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Research Article

Physiological Study on the Relaxation Effect of Bedding Materials to Sleep Quality by Body Motion Wave Reflecting Activities of Autonomic Nervous System

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Abstract

Relaxation is one of the methods to keep or improve us in good health. For suppliers, it is significant theme to know how much their services satisfied customers. Questionnaire survey is often adopted, however, the reply from customers is not always accurate. This paper describes a detecting method of a more accurate reply by entrusting the reply for the services to unconscious responses reflecting activities of autonomic nervous system during sleep.

Such experiment was performed on the idea that there is some relationship between satisfaction and conditions of both mental and physical activities. A method, body motion wave method, has been developed to detect satisfaction and to study mechanism of satisfaction. As a result, it was found that the unconscious responses of phenomena of respiration and pulse through a night showed satisfaction instead of conscious responses.

Regarding the bedding material, one of the important services, a customer usually selects it in a store through lying on it for only one minute or less to feel how much comfortable it is. However, as such a selection goes under conscious state, a customer does not know unconscious comfortableness, i.e., satisfaction or good quality of sleep with several hours sleep. Relaxation effect of services, e.g., bedding materials, to sleep quality can be physiologically detected through BMW method reflecting activities of autonomic nervous system, though a subject is not aware of receiving those services. Particularly pulse rate was controlled sophisticatedly to reveal satisfaction with reflecting a kind of service.

Through this series of study, it was found that body motion wave method detected unconscious response of how much satisfied. The relaxation effect produced by a service in awake state or by the one in sleep state made pulse rate decreased through the mental or physical procession or only the physical procession. However, there was a limit set in this decrease. Such mechanism had set a certain range to control pulse rate, and then had made pulse increase and decrease within the range, at which sophisticated control had been performed by using fluctuation of instantaneous pulse rate train. Authors have named this range Minute optimum Pulse rate Range for Sleep, and Instantaneous optimum Pulse rate Range for Sleep.

Such a body motion wave method confirmed that some kind of bedding materials obviously caused relaxation during sleep with some different degree, though each subject was not aware of influence of each material. Thus, the state of mental and physical activities has become visible by unconscious response due to activities of autonomic nervous system during sleep.

Keywords: *Satisfaction; Body Motion Wave (BMW); Autonomic Nervous System; Unconscious Response; Relaxation; Sleep*

Abbreviations

BMW: Body Motion Wave

Introduction

Most of time, we do not have a good level of awareness either of our general state of health or the condition of our body. Equally, for reasons of modesty or other individual constraints, if we are aware that we are in poor health we sometimes do not want others to know. On the other hand, people who need to be particularly careful about managing their own health – athletes, drivers, control room staff etc. need to have a thorough understanding of their own state of health. However, there is currently neither a scale nor the terminology to describe it, and there is thus no easy way of expressing an individual's overall state of health.

While, in daily life we accept various services such as articles and information, etc. The suppliers of them usually want to know how much degree the services satisfied customers. Though questionnaire survey, for example, is often adopted, the customer's reply to the service is usually distorted by some reasons, i.e., it is neither accurate nor honest. Therefore, the question here is if it is possible for suppliers to know the degree of satisfaction turning out accurate and/or honest reply to the services. If possible, they would make better services by considering the honest reply.

Therefore, in above two situations there are two common problems. The one is that verbal information is not always accurate, and the other is that we do not have a good level of awareness either of our state of health or degree of satisfaction if we are not ill or accept a service unintentionally.

For this reason, authors looked to non-verbal communication through physiological behaviour, i.e., signs of vital activities, for example, rates of respiration and pulse reflecting activities of autonomic nervous system during states of unconsciousness, i.e., during sleep [1-6].

In the series of these studies, healing music and aroma have been adopted to demonstrate the method to be adequate. The reason why is the findings obtained through above method, i.e., the findings of such unconscious responses reflecting activities of autonomic nervous system should mean the degree of satisfaction, because music or aroma to heal humans mentally and physically is already approved by some other way throughout the world as adopted in music therapy or aromatherapy.

At the present study, the phenomena of relaxation detected by the above measurement method were further investigated through fluctuation of instantaneous pulse rate implying more of information of the relaxed by using some bedding materials.

Materials and Methods

Human system at the viewpoint of input/output

Figure 1 shows a schematic chart to describe a detection method for the degree of satisfaction or state of health in mind and body. We accept various services, however, honest information for the reply does not appear, while the variation of health state due to the service does not appear. A particular camera can see the degree of satisfaction or state of health through a filter, i.e., sleep information pass filter.

