Journal of Fiber Bioengineering and Informatics 16:1 (2023) 1–14
Cite as: T. Mitsuno et al.
doi:10.3993/jfbim03644

Possibility of Pantyhose Design using Clothing Pressure and Myoelectric Potential as Indices

Tamaki T Mitsuno [a,*], Sayuki Kondo [b]

[a] *Shinshu University, Nishinagano 6-Ro, Nagano, Nagano, 380-8544, Japan*
[b] *Graduate School of Shinshu University, Nishinagano 6-Ro, Nagano, Nagano, 380-8544, Japan*

Abstract

This paper reports a study of 13 Japanese women who wore two types of pantyhose that were rated as providing an "almost-perfect pressure sensation" and three types of shoes. The root mean square of the electromyogram for eight muscles in the right leg was calculated. RMS has divided four group muscles: into each muscle around the knee, around the knee, on the ventral side, and on the dorsal side, and investigated how it changes between bare feet, pantyhose, and shoes. Each pantyhose is designed to stretch the legs well and follow the walking motion easily, but pantyhose B is double woven from the abdomen to the backside so as to connect to the back side while lifting the subcutaneous fat of the abdomen. Even if the pantyhose is made to apply almost the same pressure to the ankles, changing the design of the panty part can activate or suppress abdominal muscle activity.

Keywords: Pantyhose; Electromyogram; High-heeled Shoes; Clothing Pressure; Pressure Sensation; Japanese Women

1 Introduction

Many women wear high-heeled shoes to make their legs look slenderer and more beautiful, and to appear taller. Wearing high-heeled shoes puts more physical strain on the lower legs and hips than when barefoot [1-6]. Pantyhose is often worn with heeled shoes, to enhance the appearance of bare skin [7,8] and to exert a body-shaping effect by raising the hip line, causing the legs to appear longer. Wearers prefer pantyhose that fit well and are not restrictive [9]. Pantyhose is also intended to reduce fatigue on the legs and hips when wearing heeled shoes. As an index of fatigue reduction, we investigated the surface muscle activity of the lower extremities and examined changes when wearing pantyhose and shoes with different heel heights. The goal of the current study was to develop a pantyhose that reduces leg muscle fatigue when wearing heeled shoes [10]. To achieve this goal, a pantyhose that provides a comfortable fitting sensation was

*Corresponding author.
Email address: mitsuno@shinshu-u.ac.jp (Tamaki T Mitsuno).

Mar. 2023

developed, and the wear experience of the product and its effect on the muscle activity of the lower limbs was investigated.

2 Experimental Methods

2.1 Participants and Experimental Pantyhose

The participants were 13 healthy Japanese women aged 20–23 years. The participants ate a meal 2 h before the measurement and entered an artificially climate-controlled room (Shinshu University Artificial Climate Experimental System) with an environmental temperature of $24.5 \pm 0.3\,^{\circ}$C, a relative humidity of $50.0\% \pm 3.0\%$, an illuminance of 827 ± 27.0 lx, and an airflow of 0.8 ± 0.1 m/s. The participants' weight, muscle mass, and body fat mass were then measured using a body composition scanner (InnerScan, TANITA, Japan), and the circumference measurements (above/under bust, waist, lower waist, hip, thigh, above/under knee, calf, ankle, arch) were obtained using a tape measurer. The height measurements (hip, groin, knee, calf) were obtained using a Martin-type human body measuring instrument (Takei Scientific Instruments Co., Ltd., Japan). Changes in muscle activity, clothing pressure and pressure sensation while wearing pantyhose were measured.

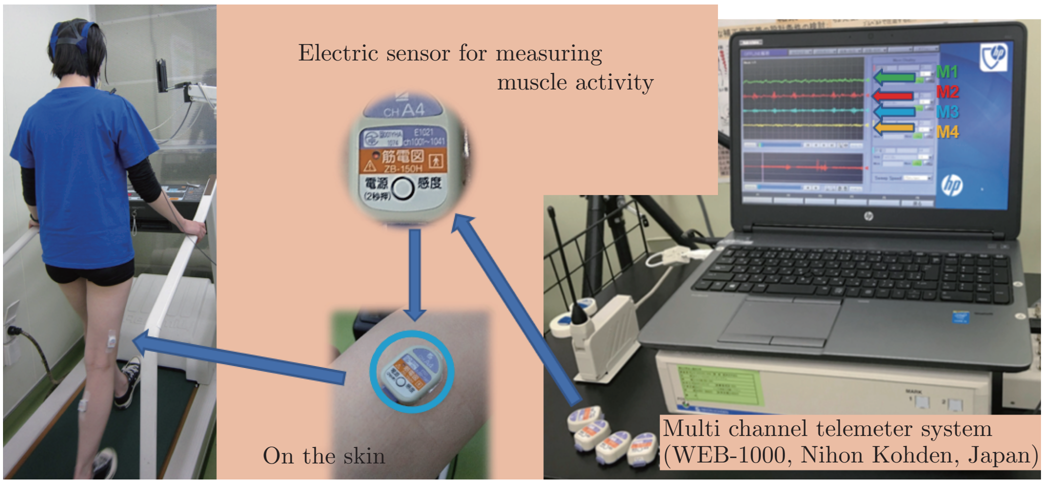
Two types of pantyhose were employed in this study. Pantyhose A was a type of basic pantyhose with a single covered yarn (SCY), composed of 20D (2.2 tex) polyurethane/12D (1.3 tex) nylon yarns in the legs. In the panty part of the pantyhose, the thickness of the nylon yarn was changed from 12D (1.3 tex) to 30D (3.3 tex), and woolly nylon yarn was added to increase the strength. Based on pantyhose A, pantyhose B was designed to change the supporting pressure of the panty part, wherein a partial double layer with SCY was added. The basic knitting structure of the pantyhose consisted of plain stitches, and the sections of the fabric with partial supporting pressure contained single-rib stitches. The tensile force and strain in the wale direction of the legs and the course and wale directions of the panty part were measured using a KES-FB1-A-AUTO (KatoTech, Kyoto, Japan) with a speed of 0.2 mm/s, chuck size of 5.0 cm, and maximum load of 25 gf/cm at $20\,^{\circ}$C and 65% relative humidity at the Fii Research Centre at Shinshu University (used in manual operation). When the sample is cut to a specified size, pantyhose fabric tends to fray, and the obtained fit value is likely to deviate from the actual fit. Therefore, the sample was not cut out, and the measurements were performed with the pantyhose in a pre-cut state [9,11].

