepiness and wakefulness regulation. Increasing the phase of lower CBT is correlated with sleep initiation and maintenance [2]. Simply stated, the decline and the rise rhythm of CBT inversed to skin temperature rhythm [3] respectively herald initiation and termination of sleep.

Body temperature influences blood circulation and then the sleep quality. Research showed that cardiovascular capacity reduced during REM sleep [4]. In normal sleep cycle, shorten of rapid eye movement (REM) stage results in bad sleep quality. Compare to low skin temperature which causes sleep onset latency, over-high skin temperature alerting CBT causes arousal. Both skin temperature and sensitivity to thermal stimulus differs from area to area on the body surface [5]. Skin temperature contains distal skin temperature (e.g., hand, calf, ankle, foot and, toe) and proximal skin temperature (e.g., thigh, rectal, forehead and abdomen). Increasing in skin temperature to improve sleep quality. 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 SWS (slow wave sleep) [6]. The effect on physiology reduced as confining the heated area from full to the lower extremities [7]. The effects on position change are considered

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to enhance blood circulation, avoid or decrease the pressure on certain areas of the body, and regulate body temperature [8].

2 Methods

One new design mattress was implemented and evaluated experimentally to examine whether the goals to improve sleep quality and enhance sleep thermal comfort were achieved, and the flow chart of mattress design process is shown in Fig. 1.

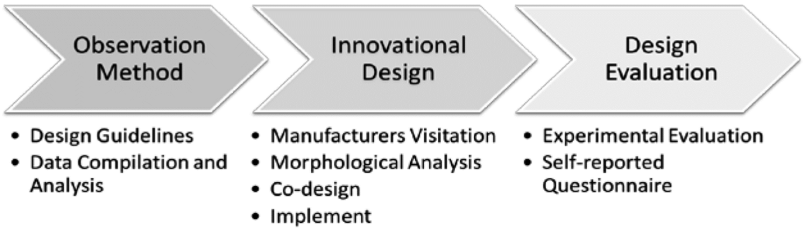

Fig. 1. Flow chart of mattress design process

Through investigating the skin temperature change and discussing particular sleep posture during sleep. The correlation of crucial sleep posture and skin temperature change were analyzed to quarry the specify requirement of body segments and develop design guidelines. All the participants is standard body ($18.5 < BMI < 24$), and with no medicine taking and caffeine or alcohol consuming during the experiment. The use of actigraphy records the sleep patterns, including sleep onset latency, sleep onset time, total sleep time, total awake time, and sleep efficiency whole night to evaluate the quality of sleep.

2.1 Procedure

The aim of observation method was to collect all night sleep posture, sleep quality and skin temperature. Through this procedure, the prior grasp of physiological requirements under certain situation during sleep. Before the day into the laboratory, all participants conducted one week adaptation night to adjust their sleep time for experiment need. For the laboratory night, participants came to the laboratory one hour before their habitual bedtime and they will dress the specific pajamas, and sleep on an installed mattress with a bed sheet in a constant room temperature at 25 °C and in a relative humidity at 50%. The thermistors stuck on proximal (forehead, abdomen, thigh) and distal skin (forearm, calf, hand and foot) by using surgical tape to monitor temperature every 30 s; the Digital Video was set up overhead for all night sleep posture recording; and the actigraphy was worn on non-dominant wrist to investigate sleep pattern, shown in Fig. 2. Time cues are given for the participants' arousal, and after the laboratory sleep night, participants were asked to do the subjective sleep quality questionnaire with self-reported sleep disturbance. An eight hours sleep from at 11:30 pm to the alarm clock went off at 8 am.

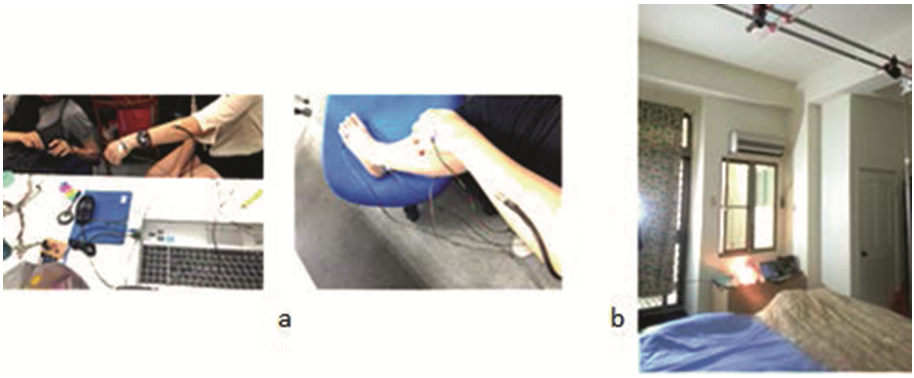

Fig. 2. Experiment environment and device. (a) Thermistors making and sticking condition (b) Laboratory environment and digital video handling overhead

