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BRIEF REPORT

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Cross-sectional study of different mattresses, lumbar back muscle activity, and autonomic nervous system function

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Abstract

To clarify the impact of different mattresses on motor and neurological functions, lumbar muscle activity and autonomic functions were compared in 16 healthy subjects lying on two mattresses: a common market type (Mattress A) and our custom-developed one (Mattress B). Surface electromyography of the dorsal lumbar muscles and an autonomic function were recorded in 16 healthy subjects in the supine position on two types of mattresses: one generally available on the market (Mattress A) and another developed by our team (Mattress B). Results showed significantly lower lumbar muscle activity and a trend towards parasympathetic dominance on Mattress B. However, the study didn't account for mechanical effects, personal preferences, or body size. The results of this study suggest that mattresses can affect lumbar muscle activity and autonomic function. Further research may help manage back pain and stress related to bedding.

Keywords Mattress, Electromyography, Lumbar back muscle, Autonomic nervous system function, Heart rate validity

Introduction

In recent years, the use of digital devices (such as smartphones, tablets, and computers), various lifestyles, and stress have increasingly impacted sleep quality and led to sleep disorders (Boniel-Nissim et al. 2023; Lund et al. 1598). While poor sleep quality and sleep disorders can contribute to cardiovascular diseases, obesity, cognitive decline, emotional disturbances, and autonomic nervous system dysfunction, they are also related to physical discomfort, such as lower back pain and decreased performance in sports (Auxier et al. 2023; Kuki et al. 2024; Abedalaziz et al. 2024; Hur et al. 2021; O'Hagan et al. 2023; Campanini et al. 2022; Halson 2014; Ochoa-Lácar et al. 1570). Although research in sleep science has examined the relationship between sleep and various diseases or performance by focusing on the central nervous system, cardiovascular system, and respiratory system (Fink et al. 2018; St-Onge et al. 2016; Lao et al. 2018), this field is still developing. Future discoveries and new treatments are anticipated. Comprehensive research and discussions aimed at improving sleep disorders can enhance our understanding of the impact of modern lifestyles on health, and disseminating accurate information and promoting proper sleep habits can contribute to the health of individuals and society.

Various approaches are being taken to improve sleep quality, including enhancing the sleep environment, stress management, supplementation, and pharmacotherapy. Among these, the importance of bedding (mattresses) as part of the sleep environment is recognized, but there is little objective (Caggiari et al. 2021).

We continue to develop mattresses that contribute to health promotion and disease prevention on the basis of our experience accumulated over many years. We believe

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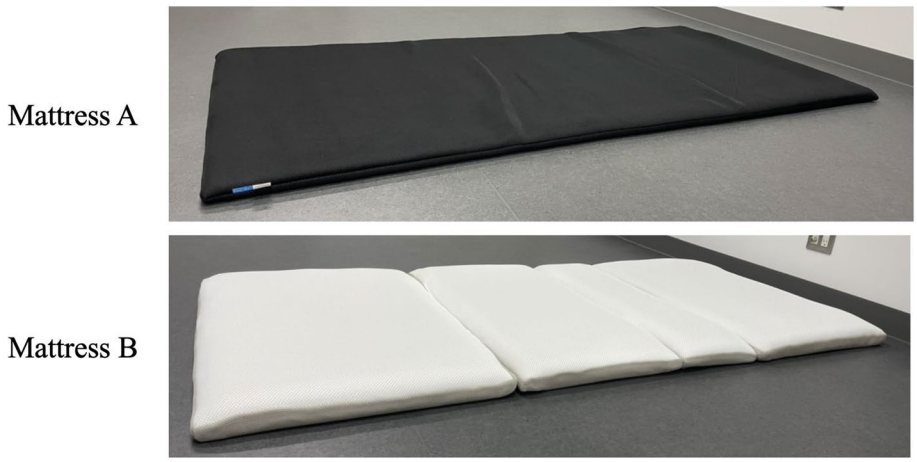

Fig. 1 Mattress used in this study

that the mattresses we have developed are characterized by their layer structure and material (firmness). Although consumers have evaluated the mattress as 'relaxing' and 'comfortable', we are still in the process of establishing and proving the objective basis for the layer structure and material and are approaching the formalization of the long-standing experience (tacit knowledge) of the development group from many different angles.