2.2 Clothing Pressure and Pressure Sensation

The clothing pressure for the two types of experimental pantyhose was determined by a measuring system based on a hydrostatic pressure-balanced method [12-15]. The clothing pressure was measured at 46 measurement points on the right half of the body, with the cross points positioned between four or five vertical lines (frontal mid/nipple/outside body/dorsal scapula/inside body lines) and eleven (waist, lower waist, hip, groin, tight, upper/lower knee, calf, ankle, arch, toe) planes. The participants wore each type of pantyhose while walking for 30 min for the measurement of muscle activity, as described below in Section 2.3. The pressure sensation was then reported on a visual scale [9,11,16,17].

2.3 Measurement of Muscle Activity While Wearing Experimental Pantyhose

After entering the artificial climate room, the participants rested in a sitting position for 1 h. The myoelectric potential of the lower limbs was then measured as the participants walked with bare feet or while wearing one of the two types of pantyhose. A typical experimental view is shown in Fig. 1. The surface myoelectric potential was measured by a multi-channel telemeter (WEB-1000, Nihon Kohden, Japan) as the participants walked on a treadmill at 3 km/h. The measuring points for electromyography (EMG) are shown in Fig. 2. Eight measuring points on the right half of the body were separated into two groups of muscles: muscles around the knee (i.e., the tibialis anterior muscle, gastrocnemius muscle, rectus femoris muscle and biceps femoris long head) and waist muscles (i.e., the rectus abdominis, latissimus dorsi, gluteus maximus and semitendinosus).



M1: Anterior tibial muscle, M2: Gastrocnemius, M3: Rectus femoris, M4: Biceps femoris long head in the figure.

Fig. 1: A typical example for measuring muscle activity using by telemeter system while walking on the treadmill

The root mean square (RMS) of muscle activity was calculated from a 2 mins myoelectric potential signal during a 3-min measurement period using Eq. 1.

$$RMS(t) = \sqrt{\frac{1}{2T}\int_{-T}^{T} e^2(t+\tau)d\tau} \tag{1}$$

Here, T is the selection time, e is the potential at the time of observation, t is the observation time, and τ is the time constant. The values obtained when the participant was barefoot or wearing pantyhose were confirmed to be significantly different using a paired analysis of variance, with the significance of the difference tested using the Bonferroni method [9, 10].

2.4 Statistical Analyses

Statistical analyses were performed using SPSS software (IBM, Ver. 27). The values obtained when participants were barefoot or wearing pantyhose A/B were confirmed to be significantly

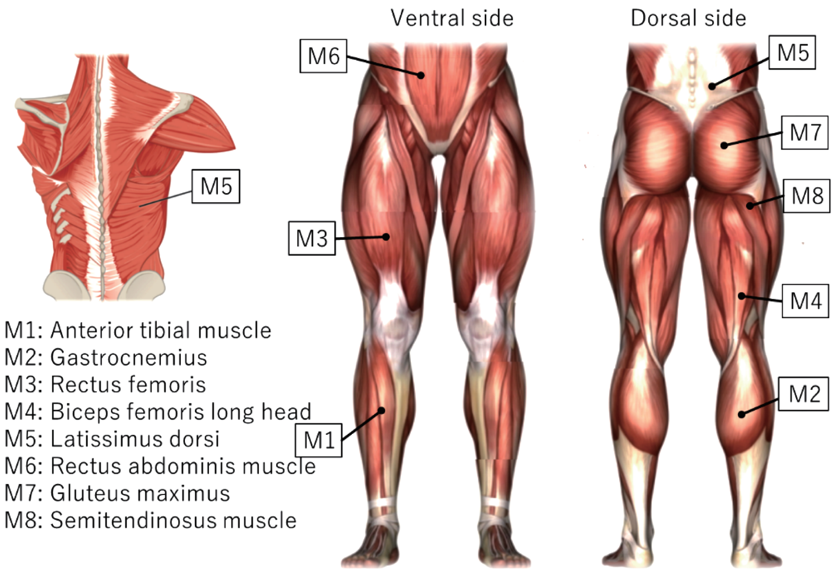


Fig. 2: EMG measurement points

different between groups by paired analysis of variance, with the significance tested using the Bonferroni method. The differences were considered significant at a level of $p < 0.05$ [9].