2.2 Data Compilation and Analysis

To obtain the relation between body segment location and the distribution on sleep surface, sleep position recorded by digital video were categorized visually by the author. Sleep positions defined as the position that was maintained more than one minute were analyzed for the whole night [9]. Sleep positions were printed from the video, and the heights of the participants in each image were adjusted to a standard scale before the images were overlaid. The image captured was analyzed according to the body parts of the participants. The joints of the body segments (shoulder, elbow, wrist, fingers, knee, ankle, heel and toes) were illustrated as circle with different proportions and colors. To obtain the distributions of sleep positions on a sleeping surface, the images captured of the participants were overlaid based on the marker which was drawn on the pillow.

By means of sleep monitoring data analysis, main sleep position percentage and specific sleep positions of body segments corresponding to mattress were obtained. The outcome presented as Fig. 3 which data collection of temperature and sleep position recording was at the testing night. Despite of time as x-axis, sleep posture and proximal and distal skin temperature change to understand (1) specific position on sleep onset and before arousal (2) specific position change when temperature change. The proportion of every sleep position in total sleep time related to sleep quality was another key point of analysis.

2.3 Innovation Mattress Ideation and Implementation

Understanding of existing products is a non-ignored preparation before ideating. For satisfying various requirements of body parts, the study developed design ideas by morphological analysis and co-design. The exterior and inner structure of existing mattress. After the existing mattress comprehension, morphological analysis was conducted for classification of vertical-layer functions and horizontal surface parallel to sleep surface division.

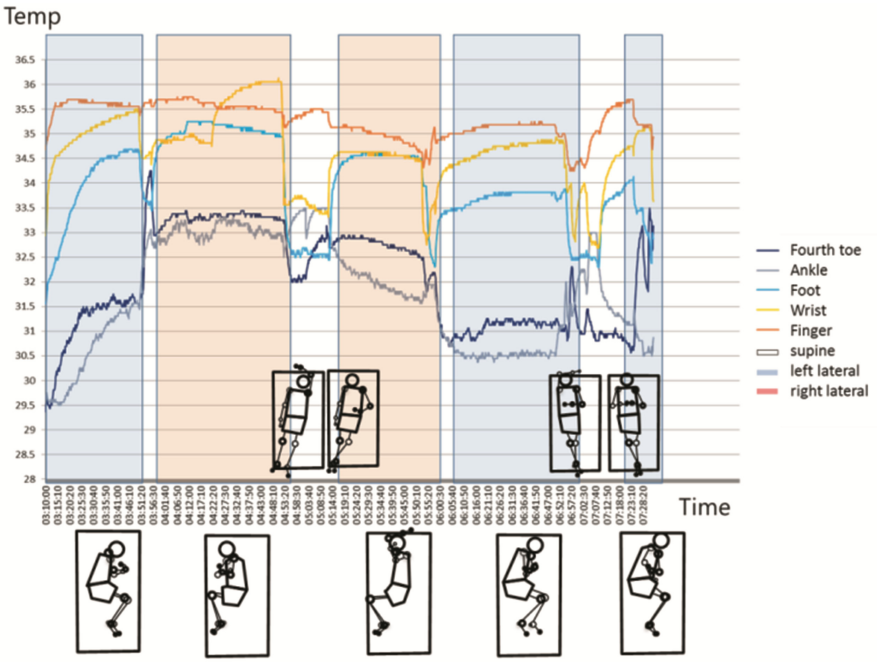

Fig. 3. Skin temperature change and body position change at testing night

Through outcomes of observational experiments, sleep surface is divided into multi zones which fit the movements of body segments and the crucial sleep posture and skin temperature change of each sleep stage are found. Body segment on mattress represented the distribution area. First step was to develop functions by co-design for vertical layer through observation information and design guidelines of improvement of thermal comfort from literature.