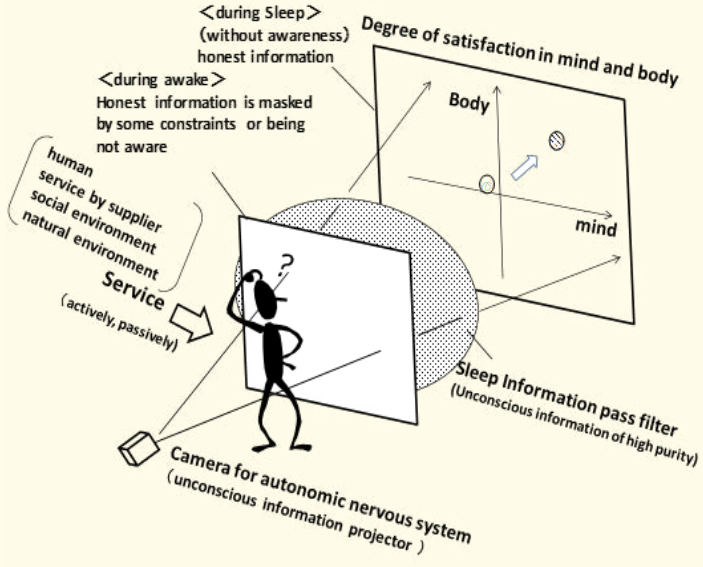

Figure 1: *Schematic chart to describe a detection method for the degree of satisfaction or state of health in mind and body through autonomic nervous system.*

Generally speaking, a system has a mechanism to produce an output modulated by its characteristics for an input. This idea was applied to following human system [1-5]. A human is an elaborate system having two functions of mental and physical activities as shown in a schematic model of Figure 2. Therefore, the human receives a stimulus, i.e., input of service, intentionally or unintentionally through human's own various biological sensors to put both or one sides of above functions into action as output of response. For the output, Fig. 2 suggests a mechanism of resulting a conscious response and an unconscious response for an input of a service. Here, article, information, energy and labour were listed for example for input. Such as listening, reading, watching, buying, and receiving something in conscious state are example input stimuli.

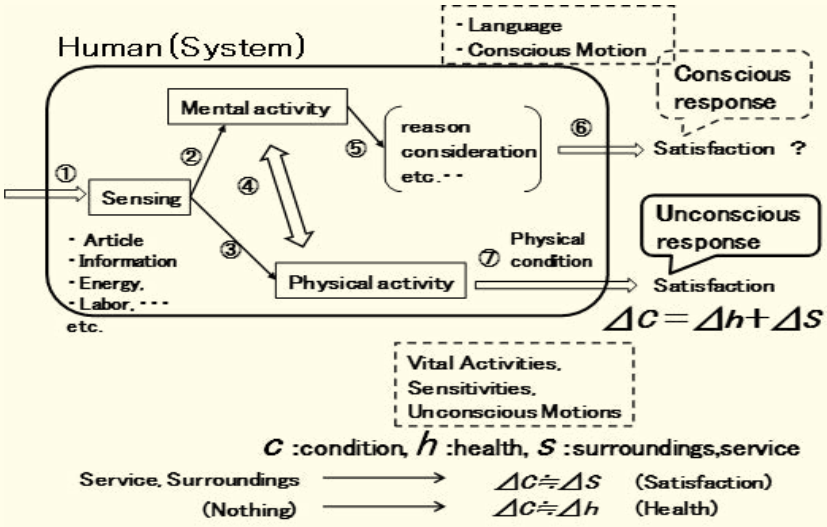

Figure 2: *Hypothetic model revealing flow of a service for a human system from sensing to response [2].*

The output through language or conscious motion, for example, is a conscious response. For the former, such as talking, writing and painting correspond, while for the latter, motions due to motor function such as walking do. On the other hand, the variation in physical condition is an unconscious response to express by vital activity, sensitivity, and unconscious motion.

Here, the flow to conscious response is as follows. A biological signal, produced due to sensing stimuli at channel 1 (circled 1), flows into channels 2 and 3 to activate mental activity and physical activity, respectively. Then, these mental and physical activities interact through channel 4. Mental activity, such as satisfaction or emotion, probably makes physical activity better. Also, good physical activity will make mental activity better.

Thus, the mental activity will reply to the service by satisfying for a conscious response through channels 5 and 6. However, there would be possible to reply apparent satisfaction, because a signal of mental activity was sometimes distorted by reasons or consideration *et al*, as shown in the bracket between channels 5 and 6. Thus, the reply in such a way is not always accurate.

In addition, the mental activity does not always have a clear idea of satisfaction or not. Also for stimuli such as less variation of temperature, background music of during unconscious state, a signal does not pass through channel 2.

On the contrary, there are two lines in the physical activity as a physical condition to express an unconscious response. The one is direct channel 3 and the other is channel 4 via a mental activity. The signals from such two pass ways are combined and then sent by channel 7 for output. This output, an unconscious response such as vital activities, sensitivities and unconscious motions, etc., should be an honest answer because it was not distorted by above reasons *et al*.