This study investigated surface electromyography of the dorsal lumbar muscles and autonomic functions while lying on the bed, with the aim of objectively demonstrating the 'relaxation' and 'comfort' that is obtained as a feeling of use of the mattress we have developed.

Materials and methods

Subjects

In this study, the differences in the mean values of each indicator are tested in an ABA design according to the differences in mat materials and shapes. Therefore, the number of samples (number of subjects) was analyzed via one-way ANOVA, and the sample size was estimated via SPSS Statistics Ver 29 (IBM) with a test power of 0.8, a standard deviation of 5, and a mean value of each indicator between 5 and 10. Therefore, the number of subjects was set to 10 or more, and the subjects were recruited.

Sixteen healthy (without subjective or objective orthopedic or neuropsychiatric problems or symptoms) university students, who were recruited through internal tools such as email, noticeboards and other on-campus tools, participated in this study, and they were first-year physiotherapy students whose specialization courses were not offered and whose age was nineteen years.

This study was conducted with the approval of the Hokuriku University Research Ethics Review Committee for Human Subjects (Approval No. 2023–27). All the study tasks were carried out in accordance with the Declaration of Helsinki. Prior to the experiment, according to the decision of the Hokuriku University Research Ethics Review Committee for Human Subjects, we explained the purpose, outline, and potential invasiveness of this experiment, as well as the possibility and format of publication, to the subjects in advance, and then obtained written consent from them.

Methods

Surface electromyography (EMG) of the dorsal lumbar muscles and autonomic function were recorded from subjects lying in the supine position on a commercially available mattress (mattress A, Fig. 1) and a mattress developed and manufactured by Yumeron Kurokawa Co., Ltd. (mattress B, Fig. 1). The recordings were performed via an ABA design (A1-B-A2), starting with mattress A (A1), mattress B, and then returned to mattress A (A2).

Posture and conditions

The subject was placed in a resting supine position with eyes closed on a mattress on the floor in a laboratory shielded from radio waves and sounds, and was instructed not to speak. The subject was not prevented from falling asleep, but if any body movement occurred, the experiment was stopped and restarted from the beginning. The room temperature was set to 25 °C, and the lighting was set to 500 lx, in accordance with the recommended illuminance specified by the Japanese Industrial Standards (JIS)."

The duration of the supine position on each mattress was 10 min, and Mattresses A and B were placed side by side with no space between them. After 10 min in the supine position, the subject was moved to the mattress beside him after sufficient rest.

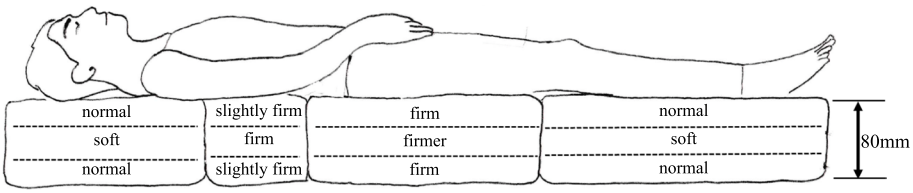

Fig. 2 Mattress, our original developed (Mattress B)

