J. Phys. Ther. Sci. 36: 633–641, 2024

The Journal of Physical Therapy Science

Original Article

Effects of different fabrics on the Hoffmann reflex during local heat exposure

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Abstract. [Purpose] The effects of multifunctional garments on neuromuscular performance have gained significant research attention in the health sciences. However, the spinal responses to different fabrics have not yet been considered. In the present study, we examined the effects of typical fabrics (cotton and polyester) on the Hoffmann reflex during local heat exposure. [Participants and Methods] Sixteen healthy males aged 20–40 years participated in this study. A heating device comprising a thermal mat, fabric, and a data logger was fabricated. The fabric was affixed to the skin as the contact surface. The temperature of the right posterior lower leg was increased to 39°C followed by 10 min for adaptation at 39–40°C. The H- and M-waves were recorded at each point, including those without heating. An identical trial was conducted seven days later using the alternative fabric. [Results] M-wave amplitude and latency were significantly decreased during heat exposure without fabric. The H-wave latency was prolonged by sustained thermal heat during the session with polyester. Interestingly, the H-wave amplitudes normalized by the maximal M-wave amplitudes decreased with prolonged heat exposure during the session with cotton. However, this index remains unchanged during the sessions using polyester. [Conclusion] During prolonged localized thermal exposure, cotton reduced spinal excitability, whereas polyester preserved spinal excitability.

Key words: Fabric, Local heat, Hoffmann reflex

(This article was submitted Jun. 11, 2024, and was accepted Jul. 16, 2024)

INTRODUCTION

In physical therapy, the facilitation and inhibition of the nervous system are crucial factors to consider in determining approaches. Among various solutions, the effects of multifunctional garments on neurological function[1–3)] and physical performance[4–6)] have garnered significant attention as manufacturing technology[7)] has developed. In our previous study[8)], a compression device was applied to a patient with severely impaired hip adductors due to obturator neuropathy, resulting in significant improvement in physical performance. However, its effectiveness could be affected by the material properties[7)], and the neurological response to stimulation needs to be clarified to ensure its appropriate use in clinical practice.

Homeothermic animals generate heat metabolically and must dissipate the heat efficiently to maintain a stable body temperature. Clothing studies have thus focused on fabrics with thermal and moisture transfer characteristics in evaluating subjective assessments[4, 9–12)], clothing microclimates[9–13)], physiological functions[4, 9–11, 14)], athletic performance[4, 10, 11)], surface electromyography[13, 14)], sleep quality[15)], and sound and touch[16)]. These studies have examined the effects of natural and synthetic fibers used in clothing. Indeed, clothing made from polyester and clothing made from cotton fibers are often compared. Polyester clothing has been shown to enhance athletic performance[4, 11)], and improve post-exercise comfort[11)]

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and skin cooling[9]. Consequently, polyester fibers are commonly chosen as a material for sportswear. However, Zimniewska and Kozłowski[14] reported that polyester fibers increased oxidative stress. Similarly, another study found that polyester fibers were associated with increases in average amplitudes and frequencies in surface electromyography[13]. These effects due to polyester fibers thus indicate a modulation of neurophysiological functions.

The use of the Hoffmann reflex (H-reflex) is a well-known method of neurophysiological evaluation. Defined by Magladery and McDougal[17] as the Hoffmann wave (H-wave), this reflex is initiated by low-intensity stimulation targeting Ia afferent fibers, leading to a direct monosynaptic reflex pathway that involves spinal motor neurons. Gradually increasing the stimulation directly excites motor axons, producing the M-wave, whereas the H-wave decline occurs due to collisions with antidromic impulses[18, 19]. As these reflexes use distinct pathways, they facilitate the assessment of both spinal responses and the activation of the entire motor neuron pool[19, 20]. In the field of physical therapy, the H-reflex reflects the cumulative effect of facilitation and inhibition from supraspinal sources, and it is thus a measure widely used to assess neuromodulation through joint manipulation and vocalization[21, 22]. Action potentials are affected by core and nerve temperatures, which alter the sodium channel function[23]. Consequently, H-reflex studies have explored the effects of both whole-body[24, 25] and localized heat and cooling[26–30]. However, the effects of the inconsistent materials or fabrics used in these studies on the H-reflex have not been analyzed.

Therefore, we observed the effects of stimuli from representative fabrics on neurological responses, using the soleus muscle (SOL) H-reflex, under conditions that simulated local heating and metabolic activity. This study confirms whether different types of fabrics do not hinder the expected patient responses in clinical settings, and it is expected to contribute to the development of garments that assist in physical therapy.