A group of six designers gathered to create numerous ideas following the design guidelines to improve thermal comfort induced sleep quality for one and a half hour. In the beginning, the author presented the observation results for the six designers for realizing the actuality condition, then, they started to ideate ideas. For specific position in certain sleep stage, the sleep characteristics of the observation were adopted to provide a reference to conduct the mattress design to satisfy the design guidelines and needs of different body parts. Therefore, the ppt showed the specific positions when they developed ideas. The three design guidelines were the main purpose should achieve through design criteria aligned in the column based on the design guideline. Through co-design, the preliminary attributes of the mattress and the possible solutions for requirements of each body parts of different positions were generated.

Morphological analysis was adopted to generate different kinds of mattress matrices. For co-design, the possible designed area of a mattress in vertical layers and horizontal spaces (corners, edges, and middle) were aligned in the bottom of the design criteria column. Horizontal division design considered different sleep position, and the location of body segments on mattress (Fig. 4). Designers selected the proper design area of

horizontal surface due to the position of real condition. And also, they chose the proper design layer for vertical structure. Finally, all design would be category and found out the best solution not only satisfied the design guidelines but recommend to local improvement.

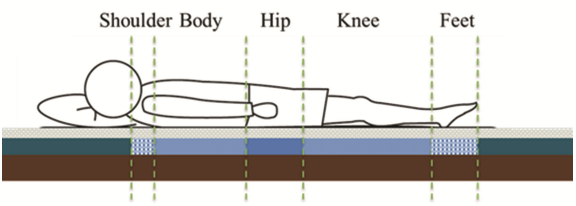

Fig. 4. Vertical layers of mattress and body segments corresponding to sleep surface

2.4 Experimental Assessment

The study was designed to achieve two critical efficacies: Improve sleep quality and enhance sleep thermal comfort by physiological and perception evaluation. One innovative mattress design implements and the original one were conducted for experimental assessment and self-reported questionnaires for subjective and objective evaluations to practical inspect all night usage of new design mattress. The original mattress called Mattress O in this research was a seven area latex mattress showed as Fig. 3. Ambient room temperature was kept at approximately 25 °C.

To investigate the skin temperature and sleep position, besides other sleep disorders, eight standard body ($18.5 < BMI < 24$) participants were involved in this study. All participants were informed to conduct sleep adaptation to reduce effect on sleep quality owing to unfamiliar sleep environment. Throughout a week sleep habit adjustment, eight good sleep-wake cycle participants filter for taking the laboratory night monitoring. During the experiment, all the participants complied with the provisions of no medicine taking and caffeine or alcohol consuming.

Participants were required to be at laboratory one hour before sleep time at 00:00 were then prepared for actigraphy and fitted with thermistors for proximal and distal skin temperature manipulation. At midnight, lights were turned off and participants were allowed to sleep until am 08:00 h. After first night sleeping in the laboratory, participants returned for a second night, and then the third night. The experiment environment shows as Fig. 5. The original mattress and mattress implement were examined alternately and randomly among three days. The original one was the multi-zone latex mattress.

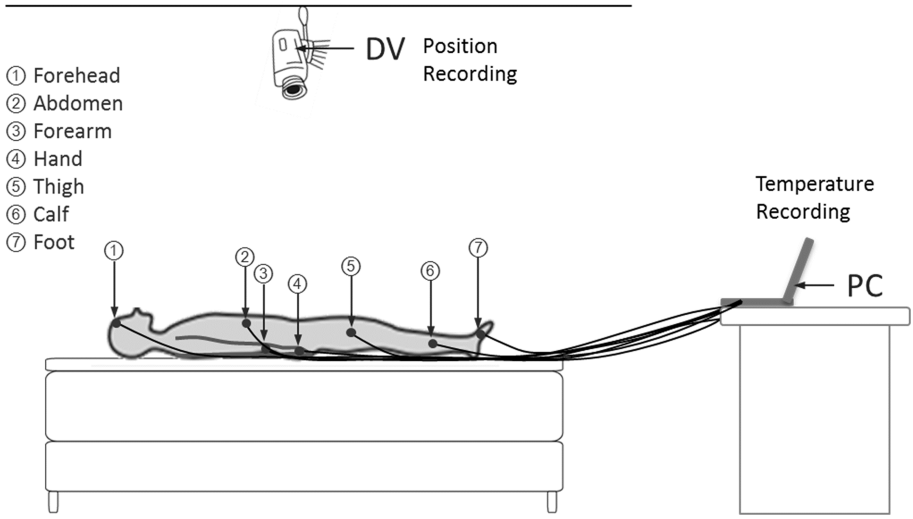

Fig. 5. Laboratory experiment environment

3 Results

A number of interesting findings emerged from this design process, and this report concludes three main results of an innovative mattress design process concerning local and dynamic physiological requirements during sleep, design ideate and product implement, and experimental assessment of mattress design.