Physical condition generating unconscious response as shown in Figure 2 was determined by a factor of condition *c*. This factor *c* was simply determined here by $c = hs$, where *h* is a factor of health and *s* is a factor of surroundings or service. For the less amount of variation, it can be simply expressed by,

$c+dc = (h+dh)\ (s+ds) = (1+dh)\ (1+ds)$, (d: delta)

$dc = dh+ds$.

As some variation of surroundings or service ds is input under a state in health maintained, i.e., $dh=0$, the output will mainly occur as $dc = ds$. If *c* varied with no sensitive input, the fraction of health condition, d*h*, must have varied.

Daily life is roughly classified into two situations of in awake and in sleep as shown in Fig. 3. In the former, mental activities produced in cerebrum will generate a conscious response. On the contrary, in the latter, because of unconscious state, autonomic nervous system activity is superior so that physical activities will generate an unconscious response. This is why the answer is put into unconscious response.

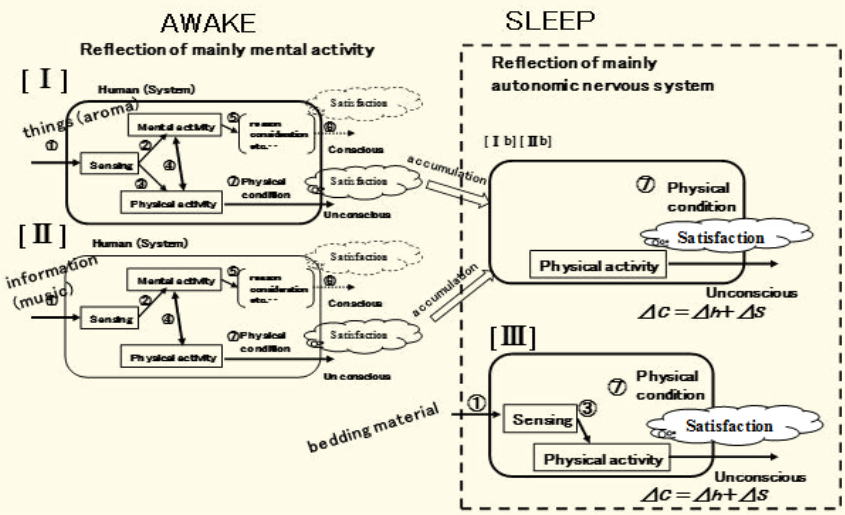

Figure 3: *Hypothetic model revealing three types of service flows I, II and III.*

Then, service input can be classified into three types as shown also in Figure 3. Articles and food are examples of type I having channels 2 and 3. Information is an example input of type II not having channel 3. Unconscious responses would be accumulated in the body and, therefore, would appear during sleep. Then we are in unconscious state, therefore, the output through several hours is free from reason, consideration, *et al.* Some bedding materials, input to human system without awareness during sleep, are examples of type III having neither channels 2 nor 4.

Fig, 3 Hypothetic model revealing three types of service flows I, II and III

At the present study, vital activities during sleep has been adopted and studied. Now, it is obvious that the mind does not answer, however, the vital activities express unconscious responses free from reason, *et al*.

Instrumentation

It is understood that both respiration and pulse during sleep are controlled by autonomic nervous system [7,8]. In order to investigate further, a measurement system with which to detect the vital activities during natural sleep has been developed [6]. Natural sleep here means that a subject spends a normal day in a waking state and sleeps with no restriction, such as drugs, sensors, etc.

A pressure sensor, named "dynamic air pressure sensor" (M.I.Labo) was adopted so as to construct a non-restraint measurement system as shown in Fig.4. In principle, it was set on a bed in order to detect dynamic air pressure arising between the sensor and a subject's

body while lying on the bed. The pressure variation detected with the sensor was converted to electric signals, the "body motion wave" as mentioned later, sampled at the rate of 400 Hz, 16 bit and stored in a personal computer.