PARTICIPANTS AND METHODS

This study employed a double-blind crossover design. Participants underwent two sessions, one with cotton fabric and one with polyester fabric, conducted on separate days with a seven day interval (details of the devices and specific methods are provided below). Sample size estimation using G*Power[31], based on analysis of variance with a moderate effect size, an alpha error of 0.05, a power of 0.80, and a correlation of 0.8 among repeated measures, determined that the 2 × 3 and 1 × 3 designs needed eight and 12 participants, respectively.

Participants were recruited using convenience sampling due to the practical considerations of time constraints and the discomfort associated with the electrical stimulation used in evoked potential measurements. This non-probability sampling method allowed for the efficient selection of healthy volunteers who were readily available and willing to endure the procedural requirements, though it may introduce bias[32]. Sixteen healthy male volunteers (mean ± standard deviation: SD, age of 29.0 ± 5.1 years, height of 169.8 ± 8.0 cm, and weight of 60.9 ± 9.2 kg) were recruited at Iida Hospital based on their availability and willingness to participate. The exclusion criteria were as follows: intolerance to electrical stimulation, inability to elicit H-reflex despite appropriate skin treatment and electrical stimulation, and inability to maintain a supine position for over 30 minutes. The study was approved by the Ethics Committees of Iida Hospital and Shinshu University (approval number: 386), and written informed consent was obtained from all participants. Three participants were excluded owing to the inability to properly elicit the H-reflex, resulting in 13 participants who were able to complete the protocol.

Two types of plain-woven fabric, comprising 100% cotton and 100% polyester (FUJIKYU, Nagoya, Japan), were used. Figure 1 shows a heating device comprising a CH-HP04 thermal mat (COSI HOME, London, UK), cotton or polyester fabrics, T thermocouples (SATO SHOUJI, Kanagawa, Japan), and a Hygrochron humidity data logger (MAXIM INTEGRATED, San Jose, CA, USA). YU-KI BAN GS surgical tape (NITOMS, Tokyo, Japan) was used to secure each component. The thermal mat, sized for the lower leg and insulated on one side, was covered with fabric on the contact area. The thermocouples affixed between the thermal mat and fabrics give the output of the heating device. A Hygrochron sensor was additionally placed on the skin-contact surface of the device for five participants. Evoked potentials were measured using a Neuropack X1 system with NM-422B surface stimulation electrodes and NE-132B surface Ag/AgCl electrodes (all from NIHON KOHDEN, Tokyo, Japan). To ensure the quality of the potential signal affected by skin moisture variations, Ag/AgCl electrodes and conductive paste were chosen[33, 34]. The surface electrodes were secured with moisture-permeable YU-KI BAN GS.

Evoked potentials recorded a submaximal H-wave (H_{SUB}) and maximal M-wave (M_{MAX}) from SOL with a 1.0-ms square wave. H_{SUB} was set at a stimulation frequency of 0.2 Hz, elicited at a stimulation intensity that produced approximately 10% of M_{MAX}. M_{MAX} was elicited at a stimulation frequency of 1.0 Hz at maximal stimulus (120%). It is generally advised to take measurements for 5–10 H-reflexes for each given stimulus[20, 35]. H_{SUB} was elicited eight times whereas M_{MAX} was averaged over four measurements to minimize discomfort. The evoked potentials were processed with a band-pass filter of 20–1,000 Hz and captured on a personal computer at a sampling rate of 10 kHz. The waveforms were evaluated in terms of amplitudes (peak to peak, mV) and latencies (ms). The H_{SUB} amplitude was normalized by the M_{MAX} amplitude to provide an index of spinal excitability[19, 20] (H_{SUB}/M_{MAX}). The M-wave to M_{MAX} amplitude ratio (M/M_{MAX}) was calculated to ensure consistent stimulation across sessions[35].

All trials were conducted in a shielded room maintained at 24°C and 40% humidity. Experimental sessions for each fabric type were conducted on two different days (approximately seven days apart), starting at 17:30. The participants changed into 100% cotton shorts and a T-shirt. The right ankle joint was fixed at a dorsiflexion angle of 0° using an ORTOP AFO orthosis