There were three design guidelines that a mattress design should cover: (1) enhance pressure balance, (2) the physiological balance of microclimate, (3) improvement of distal skin blood circulation.

Design guidelines were applied to the major sleeping posture (supine and lateral) in order to meet the requirements of different body parts. The detailed information is presented in Fig. 6.

Through sleep monitoring of whole night, the study found out the basic physiology phenomenon change during sleep. By analyzing temperature correlate to specific sleep position of different sleep quality, to gain key sleep position as design inspiration. As the major movements of each participant were repeated, therefore the changes of sleep position were categorized as supine, lateral and semi-lateral according to the direction and angle of their torsos to the mattress, and the direct definition due to the turns of their torsos.

Sleep position distribution represented the location of body segments with overlay of major sleep position and semi-lateral was integrated to lateral. The results showed that the covered sleeping surface of supine was larger than the latera. In lateral position, the positions of their shoulders inclined to one side and opposite to the side of their hips. When change into supine, sleepers bent their bodies to match the size of the mattress, especially their foot. It was the reason why some covered surface was higher than knee.

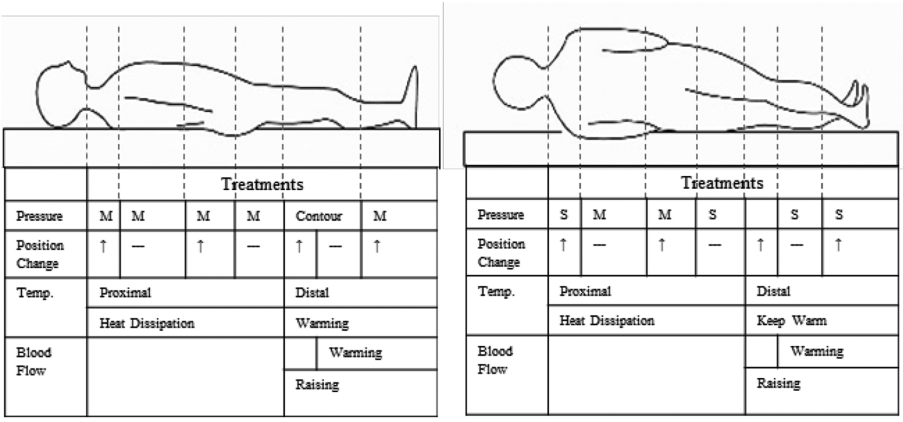

Fig. 6. Specific requirements of different body parts

The distributed area of legs in lateral was larger and placed separately during their sleeps. By understanding of the body distribution on the mattress combined with the design guideline connected with body part will later both use in mattress design. The union of body parts distribution on mattress would later as design parallel to mattress surface consideration of mattress to fit location of body part.

Compare of traditional and a better mattress, the quality was not about as many layers as the mattress involved, but about function and nature of material which was benefit to mattress structure. There presented a certain effect of each layer in mattress, and the common existing mattress structure analyzed by morphological analysis. Vertical layers arrangement was due to function and the horizontal distribution was due to the space division.

All of the ideas were classified into five items and named each one of it. No matter the design was for whole or partial of mattress. After design classification, the design of each layer was chosen. The priority was that the design can achieve more than one design criteria.

The final decision was planned. The size of the single mattress is 100 * 190 cm and 150 cm height. The proposed mattress has a five-layer sandwiched structure. The first layer had a V-shaped division line between the hip and leg and fulfilled different needs of trunk, hip and feet. For leg parts, increasing the friction between the skin and the mattress for warming, and a different material had been used to increase the heat dissipation of the torso and hip; the second layer had a rectangle on the bottom of egg shape material for keep warm and a little leg raising; the third layer is designed for ventilation and moisture transmission; the bottom layer is designed for pressure redistribution and the corrugated shape on the top was for position change. The first and third layers were designed according to physiological balance of microclimate). The second layer was for improvement of distal skin blood circulation. The top and bottom layer were for enhancing pressure balance.