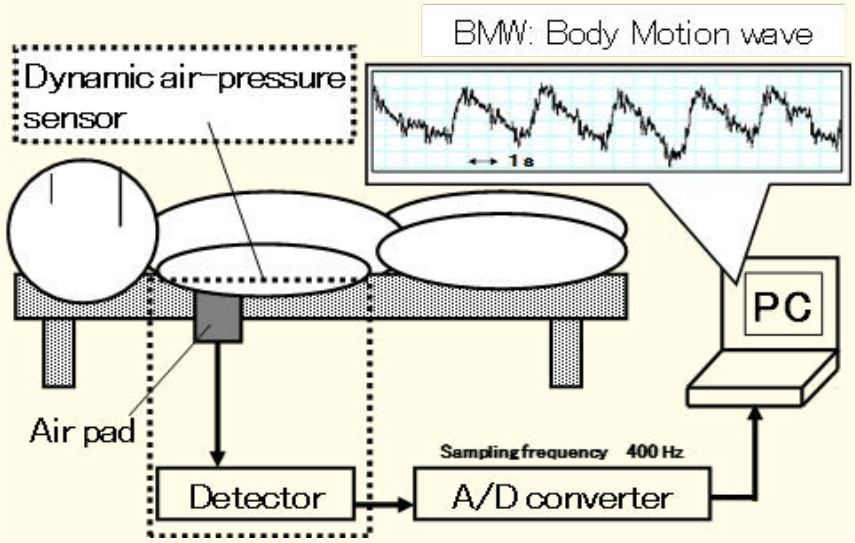

Fig. 4 *Measurement system to detect body motion wave (BMW) having components of respiration-origin BMW (R-BMW) and pulse-origin BMW (P-BMW).*

The signal was processed with Chart v4.2.2 (AD Instrument) and programmable software VEE Pro ver6.0 (Agilent Technologies).

It was understood that the vital activities, e.g., pulse and respiration, occur independently as unconscious responses free from mediation by the rational mind, and the reproducibility of this system has already been confirmed [1-5].

Body motion wave

As reported by Okawai., *et al*. [1-5], in a subject's body during sleep certain continuous motions are generated resulting in respiration and pulse, hence thus motions can be detected as pressure wave named "body motion wave (BMW)". This wave can be filtered out "respiration-origin BMW(R-BMW)" and "pulse-origin BMW (P-BMW)". In addition, during sleep, some frequent extra motions are generated resulting in unconscious actions. These can be detected as pressure waves also.

For these extra waves, two broad types of waves appear. One was named Tremble-origin BMW (T-BMW) with a small magnitude and short duration of wave due to a slight action of a part of the body. The other was named Action-origin BMW (A-BMW) having a large magnitude and wide duration of wave.

The accuracy of this present method for detecting rates of respiration and pulse has already been confirmed through comparison with data taken from a thermistor and an electrocardiogram [6].

Thus, the present method, adopting a non-adhesive, dynamic sensor, has the following merits: (i) it can be utilized in everyday life because it requires no involvement by medical professionals; (ii) it obtains data throughout an entire period in bed, even if a subject, say, goes to the bathroom during the night; (iii) it corrects data of pulse, respiration and action simultaneously; and (iv) it therefore secures a subject's privacy, since neither a video camera nor microphone are used.

Experiment

The set of experiments performed on a single subject were carried out over the course of four consecutive weekdays. The data for the

first and second days as normal days were checked from the viewpoint of physiological reproducibility, and these data were used as control. The data at the third and fourth days, i.e., the days where services, i.e., stimuli were introduced, were compared with the control data. Weeks or weekend containing a national holiday or event day were excluded because the mental or physical variations might engender. Any subject in an unusual condition as a result of some kind of mental or physical situation was excluded.

Three types of stimuli of (a) aroma, (b) healing music and (c) bedding materials were adopted for the service of healing and relaxing.
(a) For aroma, subjects who do not use aroma in daily living were selected. Any aroma each subject liked by himself/herself among more than 20 kinds of aroma oils was diffused in the room before going to bed by 1 - 2h (hours). The aroma was available for approximately 2 - 3h after going bed. (Type I in Figure 3)
(b) For healing music, subjects who do not hear healing music in daily living were selected. The subject heard a music chosen by himself/herself for approximately 30 min (minutes) to 1 h in the time of 2 h to 0.5 h before going to bed. (Type II in Figure 3)
(c)For bedding material, authors tried commercial products and authors' trial products as listed below. (Type III in Figure 3)
(1) Commercial products

- material-0 (mattress, reference, polyester50%+cotton50%, selected well, rather cheap, "Normal")
- material-1 (mattress," Feather")
- material-2 (mattress, "Low repulsion")
- material-3 (mattress, 20 cm in thickness, "Thick")

(2) Materials of author's design to produce relaxation during sleep

- material-4 (mattress, resin grain included, "Beads")
- material-5 (mattress, 1 mm thickness, graphite, "carbon C")
- material-6 (same origin material as above, different processing, "carbon D")
- material-7 (same origin material as above, different processing, "carbon E")

Results and Discussion

Regarding the aroma and music stimuli, the results has already been reported [1-5]. As shown by an example data for music in Fig. 5, the data showed the transitions for a subject of minute pulse rate in the upper and of minute respiration rate in the lower over the course of night, and the left two are for the first or second night for the normal, i.e., with no particular stimulus, and then the right two are for the third or fourth night with a music stimulus. As a result, pulse rate decreased significantly by approximately 10, while respiration rate did not decrease so much.