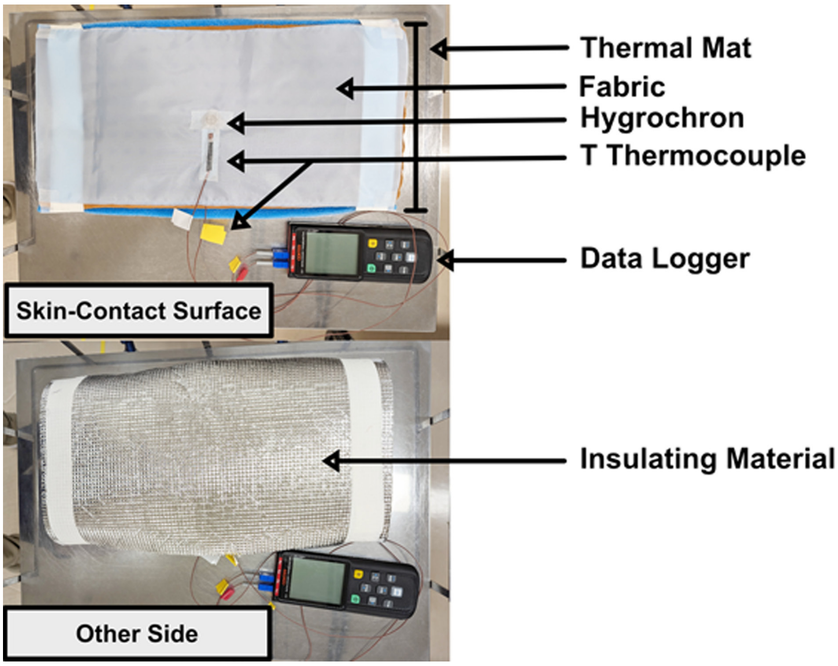

Fig. 1. Heating device setup.

(PACIFIC SUPPLY, Osaka, Japan). The participants lay prone on a bed for 10 minutes with their knee flexion adjusted to 20° with a pad. After resting, the electrode area was shaved, and a Skinpure skin preparation gel (NIHON KOHDEN, Tokyo, Japan) was used to reduce skin resistance to below 5 kΩ. Surface stimulation electrodes were fixed to the right popliteal fossa with a non-elastic belt. Surface Ag/AgCl electrodes were secured to the medial gastrocnemius, Achilles tendon, and proximal medial lower leg (ground)[19]. The distance between electrodes was set at 2.0 cm[36]. The heating device was placed to cover the entire posterior lower leg and fixed with two 0.5-kg weights. The fabrics were randomized and blinded to both the examiners and participants. An additional thermocouple was applied to the belly of the right tibialis anterior (TA) to confirm sensory input from the anterior lower leg. The three thermocouples were monitored with a CENTER 521 data logger (CENTER TECHNOLOGY, New Taipei, Taiwan). The trials followed a predetermined sequence, starting with the control condition (CT), followed by the heat condition (HT), and ending with the adaptation condition (AT). After setting up the devices and allowing the participant to rest for 10 minutes, the tympanic temperature (T_{EAR}) was measured with a CTD711 device (CITIZEN SYSTEMS JAPAN, Tokyo, Japan). Data were then recorded for the skin surface temperatures over SOL (T_{SOL}) and TA (T_{TA}), the thermal mat surface temperature (T_{MAT}), the relative humidity over SOL (%RH_{SOL}), and the evoked potentials (M_{MAX} and H_{SUB}). These procedures were defined as CT. Under HT, T_{SOL} was increased to 39.0°C by the heating device. Subsequently, the same measurements were repeated, and the heating times were recorded. Under AT, T_{SOL} was maintained between 39.0 and 40.0°C for 10 minutes. Measurements identical to those of CT were subsequently performed. The participants were instructed to relax and maintain their postures during all trials. After measurements, skin markers were applied at electrode positions to ensure reproducibility in later sessions.

The primary outcomes were waveform parameters, including M_{MAX} amplitudes, H_{SUB} and M_{MAX} latencies, and the H_{SUB}/M_{MAX}. The secondary outcomes included heating times, T_{EAR}, T_{TA}, T_{MAT}, T_{SOL}, %RH_{SOL}, and the M/M_{MAX}.

Paired t-tests were conducted to compare the heating times and M/M_{MAX} ratios across sessions. Two-way repeated measures linear mixed models (LMMs) were used for T_{EAR}, T_{TA}, T_{MAT}, T_{SOL}, %RH_{SOL}, and both M_{MAX} and H_{SUB} latencies to examine individual differences and interactions between fabric types and heating conditions, incorporating random effects for each participant, with CT and polyester fabric as the baseline. For each fabric type, one-way repeated measures LMMs (with random intercepts) were applied to the M_{MAX} amplitude and H_{SUB}/M_{MAX}, considering the impact of electrode compression on amplitude variations[37, 38]. The LMMs were used primarily to determine interactions and to prepare the marginal means for more detailed multiple comparisons. The Bonferroni method and Cohen's d[39] were applied in *post-hoc* testing and determining the effect sizes, respectively. All analyses were conducted using R version 4.3.1 with lme4, r2glmm (to calculate R^2 and partial R^{2}[40]), and emmeans (to output results of multiple comparison[6]) packages, with the level of significance set at 5%. setting the level of significance at 5%.