3 Results and Discussion

3.1 Participants and Experimental Pantyhose

The physical parameters of the participants are shown in Table 1. The participants had slightly lower body mass index (BMI) values and were taller compared with the average values for Japanese women in their twenties (height: 1.59 m, BMI: 20.1). The results revealed significant differences in some height measurements (hip/groin) when the participants were wearing pantyhose compared with not wearing pantyhose. When participants were wearing pantyhose B, the hip/groin height was significantly greater than when not wearing pantyhose (control) or wearing pantyhose A. Thus, it can be derived that pantyhose B increased the tensile strength by partially changing the clothing pressure applied to the panty part of the pantyhose, which significantly increased the hip height by 14.9 mm (12.1 mm) and groin height by 11.1 mm (14.5 mm) compared with pantyhose A (control). However, as reported in a previous paper [9], the lifted adipose tissue of the hips shifted to the hips and waist, causing the circumference of the hips and waist to increase by 12.2 mm and 9.0 mm, respectively. The participants' BMI (19.6 ± 1.6) was less than the previous report (19.9 ± 1.7) [9]. Consequently, the adipose tissue around the hips differed between the two groups. Overall, pantyhose B caused the legs to appear longer.

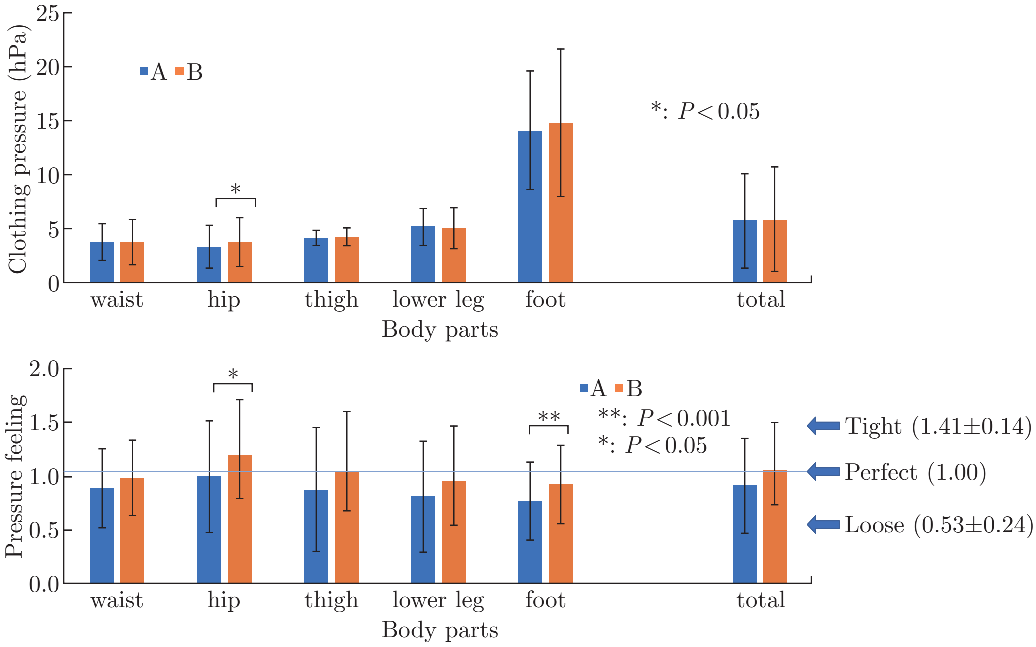
3.2 Clothing Pressure and Pressure Sensation

The clothing pressure and its pressure feeling when wearing experimental pantyhose are shown in Fig. 3. The clothing pressure for pantyhose A did not significantly differ from pantyhose B (waist: 3.8 ± 1.7 [3.5 ± 2.3] hPa, hip: 3.3 ± 2.0 [3.7 ± 2.1] hPa, tight: 4.3 ± 0.5 [4.3 ± 0.7] hPa,

Table 1: Physical parameters of the participants

Items (Unit)	Hight (cm)	Weight (kg)	Girth (cm)					BMI	shoe heel hight (mm)		
			Top bust	Waist	Hip	Tight	Calf	(kg/m^{-2})	Running	Low-heel	High-heel
Average	161.4	50.7	81.6	65.5	89.8	48.0	34.0	19.6	9.8	37.4	79.9
±SD	4.9	3.7	3.9	2.3	3.7	2.7	1.5	1.6	10.3	8.3	7.8

lower leg: 5.2 ± 1.7 [4.9 ± 2.0] hPa, foot: 14.6 ± 5.6 [15.4 ± 7.1] hPa). There were no significant differences in pressure sensation between the two samples. The pressure sensation for pantyhose A was 0.87 ± 0.49 whereas pantyhose B was 1.02 ± 0.34, with participants approximately reporting a perfect fitting sensation of “1”. Participants reported a slightly loose sensation when wearing pantyhose A and a perfect fitting sensation when wearing pantyhose B. There were no significant differences between the two pantyhose types [9].



The upper figure shows clothing pressure, and the lower figure shows the pressure feeling. The horizontal line in the lower figure shows “a perfectly fitting sense” as “1” used by a ratio scale.

Fig. 3: Clothing pressure and its pressure feeling when wearing experimental pantyhose [9]

3.3 Muscle Activity While Wearing Experimental Pantyhose and Shoes

3.3.1 Muscle Activity with Bare Feet

The RMS values obtained for bare feet are shown in Fig.4, and correlation coefficients among the four muscle groups are shown in Table 2. The results in Table 3 to Table 5 follow the same method used in Table 2. As different sensors were involved, the RMS values of M1–M8 cannot be directly compared. However, it appears that the M2 (gastrocnemius muscle) and M6 (rectus abdominis) muscles were frequently used for walking (see Fig. 4). Among the eight muscle groups, the following four muscle groups were compared: the muscle group around the knee (M1-4), the muscle group around the waist to the hip (M5-8), the muscle group on the ventral side (M1, 3, and 6), and the muscle group on the dorsal side (M2, 4, 5, 7, 8). There was a significant positive correlation between the muscles around the knee and the dorsal muscles, and a significant positive correlation between the hip muscles and the ventral and dorsal muscles. It was found that participants who used muscles around the knee also used muscles on the dorsal side, and those who used muscles around the waist used muscles on both the ventral and dorsal sides. Thus, the results suggested that some people tend to use muscles around the knees when walking, whereas others use muscles around the hip. How these correlations changed when shoes and pantyhose were worn were investigated [18].