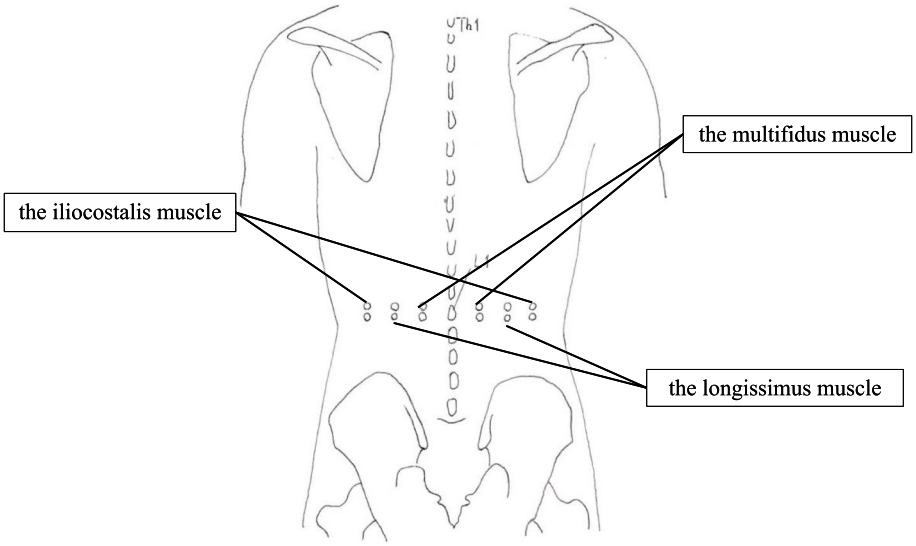

Fig. 3 The location of electrodes

Mattress

Both mattresses A and B are made of polyester and are 80 mm thick. Mattress A is a one-piece, one-layer structure with normal firmness throughout. Mattress B, on the other hand, was based on accumulated knowledge and experience from Yumeron Kurokawa Co., Ltd. It was designed with the following specifications:

It is divided into four sections and is made of polyester, with a three-layer structure that has varying degrees of polyester hardness (Fig. 2)."

1) The mattress was divided into the following four parts:

   i. Head and shoulder area
   ii. Chest area
   iii. Waist and thigh areas
   iv. Calf and heel area

2) Each of the above three parts consists of three layers with varying firmness:

   i. Head and shoulder area: normal, soft, normal
   ii. Chest area: slightly firm, firm, slightly firm
   iii. Waist and thigh area: firm, firmer, firm
   iv. Calf and heel area: normal, soft, normal

Surface electromyography

Surface electromyography (EMG) was performed via an Ultium EMG EM-U880 (Noraxon). The same examiner performed skin pretreatment and electrode placement and confirmed that the electrical resistance between electrode and skin was less than 5 kΩ. Surface electrodes were placed on the muscles of the lumbar region on the basis of the report by Vink et al. (1989) (Fig. 3). The muscles assumed from the electrode placement sites by Vink et al. (1989) were the multifidus muscle, the longissimus muscle, and the iliocostalis muscle. Surface electrodes were placed parallel to the muscle belly in the vertical direction with 1 cm between electrodes.

Surface EMG was measured during the 60-s period starting 3 min before the end (i.e., 7 min after the start of the supine position). The sampling frequency was set at 1 kHz, and the frequency range was set between 10 and 500 Hz. The data were A/D converted and imported into

Table 1 Results of %IEMG

		%IEMG					
		Multifidus		Longissimus		Iliocostalis	
		Rt	Lt	Rt	Lt	Rt	Lt
A1		1.32 ± 1.15*	1.28 ± 1.03*#	0.84 ± 0.46*	1.28 ± 1.12*#	1.22 ± 0.79#	1.03 ± 0.54*#
B		0.94 ± 1.45	0.75 ± 0.52	0.70 ± 0.41	0.75 ± 0.46	0.95 ± 0.54	0.67 ± 0.25
A2		1.39 ± 2.66*	0.86 ± 0.60	0.73 ± 0.44	0.90 ± 0.66	1.01 ± 0.76	0.82 ± 0.50
(mean ± SD)							
Friedman's Test		$p < 0.001$	$p < 0.001$	$p = 0.003$	$p < 0.001$	$p = 0.015$	$p = 0.002$
post hoc Bonferroni correction	df	2	2	2	2	2	2
	$\chi 2$	22.93	14.39	11.84	20.67	8.38	12.98
	p	< 0.001	< 0.001	0.003	< 0.001	0.015	0.002

(* $p < 0.05$ vs. Mattress B# $p < 0.05$ vs. Mattress A2)

a personal computer to calculate the integrated EMG value (IEMG). After confirming that the EMG waveform was stable and unaffected by the ECG waveform, the EMG integral values for the middle 10 s were calculated. The obtained IEMG was normalized to the IEMG during the resting standing position recorded prior to the start of the experiment, and the relative values (%IEMG) were calculated.