RESULTS

Absences of significant differences were observed in both heating times (mean difference of 0.2 minutes) and M/M_{MAX} (mean difference of 0.8 mV).

Table 1 gives the results of the LMMs for environmental temperatures and humidity. Table 2 presents the multiple comparison results corresponding to the LMM results in Table 1. Both T_{EAR} and T_{TA} showed consistency throughout the trials, being unaffected by fabric or heating factors. Significant main effects of the heating factors were identified in T_{SOL}, T_{MAT}, and $\%RH_{SOL}$. The post-hoc tests revealed significant increases in these variables in both HT and AT relative to CT (Table 2).

Table 3 shows the results of the LMMs for waveform parameters. Table 4 presents the multiple comparison results corresponding to the LMM results in Table 3. The H_{SUB} latency exhibited significant interactions between the heating factors and fabric type. In contrast, the M_{MAX} latency showed a significant main effect of heating factor.

As demonstrated by multiple comparisons, the polyester fabric significantly prolonged the H_{SUB} latency in HT and AT relative to CT. Conversely, the M_{MAX} latency was significantly shortened in AT relative to CT, unaffected by the fabric type.

Both the M_{MAX} amplitude and H_{SUB}/M_{MAX} exhibited significant main effects of decline under AT (Table 3). As demonstrated by the Bonferroni method (Table 4), the M_{MAX} amplitudes significantly declined in HT and AT versus CT in both cotton and polyester sessions. However, for the H_{SUB}/M_{MAX}, the polyester fabric showed no significant decrease when the heating factor was applied, thereby maintaining the H_{SUB}/M_{MAX}.

Table 1. Linear mixed models of environmental temperature and humidity

Evaluation	Factor	Fixed effect	Beta [95% CI]	Partial R^2	R^2
T_{EAR} (°C)		Intercept	36.520 [36.340, 36.690]***		0.108
	Fabric	Polyester	−0.054 [−0.219, 0.111]	0.030	
	Condition	Heat	0.038 [−0.001, 0.078]	0.015	
		Adaptation	0.000 [−0.039, 0.039]	0.000	
	Interaction	Polyester:Heat	0.000 [−0.048, 0.048]	0.000	
		Polyester:Adaptation	0.008 [−0.040, 0.055]	0.000	
T_{TA} (°C)		Intercept	31.815 [31.029, 32.601]***		0.062
	Fabric	Polyester	−0.215 [−1.186, 0.755]	0.014	
	Condition	Heat	0.177 [−0.076, 0.429]	0.010	
		Adaptation	0.108 [−0.145, 0.360]	0.004	
	Interaction	Polyester:Heat	0.015 [−0.293, 0.324]	0.000	
		Polyester:Adaptation	−0.031 [−0.339, 0.278]	0.000	
T_{SOL} (°C)		Intercept	33.431 [33.220, 33.642]***		0.988
	Fabric	Polyester	−0.038 [−0.269, 0.193]	0.001	
	Condition	Heat	5.631 [5.333, 5.929]***	0.965	
		Adaptation	6.354 [6.056, 6.652]***	0.972	
	Interaction	Polyester:Heat	0.031 [−0.296, 0.358]	0.000	
		Polyester:Adaptation	−0.100 [−0.427, 0.227]	0.004	
T_{MAT} (°C)		Intercept	33.085 [32.716, 33.453]***		0.984
	Fabric	Polyester	−0.123 [−0.563, 0.317]	0.005	
	Condition	Heat	9.431 [8.988, 9.874]***	0.964	
		Adaptation	8.562 [8.118, 9.005]***	0.956	
	Interaction	Polyester:Heat	−0.446 [−0.932, 0.040]	0.029	
		Polyester:Adaptation	−0.377 [−0.863, 0.109]	0.021	
$\%RH_{SOL}$ (%)		Intercept	35.460 [29.918, 41.002]***		0.600
	Fabric	Polyester	−0.060 [−7.898, 7.778]	0.000	
	Condition	Heat	11.480 [6.514, 16.446]***	0.263	
		Adaptation	18.620 [13.654, 23.586]***	0.485	
	Interaction	Polyester:Heat	−0.820 [−7.843, 6.203]	0.001	
		Polyester:Adaptation	−6.120 [−13.143, 0.903]	0.048	

Statistical significance of regression coefficients of linear mixed models: *p<0.05, **p<0.01, ***p<0.001.
Partial R^2: R^2 statistic as effect size.
CI: confidence interval; T_{EAR}: tympanic temperatures; T_{TA}: skin surface temperatures over tibialis anterior; T_{SOL}: skin surface temperatures over soleus; T_{MAT}: thermal mat surface temperatures; $\%RH_{SOL}$: relative humidity over soleus.