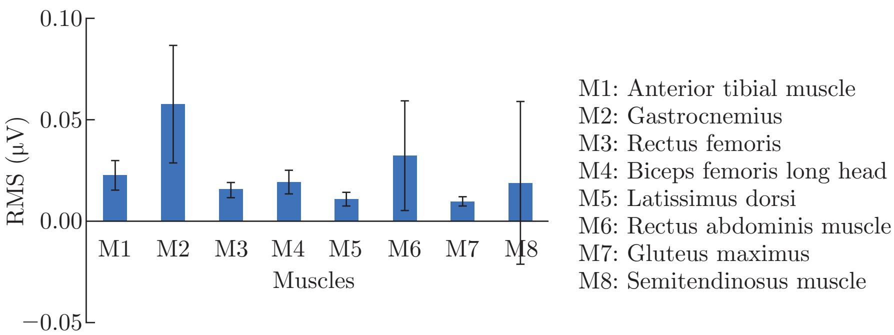


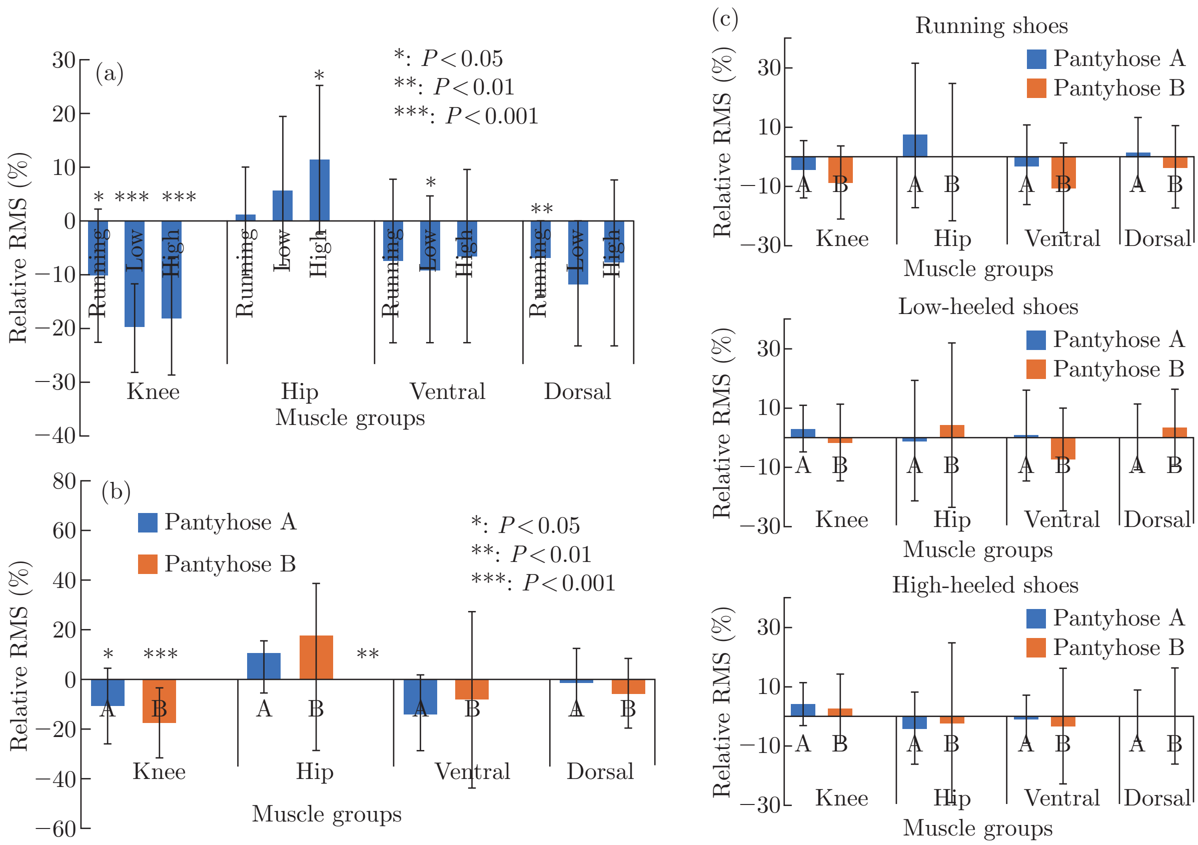
Fig. 4: RMS for bare feet

Table 2: Correlation coefficients among four muscle groups

Items	Around knee		Around hip		Ventral side	
	Coefficient	Judge	Coefficient	Judge	Coefficient	Judge
Around hip	0.053					
Ventral side	0.133		0.621*			
Dorsal side	0.700**		0.621*		0.134	

3.3.2 Muscle Activity While Wearing Shoes Without Pantyhose

Fig. 5-a shows the relative RMS of the four groups when the participants wore three types of shoes, with 100% corresponding to the case in which the participants were barefoot. The relative RMS around the knee was significantly suppressed for all shoes compared with the barefoot case. For the muscle group around the hip, muscle activity was significantly activated, particularly when the participants wore high-heeled shoes. In addition, the relative RMS of the ventral muscle group was suppressed when the participants wore low-heeled shoes. Similarly, the muscle activity of the dorsal muscle group was suppressed when the participants wore running shoes or low-heeled shoes. The correlation coefficients among the four muscle groups are shown in Table 3. For all shoes, there was a significant positive correlation between the muscles around the knee and the dorsal muscles, and between the muscles around the hip as well as the ventral and dorsal muscles. Thus, as observed in the barefoot condition, participants who used muscles around the knee used muscles on the dorsal side, and those who used muscles around the hip used muscles



The asterisk above the bar graph indicates significant changes compared with the barefoot results (Y = 0). Figure a shows wearing only shoes, figure b shows wearing only pantyhose, figure c shows wearing pantyhose and shoes.