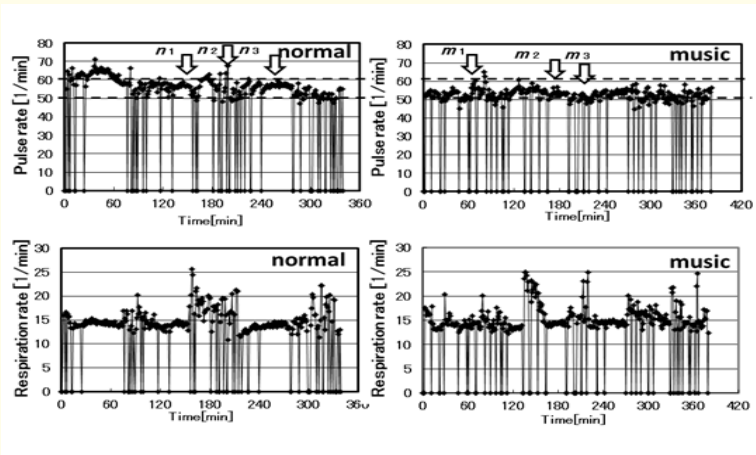

Fig. 5 Transition of rates of pulse, upper, and respiration, lower, during sleep through a night. The left shows for "normal", i.e., with no particular service (stimulus) while the right shows for "music" stimulus as a service.

Regarding the aroma, not shown here, pulse rate decreased also, however, respiration rate did not vary. Some other data of respiration rate for music showed distinct decrease while no data for aroma did.

These results have demonstrated that (I) the satisfaction a subject felt through mental or physical activities at awake state due to a stimulus by aroma or music for relaxation was accumulated in the body physiologically. (ii) Consequently, the variation in physiological data was successfully detected by BMW method during sleep, i.e., at the condition that activities of parasympathetic nerves became relatively dominant compared with that of normal days in principle.

Findings from the series of these investigation are as follows:

(i) A considerable number of small deletions traced like pillars getting to zero in the rates of both pulse and respiration showed body actions to disturb counting.

(ii) Autonomic nervous system controls pulse and respiration in different manner because the period shown by a set of increase and decrease in the transitions of rates of pulse and respiration were not same.

(iii) There were some difference in the mechanism of relaxation due to aroma and music because aroma did not make respiration rate decrease, but music did.

(iv) Quick and tremendous increase in the transition of respiration rate, occurred by more than 3 per minute with the duration 5 to 10 minute at the neighbourhood of number of pillars.

(v) Quick and tremendous increase by up to larger than 1.5 to 2 times with the duration of 5 to 30 minute also at the neighbourhood of number of pillars. It means errors for counting respiration rate though not quite satisfactorily, however, it rather means the waveform of BMW in one period of inspiration and expiration varies to have two peaks and, namely to be counted twice by our program for processing. Such "miscount" was confirmed to be almost lateral position in sleeping posture during entirely one minute. In another word, this phenomenon is one of the significant information.

In previous study, authors determined a certain range in the transition of minute pulse rate. This rate was calculated, as an average value, from instantaneous pulse rate train during every one minute. This instantaneous pulse rate train has fluctuation determined by magnitude of variation.

After careful consideration, it was found that large magnitude occurred at which minute pulse rate was at around both maximum and minimum. On the contrary, less magnitude was kept in the range between maximum and minimum.

Authors hereby has classified the range expressed by minute pulse rate into three ranges*: Ra, Rb* and *Rc* as,
Ra: the range at which large magnitude in fluctuation of instantaneous pulse rate occurs, especially at around maximum, i.e., at higher minute pulse rate level,
Rb: the range at which less magnitude in fluctuation of instantaneous pulse rate is kept. i.e., in the range between maximum and minimum in minute pulse rate, and
Rc: the range at which large magnitude in fluctuation of instantaneous pulse rate occurs, especially at around minimum, i.e., at lower minute pulse rate level.

For the upper two panels in Figure 5, for example, the range *Rb* was roughly determined between 50 to 60 for normal, while 50 - 55 for

At the current study, attention was paid to further study for the range *Ra, Rb* and *Rc* using bedding materials expected to produce relaxation effect. Three ranges were determined in a same way, however, they were assumed to vary downward against time as shown in Fig. 6, hereby sample points s1, s2 and s3 were selected from left for *Ra, Rb* and *Rc*, respectively. The points s1 and s3 had amplitude of the train of instantaneous pulse rate larger than 15 as shown in the small panels inserted, while s2 had 5 - 10.