Table 2. Environmental temperatures and humidity

Evaluation	Fabric	Condition		
		Control	Heat	Adaptation
T_{EAR} (°C)	Cotton	36.5 [0.08]		
	Polyester			
T_{TA} (°C)	Cotton	31.8 [0.32]		
	Polyester			
T_{SOL} (°C)	Cotton	33.4 [0.09]	39.1 [0.09]*** *d*=13.1	39.7 [0.09]*** *d*=14.6
	Polyester			
T_{MAT} (°C)	Cotton	33.0 [0.16]	42.2 [0.16]*** *d*=14.5	41.4 [0.16]*** *d*=13.2
	Polyester			
$\%RH_{SOL}$ (%)	Cotton	35.4 [2.11]	46.5 [2.11]** *d*=1.8	51.0 [2.11]*** *d*=2.6
	Polyester			

Estimated marginal means [standard error] based on results of linear mixed models.
Statistical significance of multiple comparisons: *p<0.05, **p<0.01, ***p<0.001 (relative to Control).
T_{EAR}: tympanic temperatures; T_{TA}: skin surface temperatures over tibialis anterior; T_{SOL}: skin surface temperatures over soleus; T_{MAT}: thermal mat surface temperatures; $\%RH_{SOL}$: relative humidity over soleus; *d*: Cohen's *d* as effect size.

Table 3. Linear mixed models of waveform parameter

Evaluation	Factor	Fixed effect	Beta [95% CI]	Partial R^2	R^2
H_{SUB} latency (ms)		Intercept	28.947 [28.084, 29.811]***		0.108
	Fabric	Polyester	−0.137 [−0.344, 0.069]	0.015	
	Condition	Heat	0.008 [−0.164, 0.180]	0.000	
		Adaptation	−0.032 [−0.204, 0.140]	0.001	
	Interaction	Polyester:Heat	0.265 [0.039, 0.490]*	0.028	
		Polyester:Adaptation	0.373 [0.147, 0.598]**	0.054	
M_{MAX} latency (ms)		Intercept	5.555 [5.116, 5.995]***		0.363
	Fabric	Polyester	0.226 [−0.050, 0.502]	0.094	
	Condition	Heat	−0.021 [−0.112, 0.071]	0.001	
		Adaptation	−0.256 [−0.348, −0.165]***	0.118	
	Interaction	Polyester:Heat	−0.088 [−0.214, 0.039]	0.008	
		Polyester:Adaptation	−0.068 [−0.195, 0.059]	0.005	
M_{MAX} amplitude (mV)	Cotton	Intercept	15.748 [13.219, 18.276]***		0.252
		Heat	−0.496 [−0.842, −0.150]**	0.037	
		Adaptation	−1.452 [−1.797, −1.106]***	0.246	
	Polyester	Intercept	16.654 [14.053, 19.254]***		0.192
		Heat	−0.858 [−1.304, −0.412]***	0.074	
		Adaptation	−1.477 [−1.923, −1.031]***	0.191	
H_{SUB}/M_{MAX}	Cotton	Intercept	0.172 [0.112, 0.232]***		0.085
		Heat	−0.007 [−0.013, 0.000]	0.015	
		Adaptation	−0.016 [−0.023, −0.009]***	0.084	
	Polyester	Intercept	0.150 [0.107, 0.192]***		0.036
		Heat	−0.002 [−0.009, 0.005]	0.002	
		Adaptation	−0.009 [−0.016, −0.002]*	0.033	

Statistical significance of regression coefficients of linear mixed models: *p<0.05, **p<0.01, ***p<0.001.
Partial R^2: R^2 statistic as effect size.
CI: confidence interval; H_{SUB}: submaximal H-wave; M_{MAX}: maximal M-wave.