Fig. 5: Relative RMS while wearing only shoes, wearing only pantyhose, and wearing pantyhose and shoes

on the ventral and dorsal sides when walking. This contrasts to the initial expectation that the basic usage of muscles would not change when shoes or pantyhose were worn [18].

Table 3: Correlation coefficient among four muscle groups while wearing three kinds of shoes

	Running shoes			Low-heeled shoes			High-heeled shoes		
Items	Around knee Coefficient Judge	Around hip Coefficient Judge	Ventral side Coefficient Judge	Around knee Coefficient Judge	Around hip Coefficient Judge	Ventral side Coefficient Judge	Around knee Coefficient Judge	Around hip Coefficient Judge	Ventral side Coefficient Judge
Around hip	0.224			0.079			0.179		
Ventral side	0.100	0.732**		0.136	0.805***		0.151	0.767***	
Dorsal side	0.801***	0.637*	0.171	0.754***	0.557*	0.249	0.711***	0.680**	0.258

The grey regions in the table show the same correlation points as the barefoot condition. * : $p < 0.05$, ** : $p < 0.01$, *** : $p < 0.001$

3.3.3 Muscle Activity While Wearing Pantyhose Without Shoes

Fig.5-b shows the relative RMS for the four muscle groups when participants wore the two types of pantyhose, with 100% corresponding to the barefoot condition as a reference. The relative RMS

Table 4: Correlation coefficient among four muscle groups while wearing two kinds of pantyhose

	Pantyhose A						Pantyhose B					
	Around knee		Around hip		Ventral side		Around knee		Around hip		Ventral side	
	Coefficient	Judge	Coefficient	Judge	Coefficient	Judge	Coefficient	Judge	Coefficient	Judge	Coefficient	Judge
Around hip	0.217						−0.336					
Ventral side	0.785***		0.357				−0.215		0.931***			
Dorsal side	0.911***		0.305		0.542		0.882***		−0.073		−0.098	

The grey regions in the table show the same correlation points as the barefoot condition, and the dark grey regions indicate a lack of significant correlation among the four groups compared with the barefoot condition results. * : $p < 0.05$, ** : $p < 0.01$, *** : $p < 0.001$

around the knee was significantly suppressed when each type of pantyhose was worn compared with the barefoot condition. In addition, the muscle activity in the ventral muscle group was suppressed by pantyhose A. There were no significant differences between pantyhose A and B.

The correlation coefficients among the four muscle groups for participants wearing pantyhose are shown in Table 4. For pantyhose A, there was a lack of two combinations between the hip muscles and the ventral- and dorsal-side muscles. In contrast, for pantyhose B, there was a lack of combination between the hip muscles and dorsal-side muscles. Thus, it was found that wearing pantyhose changed the basic usage of muscles [18].

3.3.4 Changes in Muscle Activity While Wearing Pantyhose and Shoes

Fig.5-c shows the relative RMS values for the four muscle groups when the participants wore the two types of pantyhose and three types of shoes, with 100% corresponding to the barefoot condition as a reference. There was no significant difference between pantyhose A and B. However, for pantyhose B, the relative RMS for knee muscles and ventral-side muscles for participants wearing running shoes was significantly suppressed compared with the barefoot condition. The results from all three types of shoes revealed that a larger heel height corresponded to a bar graph length closer to Y = 0. It may be desirable for the effects of pantyhose on muscle activity to be altered so that the same muscle activity observed in the barefoot condition can be achieved as the heel height changes.

The correlation coefficients among the four muscle groups for participants wearing pantyhose and shoes are shown in Table 5. A detailed comparison between wearing pantyhose and shoes conditions and the barefoot condition was conducted. The grey regions in the table show the same correlations observed in the barefoot condition, and the dark grey regions show the absence of a significant correlation among the four groups compared with the barefoot condition. In the pantyhose A condition, there were three lacked combinations: a combination between the knee and dorsal muscle groups for low-heeled shoes as well as two combinations between the knee and dorsal muscles and between the hip and ventral muscles for high-heeled shoes. In contrast, for pantyhose B, there was a lack combination between the muscles around the hip and the dorsal-side muscles for running shoes and three lack combinations between the muscles around the knee/hip and the ventral/dorsal side muscles for low-heeled shoe combinations. Thus, the pantyhose B results were significantly different for all combinations for high-heeled shoes, but not for low-heeled shoes. Similarly, for pantyhose A, it was found that the combination of wearing pantyhose and shoes changed the basic usage of muscles. Thus, it can be derived that pantyhose A is suitable for low-heeled shoes, whereas pantyhose B are desirable for high-heeled shoes. Overall, it was found that wearing pantyhose can suppress or activate muscle activity in the legs [18].