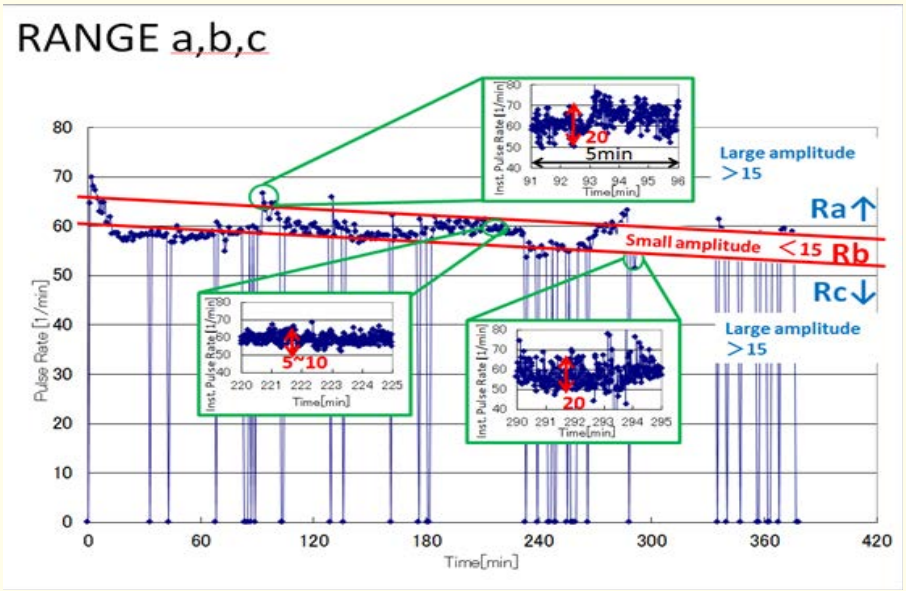

Fig. 6 Determination of a certain range Ra, Rb and Rc in the transition of minute pulse rate and instantaneous pulse rate train with 5 minute duration.

Regarding to material-1," Feather", as shown in Fig. 7, the left panel was obtained from "Normal", while the right was "Feather". For example, two points were selected, i.e., the one circled in the left panel, level 52 and the other at the almost same level 50 in the right panel.

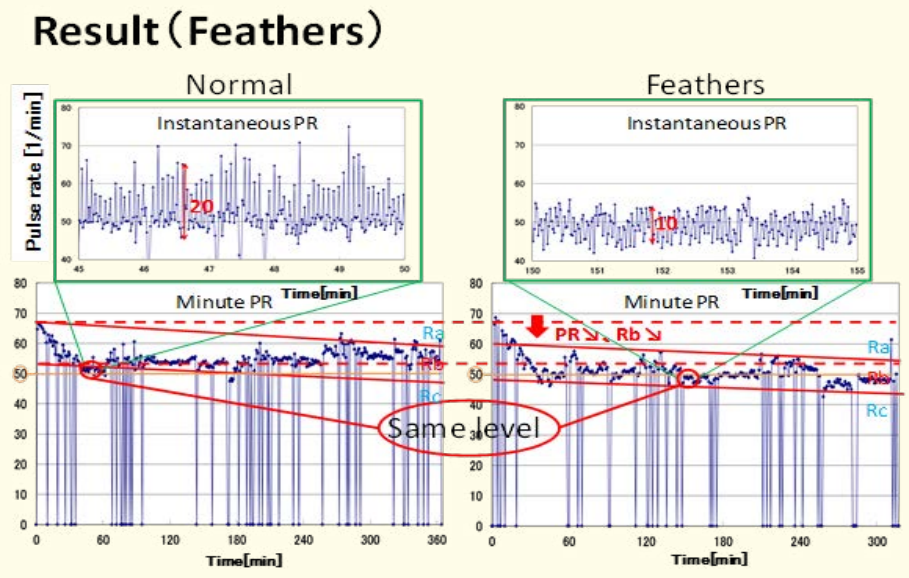

Figure 7: *Transition of minute pulse rate for the normal (left, lower) and Feather (right, lower) and each instantaneous pulse rate train (upper).*

The former had magnitude of instantaneous PR (pulse rate) train of approximately 20 as shown in the upper panel inserted, while the latter had that of 10 as shown same way. Minimum level in the left panel, i.e., a boundary between *Rb* and *Rc* was approximately 53 to 48 as drawn by solid line varying downward, while the one of the right panel was 49 to 45 as drawn by lower solid line varying downward.

These data mean that the former point was in the range *Rc*, while the latter was in the range *Rb* even if the value of the point is less than the former, that is, the range *Rb* shifted downward. Thus, "Feather" made the range *Rb* shift downward as well as it made minute pulse rate decrease as shown by two traces of minute PR.

Regarding to material-2, "Low repulsion", as shown in Fig. 8, the layout of panels is the same as previous material. Two points at the same level were selected, for example, in the same way to compare amplitude of fluctuation of instantaneous pulse rate, i.e., the one circled in the left panel, level 48 and the other at the almost same level 45 in the right panel.