Table 4. Latency responses and amplitude parameters

Evaluation	Fabric	Condition		
		Control	Heat	Adaptation
H_{SUB} latency (ms)	Cotton	28.9 [0.43]	29.0 [0.43]	28.9 [0.43]
	Polyester	28.8 [0.43]	29.1 [0.43]* *d*=0.9	29.2 [0.43]** *d*=1.2
M_{MAX} latency (ms)	Cotton	5.67 [0.21]	5.60 [0.21]	5.38 [0.21]*** *d*=1.8
	Polyester			
M_{MAX} amplitude (mV)	Cotton	15.7 [1.25]	15.3 [1.25]* *d*=0.8	14.3 [1.25]*** *d*=2.3
	Polyester	16.7 [1.28]	15.8 [1.28]** *d*=1.0	15.2 [1.28]*** *d*=1.8
H_{SUB}/M_{MAX}	Cotton	0.172 [0.03]	0.166 [0.03]	0.156 [0.03]*** *d*=1.3
	Polyester	0.150 [0.02]	0.148 [0.02]	0.141 [0.02]

Estimated marginal means [standard error] based on results of linear mixed models.
Statistical significance of multiple comparisons: *p<0.05, **p<0.01, ***p<0.001 (relative to Control).
H_{SUB}: submaximal H-wave; M_{MAX}: maximal M-wave; *d*: Cohen's *d* as effect size.

DISCUSSION

The present study investigated the differential effects of cotton and polyester fabrics on neural drive under consistent thermal stimulation. The results showed that the M_{MAX} and H_{SUB}/M_{MAX} exhibited distinct responses depending on the type of fabric. Specifically, the polyester fabric was found to prolong the H_{SUB} latency while maintaining the H_{SUB}/M_{MAX}.

Racinais et al.[24, 25] highlighted the critical role of an increased core temperature in reducing the amplitudes and latencies of both the M-wave and H-wave, as well as the H/M ratio. Our results indicate that the T_{EAR} had no significant effect, suggesting its minimal impact on the waveform.

Rutkove et al.[26] reported a decline in the M-wave amplitude of the first dorsal interosseous, following 20 minutes of heating the upper limb to 44°C. Kiernan et al.[27] distinguished a similar reduction in the M-wave amplitude of the abductor pollicis brevis muscle after 35 minutes of warming the forearm. Dewhurst et al.[28] found that heating the lower limb for 40 minutes with an electric blanket, increased the SOL skin temperature to approximately 37°C, reduced M-wave and H-wave amplitudes and H-wave latency without altering the H/M ratio. These reports suggest that the presence of prolonged thermal agents at the recording site typically decreases amplitude and latency signals. This mechanism likely stems from reduced sodium ion influx, as the sodium ion channel closes rapidly with increased nerve temperature[23, 26]. Our findings regarding the reduction in the M_{MAX} align with the results of these studies[26–28], indicating that the thermal effects are readily reflected in the neuromuscular junction. However, the H_{SUB} latency and H_{SUB}/M_{MAX} exhibited different responses depending on the type of fabric. It has been suggested that there are synaptic connections between Ia afferent fibers and the motor neurons of SOL[41]. In addition, specific skin stimuli reportedly induce connections with interneurons at the spinal level, inducing central delays[42, 43]. Our results indicate that the different fabrics have varying impacts on the cumulative effect of facilitation and inhibition from supraspinal sources. This finding aligns with previous research indicating that polyester clothing affects neural activation[13]. Nevertheless, the H/M ratio with the interaction of the H-wave and M-wave, making it difficult to accurately compare different experimental conditions involving varying ranges of exposure and thermal conductive materials.

The thermal conductivity and moisture regain of materials need to be considered in clarifying the effects of a fabric. The heat transfer rate of cotton fabric is greater than that of polyester fabric for materials of the same construction[44]. Furthermore, the higher moisture regain of cotton fabric contributes to an accelerated increase in thermal conductivity[45]. Tang et al.[46] conducted a subjective stickiness assessment using various wetted fabrics and suggested that moisture in cotton fabric increases fabric–skin adhesion. According to Arshi et al.[47], cotton fiber, possessing polar groups, swells through an increase in relative humidity, which enhances adhesion at temperatures below 45°C. These reports suggest that fabric characteristics alter heat and tactile stimuli on the skin surface. Skin stimulation applications such as compression garments and elastic tapes reportedly reduce H-wave amplitudes[3, 48, 49]. Therefore, the reduction in spinal excitability for cotton fabric may stem from presynaptic inhibition[19] linked to enhanced skin stimulation from increasing humidity. Concurrently, the swollen cotton might increase the areas of tactile contact with the skin and conduct heat more efficiently, altering sodium ion channels[23, 26].

In clinical settings of physical therapy, using dry heat packs wrapped specifically in cotton fabric, as opposed to blended or synthetic fibers, reduces spinal excitability at rest. This method effectively aids in managing muscle hypertonia and contractures by providing cotton's natural properties for even heat distribution and comfort. Using polyester-based supports during exercise that induce sweating prevents neurological inhibition and thus enhances exercise efficiency. Although polyester's hydrophobic properties potentially lead to discomfort due to stickiness, this sensation often goes unnoticed during physical activity, making it suitable for exercise[9, 10]. Conversely, cotton-based supports increase skin stimulation through their adhesive effects, enhancing sensory feedback. However, differences in spinal responses to the fabrics only appear when the local area is exposed to high heat and humidity for prolonged periods; otherwise, these effects are negligible. By elucidating the electrophysiological responses to fabric stimuli, this study contributes to the design of cutaneous afferent stimulation devices, such as compression garments, that combine pressure and textured stimuli.