All participants were standard-bodied young women aged 20–25. Sleep quality data were analyzed by PC based MotionWare Software. In composed of seven data each

mattress, the results indicated the relationships among sleep quality and mattress design were what was expected, that is, mattress D enhanced sleep quality. Exclude one outliners, participant 7's data showed great difference evenly in most situation, and almost every index was opposite to others. The results of four representative index, sleep efficiency, sleep latency, actual wake and mean activity, were showed as following. Mattress D had 3.38% higher sleep efficiency, five minutes shorter sleep latency, 2.57% less actual wake, and 1.85 epochs less mean activity. Expect for outliner a, every index illustrated the sleep quality of mattress D was better.

A t-test analysis indicated a significant difference of actual wake time; $t(5) = 3.34$, $p = 0.021$, and sleep efficient; $t(5) = -5.48$, $p = 0.003$, between the means of two groups, but there was not significant in the sleep onset latency; $t(5) = 1.55$, $p = 0.183$ and mean activity, $t(5) = 1.24$, $p = 0.270$.

4 Discussion

Comparison between traditional and a better mattress, the quality was not about as many layers as the mattress involved, but about functions and nature of material which were benefit to mattress structure. There were several physiological factors associated with comfort and interface skin temperature also included in those factors [10]. The innovative mattress of this study combined three aspects of mattress design factors that influenced efficiency of thermal comfort improvement to propose the design guidelines. Design guidelines included enhance of pressure balance, physiological balance of microclimate, and improvement of distal skin blood circulation. To increase nature character of innovative mattresses, both of the design excluded heating system which reduced the effect on fast-deducing thermoregulation. Another reason that heating-considering design was not chosen was that in previous studies, passive heating products were usually suggested to operate under the condition of low ambient temperature. It may reduce cold stress, thereby supporting sleep stability and thermoregulation during sleep [7]. Compared to the innovative design implant in the mattress structure of this study, numerous interrelated products which are used to improve sleep thermal comfort increase in recent years. Most of those products were not integrated to the bedding system, such as electronic temperature control devices (electric blanket and ChiliPad) or focus on the textiles substitution, such as foam and fabrics [5].

This study enhances the previous studies' finding by integrating effect factors of whole body and local needs of mattress design. The result of this study developed an innovative mattress fulfilled local need according to physiological condition information. Owing to sleep pattern and habitual sleep posture are personal, Tsai and Liu (2008) referred the good bed is the familiar one to achieve the local need of body sites [10, 11]. The information of position change provides mattress design a virtual condition for designers to ideate design. For guideline of this study, a mattress design is required to conform to the body contours to avoid local point pressures on the human body tissue especially at the location of bony prominence and it should support human to change their sleep position when they felt uncomfortable and tried to reduce sleep discomfort by redistributing the interface pressures of the body. The first layer had a V-shaped

division line between the hip and leg and fulfilled different needs of trunk, hip and feet. For leg parts, increasing the friction between the skin and the mattress for warming, and a different material had been used to increase the heat dissipation of the torso and hip; the second layer had a rectangle on the bottom of egg shape material for keep warm and a little leg raising; the third layer is designed for ventilation and moisture transmission; the bottom layer is designed for pressure redistribution and the corrugated shape on the top was for position change.

5 Conclusion

Exile investigation of continuous sleep position change information provided a benefit resource to valid sleep surface comfort with more physiological message other than body temperature. The images of sleep monitoring attempts to account for most of particular temperature change and sleep quality affected by body movement. To conclude the thermal comfort achievement of this study, the design of Mattress D was benefit for heat dissipation to distal skin, and had comfort feeling in extremities and whole body thermal comfort promotion.

The mattress design due to sleep position change was contributed to reduce minor position period to enhance sleep quality during sleep. The relationship between sleep position, skin temperature and sleep quality needs further exploration. A t-test analysis indicated a significant difference of actual wake time and sleep efficient. Furthermore, despite of one of seven participants had poor sleep quality when slept on Mattress D, and others had a better sleep at the night on new Mattress. Two participants reported that they took more than half an hour to fall asleep and four participants had chance to wake up in the middle of the night when slept on original Mattress.

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