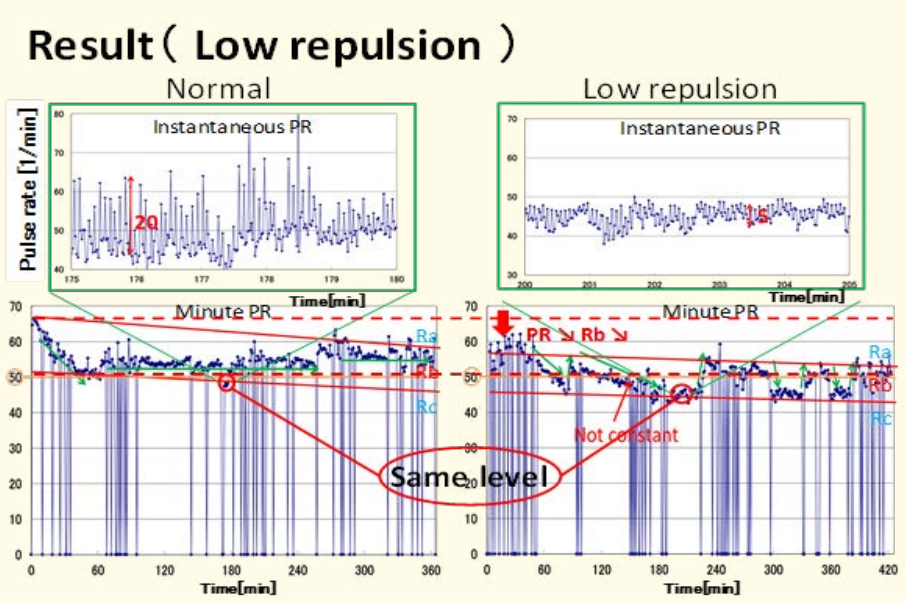

Figure 8: *Transition of minute pulse rate for the normal (left, lower) and Low repulsion (right, lower) and each instantaneous pulse rate train (upper).*

The former had magnitude of instantaneous pulse rate train of approximately 20 as shown in the upper panel, while the latter had that of 5 as shown same way. In the left panel, the boundary between *Rb* and *Rc* was approximately 50 to 46 as drawn by solid line varying downward, while the one of the right panel was approximately 45 to 42 as drawn by lower solid line varying downward.

As same as previous material, these data mean that the former point was in range *Rc*, while the latter was in the range *Rb* even if the value of the point is less than the former, i.e., range *Rb* shifted downward. Thus, "Low repulsion" made the range *Rb* shift downward as well as it made minute pulse rate decrease as shown by two traces of minute Pulse rate.

In addition, it I noticed that the transition does not have a flat pattern at low level as the other case has, but has saw-like patterns with duration of 80 minute.

A part of the data has been reported for material-1 [1-3], and that for material-5 has done (Carbon) has done [9-10], then at the current study, new results were summarized for the material-1 to material-7. The data for minute pulse rate were listed in Table 1. Tendency for the decreased showed almost same for the shift of range *Rb*, though each value itself varied was not same.

Material	Number of Subjects	Decreased	Not varied	Increased
1 Feather	13	9	1	3
2 Low repulsion	5	3	2	0
3 Thick	8	6	1	1
4 Beads	6	5	1	0
5 Carbon C	7	4	3	1
6 Carbon D	3	1	2	0
7 Carbon E	4	0	0	4

Table 1: *Result for the variation in the pulse rate during sleep over the course of a night.*

On the contrary, "Carbon E", pulse rate increased, showed opposed tendency, i.e., the range Rb drawn by solid lines shifted upward and magnitude of fluctuation at the portion circled in the right panel became larger compared with the portion circled as same level in the left panel, as shown in Fig.9. Thus, Carbon C. Carbon D and Carbon E of which original material was same but product process was different produced different PR behaviour. Carbon C was the best material among these three.