Clothing worn constantly can continue to provide less physiological benefit than manual therapy. However, the specific effects of various fabrics remain largely unexplored. Collaboration between the fields of fiber science and rehabilitation has the potential to lead to new discoveries and contribute to the development of physical therapy.

We believe that it is crucial to observe the electrophysiological responses to typical fabric stimuli and ensure that these responses do not conflict with the desired neurological excitation or inhibition changes. Ultimately, we aim to develop garments that complement or improve motor performance in individuals with functional impairments.

Research limitations are described. The skin impedance was measured only immediately after skin preparation, making it difficult to accurately assess the effects of increased conductivity due to rising temperature and humidity during the experiment. Two typical plain-woven fabrics made of cotton and polyester were used, but the combinations of fiber types, blend ratios, and weaving techniques are diverse, and each requires individual verification. The present study focused exclusively on young male individuals, yet the effects of local heat exposure on the H-reflex vary with age[28, 30)]. In addition, previous studies have shown that progesterone, a hormone that plays a crucial role in the female reproductive system, affects the H-reflex[50)]. We measured the H-reflex in a resting-prone position. This approach overlooks changes in neural drive due to variations in posture, along with not assessing reflex gain during muscle activity, restricts the generalizability of our findings. A fundamental limitation exists in using the H-reflex to study human movement, as it is an electrically induced reflex that does not naturally occur. Furthermore, H-reflex changes offer insights into neural mechanisms but may not directly translate to clinical outcomes, necessitating caution in interpretation.

Our research revealed the different effects of cotton and polyester fabrics on spinal excitability during local heat exposure. During thermal agent application, the cotton fabric reduced H_{SUB}/M_{MAX} whereas the polyester fabric maintained H_{SUB}/M_{MAX}. These fabric properties contribute to the selection of wrapping materials for thermal agents and the fundamental design of wearable devices that control cutaneous afferent input in physical therapy.

Funding

No specific funding from any public, private, or nonprofit agencies was received to support this research.

Conflict of interest

This study has no conflicts of interest to report.

ACKNOWLEDGEMENTS

We thank clinical laboratory technicians and professionals for their expertise and guidance. We especially acknowledge Mr. Nishijima from Iida Hospital, Mr. Nakata, and Mr. Saito from Nihon Kohden for their advice and mentorship throughout the testing process.

REFERENCES

1) Mancini S, Mariani F, Rossi A, et al.: Effects of elastic stockings on peripheral and central nervous system. Int Angiol, 2020, 39: 155–160. [Medline] [CrossRef]
2) Espeit L, Pavailler S, Lapole T: Effects of compression stockings on ankle muscle H-reflexes during standing. Muscle Nerve, 2017, 55: 596–598. [Medline] [CrossRef]
3) Barss TS, Pearcey GE, Munro B, et al.: Effects of a compression garment on sensory feedback transmission in the human upper limb. J Neurophysiol, 2018, 120: 186–195. [Medline] [CrossRef]
4) Hooper DR, Cook BM, Comstock BA, et al.: Synthetic garments enhance comfort, thermoregulatory response, and athletic performance compared with traditional cotton garments. J Strength Cond Res, 2015, 29: 700–707. [Medline] [CrossRef]
5) Goto K, Morishima T: Compression garment promotes muscular strength recovery after resistance exercise. Med Sci Sports Exerc, 2014, 46: 2265–2270. [Medline] [CrossRef]
6) Brown F, Hill M, Renshaw D, et al.: The effect of medical grade compression garments on the repeated-bout effect in non-resistance-trained men. Exp Physiol, 2023, 108: 1490–1499. [Medline] [CrossRef]
7) Kawabata S: Characterization method of the physical property of fabrics and the measuring system for hand-feeling evaluation. Seni Kikai Gakkaishi, 1973, 26: 721–728. [CrossRef]
8) Ikeda H, Matsuura T, Hayashi T, et al.: Kinesio taping of the medial thigh and a thigh pressure orthotic device had an immediate effect on hip adduction and gait function in a case of obturator nerve injury. Rigakuryoho Kagaku, 2023, 38: 84–89. [CrossRef]
9) Brazaitis M, Kamandulis S, Skurvydas A, et al.: The effect of two kinds of T-shirts on physiological and psychological thermal responses during exercise and recovery. Appl Ergon, 2010, 42: 46–51. [Medline] [CrossRef]
10) Sperlich B, Born DP, Lefter MD, et al.: Exercising in a hot environment: which T-shirt to wear? Wilderness Environ Med, 2013, 24: 211–220. [Medline] [CrossRef]