Autonomic function

Autonomic function was also measured during the 150-s period starting 3 min before the end (i.e., 7 min after the start of the supine position). Autonomic function was recorded via the Pulse Analyzer Plus View "TAS9 VIEW" (TKC Corporation). A sensor was clipped onto the subject's left index finger. The low-frequency (LF) and high-frequency (HF) components of heart rate variability (HRV) were measured, and the LF/HF ratio was calculated.

The results obtained were examined for significance via the Friedman test with a significance level of less than 5% followed by post hoc Bonferroni correction to identify significant differences using SPSS Statistics Ver 29 (IBM).

Results

The results of the %IEMG of the dorsal lumbar muscles and the significance levels calculated using the Friedman test, followed by post hoc Bonferroni correction to identify significant differences, are presented in Table 1. The %IEMG of the dorsal lumbar muscles tended to decrease with mattress B.

The results of LF, HF and LF-HF ratio demonstrated in Table 2. The LF/HF ratio was not significantly different among the ABAs but tended to be lower in mattress B than in mattress A (A1).

Table 2 Results of LF, HF and LF-HF ratio

	Autonomic function		
	Low Frequency (LF)	High Frequency (HF)	LF /HF ratio
A	**637.77**	**1163.12**	**1.13**
	698.62	1046.46	1.31
B	**446.78**	**943.29**	**0.91**
	288.76	969.11	1.22
A	**639.06**	**1064.97**	**0.86**
	801.57	1304.65	1.22
The upper shows the mean value and the lower shows the standard deviation.			
Friedman's Test	NS	NS	NS

Discussion

This study aimed to clarify the relationships between bedding (mattresses) and changes in indicators of motor and neurological functions by comparing the surface electromyography (EMG) results of the dorsal lumbar muscles, autonomic functions, and peripheral blood flow dynamics in the supine position on mattresses of different materials and shapes. Insights into lumbar muscle activity are particularly important for those with lower back pain, as understanding the relationship between mattress choice and lumbar activity dynamics can help alleviate lower back pain and discomfort. Furthermore, since comfort during sleep is believed to be related to mental relaxation and stress reduction, understanding the relationship with autonomic functions, particularly the balance of sympathetic and parasympathetic activity, can reveal methods for stress management and relaxation through bedding.

Since the activity of the dorsal lumbar muscles significantly decreased on Mattress B, it was possible that the load, overuse, and fatigue of the dorsal lumbar muscles

may decrease when lying on Mat B. However, the differences between the shape and material of the mat and changes in muscle activity are likely to be influenced by individual preferences, individual characteristics, i.e., lying posture, skeletal structure, degree of muscle development, amount of subcutaneous fat, and other factors. The point at which these individual preferences and characteristics were not verified must be considered a limitation of this study.