Table 5: Correlation coefficients among the four muscle groups for participants wearing two types of pantyhose and three types of shoes

	Running shoes			Low-heeled shoes			High-heeled shoes		
	Around knee Coefficient Judge	Around hip Coefficient Judge	Ventral side Coefficient Judge	Around knee Coefficient Judge	Around hip Coefficient Judge	Ventral side Coefficient Judge	Around knee Coefficient Judge	Around hip Coefficient Judge	Ventral side Coefficient Judge
Around hip	0.224			0.079			0.179		
Ventral side	0.100	0.732**		0.136	0.805**		0.151	0.767***	
Dorsal side	0.801***	0.637*	0.171	0.754***	0.557*	0.249	0.711***	0.680**	0.258

The grey regions in the table show the same correlation points as the barefoot condition, and the dark grey regions indicate a lack of significant correlation among the four groups compared with the barefoot condition results. * : $p < 0.05$, ** : $p < 0.01$, *** : $p < 0.001$

4 Discussion

4.1 Relationship among Muscle Activity in Each Conditions

Using the RMS of 4 groups, 2 556 correlation coefficients were obtained between bare feet, wearing only 2 types of pantyhose, wearing only 3 types of shoes, and wearing a combination of shoes and pantyhose. Among all combinations, the RMS around the knee, around the hip, on the ventral side, and on the dorsal side had a significant positive correlation, indicating that individual differences in muscle activity were maintained. In addition, there was also a significant positive correlation between the combination of the knee and the dorsal side and the hip and the ventral side. In other words, participants walked using their knees used their dorsal muscles, and those using their hips used their ventral muscles. Thus, there was a significant positive correlation among the six combinations described above even in almost all combinations of conditions. However, this rule did not hold for three combinations which were RMS between stockings A and B when wearing running shoes, and no significance was observed between around the hip and on the ventral side. In addition, there was no significant difference in RMSs around the hip/on the ventral side, the combinations between wearing pantyhose A and B when wearing low-heeled shoes. From this, we thought that the difference in the design of pantyhose A and B had some effect on muscle activity when wearing shoes with different heel heights.

4.2 Relationship Among Muscle Activity, Clothing Pressure, and Its Pressure Sensation

Correlation coefficients between muscle activity and pressure/pressure sensation were calculated. Clothing pressures included waist, hip, thigh, under knee, calf, ankle, and foot circumference pressures, as well as four groups of the around the knee, around the hip, on the ventral side, and on the dorsal side clothing pressures. There were eight pressure sensations corresponding to seven circumferences and the whole. As follows, the correlation of RMS was examined for each condition only wearing pantyhose and both wearing pantyhose and shoes.

4.2.1 When Wearing Only Pantyhose

When pantyhose A was worn, RMS around the hip was negatively correlated with clothing pressures around the hip/on the ventral side/ at the ankle. When pantyhose B was worn, there was a significant positive correlation between RMSs (around the hip/on the ventral side) and the pressure sensations (around the hip/waist circumference) /the clothing pressure (at the ankle/on the ventral side). Based on this, when wearing pantyhose A, the higher the clothing pressure on the hips, ankles, and abdomen, the more suppressed the muscle activity around the hip. On the contrary, when wearing pantyhose B, the higher the clothing pressure at the ankle and so on, the RMS around the hip/on the ventral side increased. It was found that muscle activity was promoted to increase or decrease. Thus, pantyhose changed muscle activity.

4.2.2 When Wearing Both Pantyhose and Shoes

There was no correlation between RMS and pressure sensation, as pressure sensation was rated as nearly perfect on all body parts. Therefore, excluding pressure sensation, Table 6 shows the correlation coefficients between clothing pressure at the ankle and RMS around the hip/ on the ventral side. When pantyhose A was worn, there were significant negative correlations between ankle clothing pressure and RMS around the hip/on the ventral side for all shoes. In other words, the ankle clothing pressure increases, and the activity of the muscles around the hip and abdomen is suppressed. In pantyhose B, when running shoes were worn, there was a significant positive correlation between ankle clothing pressure and the ventral side RMS. In this way, the different muscle activity occurred in the same clothing pressure at the ankle wearing pantyhose A or B.

Table 6: Correlation coefficients between RMS and clothing pressure at the ankle wearing shoes

CP at ankle	RMS					
	Running shoes		Low-heeled shoes		High-heeled shoes	
	Around hip	Ventral side	Around hip	Ventral side	Around hip	Ventral side
	Coefficient Judge	Coefficient Judge	Coefficient Judge	Coefficient Judge	Coefficient Judge	Coefficient Judge
Pantyhose A	−0.588*	−0.560*	−0.598*	−0.599*	−0.650*	−0.587*
Pantyhose B	0.491	0.533*	0.389	0.418	0.301	0.350

4.3 Possibility of Pantyhose Design

As mentioned in 4.2, pantyhose A had a significant negative correlation between the hip and ventral RMS and ankle clothing pressure when wearing three types of shoes. On the contrary, pantyhose B showed a significant positive correlation between ventral RMS and ankle clothing pressure wearing only running shoes.

If we would like to control the clothing pressure with pantyhose, it's easier to adjust the clothing pressure around the circumference than the plane on the back and abdomen. Therefore, focusing on the ankle pressure's strong correlation to ventral or hip RMS, the relationship between the ankle clothing pressure and the ventral side RMS is shown in Fig. 6. The relationship between RMS on the ventral side (y1 and y2 show RMSs wearing pantyohose A and B) and clothing pressure at the ankle (x) wearing experimental pantyhose were shown in straight lines. When wearing pantyhose A, y1=-0.003x+0.036, and wearing pantyohose B, y2=0.003x+0.002. Here, substituting y1 = 0 gives x = 12 hPa. In other words, when pantyhose A is worn, the RMS of the abdomen can be lowered by increasing the ankle pressure to 12 hPa. Also, by substituting x = 0 to create a gap in the ankle and not generating pressure, it is possible to activate muscle activity up to 0036 mV. Relationship among RMS on the ventral side, clothing pressure at the ankle, and its pressure sense wearing pantyhose B are shown in Fig. 7. The relationship between clothing pressure and pressure sense at the ankle (y3) is added with y2 wearing pantyhose B. Substituting a value of 1, which feels just right pressure sensation, into y3=1, x= 5.2 hPa. Substituting this value into the y2 equation gives an RMS of 0.018 mV. In this way, when pantyhose B is applied to the ankle with a pressure of 5.2 hPa, which feels just right, muscle activity in the abdomen is suppressed from the average RMS value of 0.202 mV for bare feet, indicating the possibility of reducing fatigue.