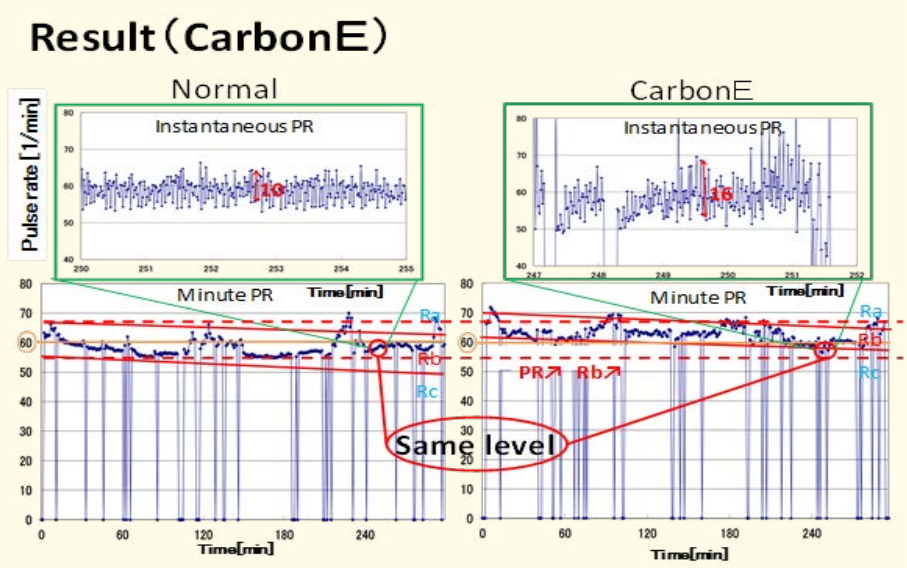

Figure 9: *Transition of minute pulse rate for the normal (left, lower) and Carbon E (right, lower) and each instantaneous pulse rate train (upper).*

All of the data for the minute rates of pulse and respiration were summarized as shown in Fig. 10.

Consequently, it can be considered as follows:

(i) Generally speaking, information for the satisfaction supplied by the bedding material will not so accurate because of under conscious state, i.e., in awake state. On the contrary, BMW method, developed through the series of current study, will answer how much satisfied quantitatively and accurately, because mental activity dose not answer, but physical activity replies physiologically under sleep state.

(ii) It was confirmed the relaxation effect produced by a service mentally or physically made pulse rate decreased, i.e., the decrease was one of the phenomenon of relaxation. If it is absolutely right, it will be possible to understand that the more pulse rate decreases, the more body relaxed. However, it is natural that pulse rate would have lower limit so as not stop. This limit was found as the level at which large fluctuation occurred with large amplitude of instantaneous pulse rate train. Subsequently, the pulse

rate started increasing, not kept the lower limit level. In the same way, the pulse rate had a larger limit at which large amplitude of instantaneous pulse rate occurred also. Thus, a mechanism to control minute pulse rate range and amplitude of fluctuation was found. Authors have named this range Minute optimum Pulse rate Range for Sleep (moPR-S), and Instantaneous optimum Pulse rate Range for Sleep: (ioPR-S), respectively. For this sophisticated control, authors guessed that Autonomic nervous system decided outline of minute pulse rate, the range *R*b and its position and gave the direction to the sinus node, while the sinus node drove heart precisely under the direction.

(iii) Through this study, bedding materials obviously caused relaxation during sleep with some different degree as shown in Figure 10, though each subject was not aware of influence of each material. It means the subject accepted service through Type III in Figure 3, i.e., with no mental activity.

(iv) Mental or physical improvement makes each health state improve each other as the proverb goes in the world. This series of study has demonstrated it physiologically. This result would be useful to study more of health.

(v) Regarding to respiration, some phenomena have been obtained, e.g., decrease of pulse rate, indicator of sleeping posture, different control mechanism from pulse in transition profile pattern as shown in Figure 5, however, it has not yet summarised, but only a little further investigation would solve it.

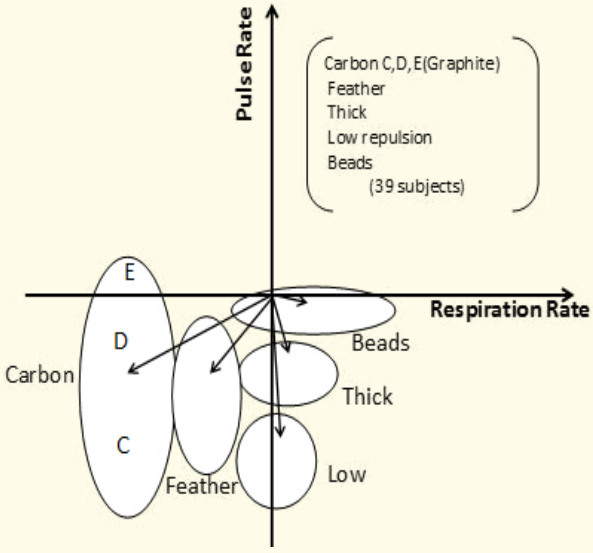

Figure 10: *Summarized data of variation of rates of pulse and respiration for some bedding materials. Origin of the axes corresponds to the PR and RR for Material 0 as described in section 5.4.*

Thus, as shown in Figure 1, the state of mental and physical activities has become visible by unconscious response due to activities of autonomic nervous system during sleep.

Conclusion

Relaxation effect of services, e.g., bedding materials, to sleep quality can be physiologically detected through BMW method reflecting activities of autonomic nervous system, though a subject is not aware of receiving those services. Particularly pulse rate was controlled sophisticatedly to reveal satisfaction with reflecting a kind of service.

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