Heart rate variability (HRV) refers to the variation in the cardiac cycle, originating primarily from fluctuations in autonomic nervous system input to the sinoatrial node. Frequency analysis captures irregular time series data as a collection of sine waves, extracting characteristics such as the frequency and power of periodic fluctuation components. Using frequency analysis to evaluate HRV enables distinguishing and assessing cardiovascular autonomic function between the sympathetic and parasympathetic nervous systems. When the HRV is analyzed by frequency, it is categorized into three components known to exhibit three peaks: low frequency (LF, 0.04–0.15 Hz), high frequency (HF, 0.15–0.4 Hz), and a nonperiodic direct current component. The powers of the LF (ms^2) and HF (ms^2) components of the HRV have become the standard metrics for the assessment of the stress response and the related activities of the sympathetic nervous system and the parasympathetic nervous system (PNS) (Rocha et al. 2024). LF is the power spectrum of the frequency band ranging from 0.004 to 0.15 Hz. This value is thought to reflect the activities of both the sympathetic and parasympathetic nervous systems (vascular motility). HF is the power spectrum of the frequency band ranging from 0.15 to 0.4 Hz. This value is thought to reflect the activity of the parasympathetic nervous system (vagus nerve). The LF/HF ratio is the ratio of the power of LF to that of HF. The LF/HF ratio indicates the balance between sympathetic and parasympathetic influences on heart rate and seems to represent the overall balance between the sympathetic and parasympathetic nervous systems. A high value indicates sympathetic dominance, whereas a low value indicates parasympathetic dominance. These indicators are used in various fields, such as cerebral homeostasis and orthostatic responses (Furian et al. 2024), depression (Krivosova et al. 2024), hypertensive sleep apnea (Xu et al. 2024), and training effects in diabetic patients (Zaki et al. 2024). In this study, no significant differences were found in autonomic function. But, the LF/HF ratio tended to be lower in mattress B than in mattress A (A1). This finding indicates a parasympathetic predominant state in mattress B. However, this may have been influenced by the passage of time as an experimental system. And also, although the results of autonomic function are also influenced by individual preferences, which is a limitation of this study, together with the results of %IEMG of the lumbar back muscles, it can be inferred that our mattresses have a relaxing effect physically and mentally.

The limitations of this study include the following points: that is the shape of individual's spine, their body type and body weight, and the reaction force from the mattress, as well as personal preferences regarding the shape and firmness of the mattress, were not taken into consideration. Additionally, since autonomic function was measured in an ABA design where subjects maintained a resting supine position for each 10 min at a time, the effect of time progression on autonomic function may need to be considered. These points should be addressed in future investigations by establishing methodologies based on the results of this experiment and continued fundamental research.

Conclusion

In conclusion, this study demonstrated that the originally developed mattress significantly reduced lumbar muscle activity and promoted a parasympathetic dominant state, suggesting improved relaxation and comfort. These findings indicate that our originally developed mattress could alleviate lower back pain and enhance sleep quality. The results of this study suggest that the knowledge gained can help to decrease the activity of the individual's lumbar back muscles in the supine position and reduce complaints such as lower back pain and so on through the appropriate selection and development of bedding. Future research should further investigate the impact of mattress characteristics on sleep quality and autonomic function, taking into account individual differences and preferences.

Abbreviations

LF	The low-frequency components of heart rate variability
HF	The high-frequency components of heart rate variability
HRV	Heart rate variability
EMG	Electromyography
IEMG	The integrated EMG value
%IEMG	The relative values of IEMG

Acknowledgements

This study was conducted in collaboration with Yumelon Kurokawa Co., Ltd. The costs associated with the transportation and development of the mattresses were funded by Yumeron Kurokawa Co., Ltd. Additionally, expenses incurred by Hokuriku university, including the purchase of consumables, travel, and accommodation, were funded through joint research funds provided under a research agreement between the University and Yumeron Kurokawa Co., Ltd.

Authors' contributions

SD designed and managed the study, analyzed and interpreted the data, and was the primary author of the paper; YO recruited participants and collected and analyzed the data.

Funding
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Data availability
Data is provided within the manuscript or supplementary information files. If more detailed data are required to be disclosed, they will be published by the responsible author upon request to the corresponding author.

Declarations

Ethics approval and consent to participate
This study was conducted with the approval of the Hokuriku University Research Ethics Review Committee for Human Subjects (Approval No. 2023–27). All study tasks were carried out in accordance with the Declaration of Helsinki. Prior to experiment, according to the decision the Hokuriku University Research Ethics Review Committee for Human Subjects, we explained in advance the outline and invasion of this experiment and the presence / absence and form of publication, and then conducted subjects who obtained written consent to the purpose of this experiment.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests. However, This study was conducted in collaboration with Yumelon Kurokawa Co., Ltd. The costs associated with the transportation and development of the mattresses were funded by Yumeron Kurokawa Co., Ltd. Additionally, expenses incurred by Hokuriku university, including the purchase of consumables, travel, and accommodation, were funded through joint research funds provided under a research agreement between the University and Yumeron Kurokawa Co., Ltd.

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