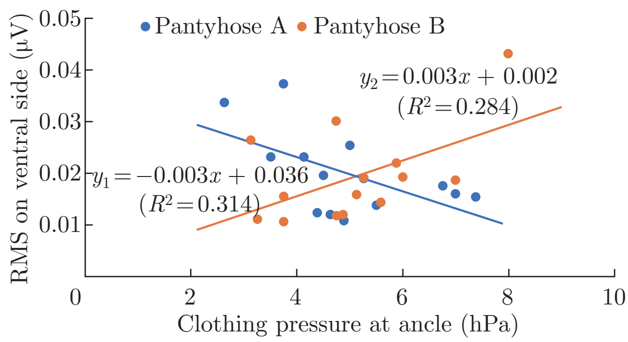


Fig. 6: Relationship between RMS on ventral side and clothing pressure at ankle wearing experimental pantyhose

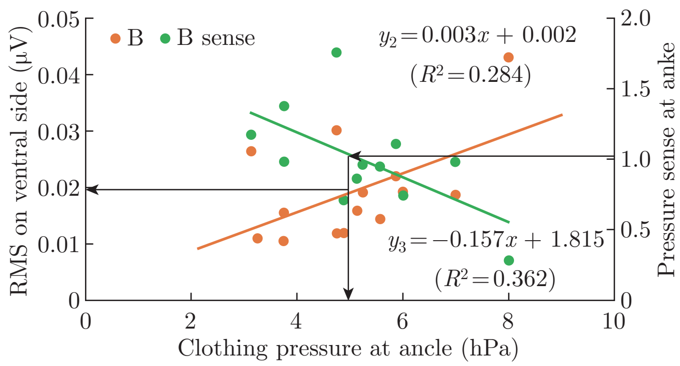


Fig. 7: Relationship among RMS on ventral side, clothing pressure at ankle, and its pressure sense wearing pantyhose B

As shown in Figs. 6 and 7, even if the pantyhose is made to apply almost the same pressure to the ankles, changing the design of the panty part can activate or suppress abdominal muscle activity.

Both pantyhose are designed to stretch the legs well and follow the walking motion easily, but pantyhose B is double woven from the abdomen to the backside so as to connect to the back side while lifting the subcutaneous fat of the abdomen. It was designed Then since the legs are highly elastic, pantyhose A was able to move without communicating the movement of the legs to other parts. In pantyhose B, the walking movement of the leg was affected on the abdomen, which was a stimulus that activated muscle activity in the front abdomen. By the way, Fig. 8 shows the RMS of 4 groups in pantyhose B with bare feet, only pantyhose, and both wearing pantyhose and high-heeled shoes. RMS around the knee was significantly inhibited when wearing pantyhose B alone and when wearing high heels. In addition, RMS on the ventral side was significantly suppressed when wearing pantyhose and high heels than when wearing bare feet. From this, it can be said that pantyhose B suppresses muscle activity on the ventral side when wearing high heels. When adjusting the circumferential pressure, designing with a bandage is different from designing with a stocking. Even if it is designed with the same tightening rate, the stocking pressure is 10% lower than the bandage pressure due to the organizational structure [19]. The target body part clothing pressure, eg, ankle pressure, should be designed with this in mind.

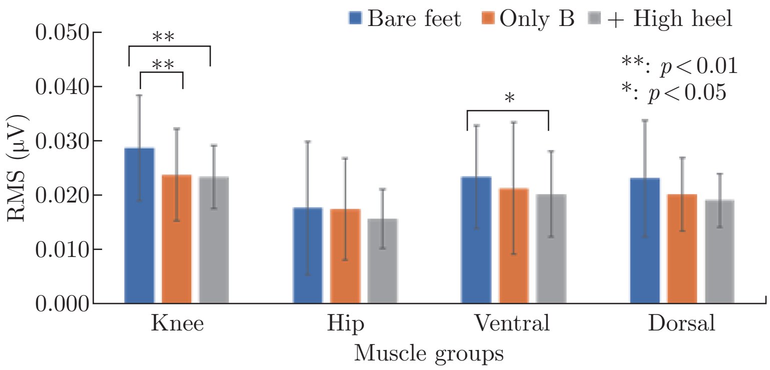


Fig. 8: Relationship among RMS with bare feet, wearing pantyhoseB, and wearing pantyhose B/high-heeled shoes

5 Conclusion

The goal of this study was to develop a pantyhose that can reduce leg muscle fatigue while wearing heeled shoes. A study of 13 Japanese women who wore two types of pantyhose was conducted, wherein an almost-perfect pressure sensation and three types of shoes was reported. The clothing pressure for the two types of experimental pantyhose was determined by a measuring system based on a hydrostatic pressure-balanced method at 46 measuring points on the right half of the body. The clothing pressure for pantyhose A did not significantly differ from pantyhose B (waist: 3.8 ± 1.7 [3.5 ± 2.3] hPa, hip: 3.3 ± 2.0 [3.7 ± 2.1] hPa, tight: 4.3 ± 0.5 [4.3 ± 0.7] hPa, lower leg: 5.2 ± 1.7 [4.9 ± 2.0] hPa, foot: 14.6 ± 5.6 [15.4 ± 7.1] hPa). There were no significant differences in pressure sensation between the two samples. The pressure sensation in ratio scale for pantyhose A was 0.87 ± 0.49, whereas for pantyhose B was 1.02 ± 0.34 when the participants reported a perfect fitting sensation of “1”. The participants reported a slightly loose sensation when wearing pantyhose A and a perfect fitting sensation when wearing pantyhose B. There were no significant differences between the two pantyhose types. The RMS of the EMG for eight muscles in the right leg was calculated. Participants who used muscles around the knee also used their dorsal-side muscles, and those who used muscles around the hip used their ventral- and dorsal-side muscles when walking. When wearing shoes, participants stopped using muscles around the knees and back. Even with an increased heel height, the RMS of the EMG for participants wearing pantyhose were the same for bare feet.

RMS was changed in some wearing conditions: bare feet, only wearing pantyhose, only wearing three different heel height shoes, and the combinations with two kinds of pantyhose and three different heel height shoes. Pressure sensations were almost just right in all conditions because each pantyhose produced the clothing pressure gradient rules, however, the clothing pressure can control RMS. It was clear we can control the RMS for the body by wearing pantyhose which were designed by clothing pressure, for example, clothing pressure at the ankle could control the ventral RMS.

Acknowledgements

Part of this work was supported by the Japanese Society for the Promotion of Science, KAKENHI Grant Number 17H01954/22K02111. The authors wish to acknowledge Mr. A. Yoshida and Ms. A. Bando of Fukusuke Co., Ltd. for providing the experimental pantyhose. We thank Professor Takatera, Associate Professor Kanai, and Technical Officer Hayashi of the Faculty of Textiles Science and Technology at Shinshu University for providing equipment for the material test. We thank Edanz (https://jp.edanz.com/ac) for editing a draft of this manuscript.

Trial Registration

This study was conducted after a review by the Ethical Review Board for Human Research at Shinshu University (approval number 222).

References

[1] Kim Y, Koo J, Oh D. Influence of Shoe Heel Height and Muscle Fatigue on Static and Dynamic Balance in Healthy Young Women. Phys. Ther. Kor: 2013; 20: 36-44.

[2] Wiedemeijer MM, Otten E. Effects of high heeled shoes on gait. A review. Gait Posture: 2018; 61: 423-430.

[3] Barkema DD, Derrick TR, Martin PE. Heel height affects lower extremity frontal plane joint moments during walking. Gait Posture: 2012; 35: 483-8.

[4] Simonsen EB. Contributions to the understanding of gait control. Dan Med J: 2014; 61: B4823.

[5] Blanchette MG, Brault JR, Powers CM. The influence of heel height on utilized coefficient of friction during walking. Gait Posture: 2011; 34: 107-10.

[6] Satsumoto Y, Shimazaki Y, Saito H, Maruta N. The effect of the height of the heel of pumps and the age to the gait analysis in wearing business pumps. Desant sports science: 2020; 40: 236-246.

[7] Orhon S, Morooka H, Morooka H, Manabe I, Nakahashi M, Wakashima K. Relationship between aesthetic and shape of legs. Kansei Engineering International: 2002; 2: 1-8 (English abstract and Japanese text).

[8] Wakako L, Shimokawa T, Kinari T. Analyss of the evaluation factors and indexes for the aesthetic properties of pantyhose. J Fiber Sci Technol: 2016; 72: 112-119. doi 10.2115/fiberst.2016-0017

[9] Mitsuno TT, Kondo S. Clothing pressure and pressure sensation while wearing pantyhose: Muscle activity change in the legs. Proceeding of the TIBS 2022 Conferences: 2022 (in press).

[10] Mitsuno T, Sugawara A. Effect of the shoe heel height on lower-limb muscle activity. Physical Ergonomics and Human Factors: 2022; 63: 13-20 https://doi.org/10.54941/ahfe1002591.

[11] Mitsuno TT, Kondo S. Clothing pressure gradient for comfortable pantyhose. Journal of Fibre Bioengineering and Informatics, in press

[12] Mitsuno T, Makabe H, Momota H, Ueda K. Study on the clothing pressure (Part 1) Measurements by a hydrostatic pressure-balanced method. J Jpn Res Assoc Text End-Uses: 1991; 32: 362-367 (English abstract and Japanese text).

[13] Mitsuno T, Makabe H, Momota H, Ueda K. Study on the clothing pressure (Part 2) Measurements by a hydrostatic pressure-balanced method. J Jpn Res Assoc Text End-Uses: 1991; 132: 368-367 (English abstract and Japanese text).

[14] Mitsuno T, Ueda K. Measurement for clothing pressure. J Home Econ Jpn: 1994; 45: 179-188.

[15] Mitsuno T, Kai A. Distribution of the preferred clothing pressure over the whole body, Textile Research Journal: 2019; 89: 2187-2198, DOI*10.1177/0040517518786272journals.sagepub.com/home/trj.

[16] Bijur PE, Silver W, Gallagher MAE. Reliability of the visual analog scale for measurement of acute pain. Academic Emergency Medicine: 2001; 8: 1153-1157.

[17] Mitsuno T, Ueda K. The clothing pressure developed at waistband and the pressure sense estimated in a ratio scale. J Home Econ Jpn: 1997; 11: 989-998 (English abstract and Japanese text).

[18] Kondo S, Mitsuno T. Effect of wearing pantyhose on lower limb muscle activity. Textile Bioengineering and Informatics Symposium Proceedings 2022, pp.128-135, ISSN: 19423438

[19] Mitsuno T, Wang L, Padhye R. Differences in Clothing Pressure between Bandages and Stockings. Journal of Fiber Bioengineering & Informatics: 2019; 12: 1-10. DOI: 10.3993/jfbim00317