11) Özkan ET, Kaplangiray B, Şekir U, et al.: Effect of different garments on thermophysiological and psychological comfort properties of athletes in a wear trial test. Sci Rep, 2023, 13: 14883. [Medline] [CrossRef]
12) De Sousa J, Cheatham C, Wittbrodt M: The effects of a moisture-wicking fabric shirt on the physiological and perceptual responses during acute exercise in the heat. Appl Ergon, 2014, 45: 1447–1453. [Medline] [CrossRef]
13) Zimniewska M, Krucińska I: The effect of raw material composition of clothes on selected physiological parameters of human organism. J Text Inst, 2010, 101: 154–164. [CrossRef]
14) Zimniewska M, Kozłowski R: Natural and man-made fibers and their role in creation of physiological state of human body. Mol Cryst Liq Cryst (Phila Pa), 2004, 418: 113–130. [CrossRef]
15) Chow CM, Shin M, Mahar TJ, et al.: The impact of sleepwear fiber type on sleep quality under warm ambient conditions. Nat Sci Sleep, 2019, 11: 167–178. [Medline] [CrossRef]
16) Cho G, Casali JG, Yi E: Effect of fabric sound and touch on human subjective sensation. Fibers Polym, 2001, 2: 196–202. [CrossRef]
17) Magladery JW, McDougal DB Jr: Electrophysiological studies of nerve and reflex activity in normal man. I. Identification of certain reflexes in the electromyogram and the conduction velocity of peripheral nerve fibers. Bull Johns Hopkins Hosp, 1950, 86: 265–290. [Medline]
18) Magladery JW: Some observations on spinal reflexes in man. Pflugers Arch Gesamte Physiol Menschen Tiere, 1955, 261: 302–321. [Medline] [CrossRef]
19) Zehr EP: Considerations for use of the Hoffmann reflex in exercise studies. Eur J Appl Physiol, 2002, 86: 455–468. [Medline] [CrossRef]
20) Theodosiadou A, Henry M, Duchateau J, et al.: Revisiting the use of Hoffmann reflex in motor control research on humans. Eur J Appl Physiol, 2023, 123: 695–710. [Medline] [CrossRef]
21) Nakamaru K, Yanagisawa K: Effects of upper limb PNF starting positions and neck-rotated positions on H-reflex of soleus muscle. J Jpn Acad Health Sci, 2005, 8: 46–50.
22) Furukawa K, Fujiwara T, Kamijo M: The effect of maximum phonation on spinal cord excitement levels of the triceps surae muscle. Annu Rep The Tohoku Sect Jpn Phys Ther Assoc, 2015, 27: 5–9.
23) Hodgkin AL, Katz B: The effect of temperature on the electrical activity of the giant axon of the squid. J Physiol, 1949, 109: 240–249. [Medline] [CrossRef]
24) Racinais S, Cresswell AG: Temperature affects maximum H-reflex amplitude but not homosynaptic postactivation depression. Physiol Rep, 2013, 1: e00019. [Medline] [CrossRef]
25) Racinais S, Gaoua N, Grantham J: Hyperthermia impairs short-term memory and peripheral motor drive transmission. J Physiol, 2008, 586: 4751–4762. [Medline] [CrossRef]
26) Rutkove SB, Kothari MJ, Shefner JM: Nerve, muscle, and neuromuscular junction electrophysiology at high temperature. Muscle Nerve, 1997, 20: 431–436. [Medline] [CrossRef]
27) Kiernan MC, Cikurel K, Bostock H: Effects of temperature on the excitability properties of human motor axons. Brain, 2001, 124: 816–825. [Medline] [CrossRef]
28) Dewhurst S, Riches PE, Nimmo MA, et al.: Temperature dependence of soleus H-reflex and M wave in young and older women. Eur J Appl Physiol, 2005, 94: 491–499. [Medline] [CrossRef]
29) Long BC, Hopkins JT: Superficial moist heat's lack of influence on soleus function. J Sport Rehabil, 2009, 18: 438–447. [Medline] [CrossRef]
30) Paulauskas H, Baranauskiene N, Wang J, et al.: Local knee heating increases spinal and supraspinal excitability and enhances plantar flexion and dorsiflexion torque production of the ankle in older adults. Eur J Appl Physiol, 2020, 120: 2259–2271. [Medline] [CrossRef]
31) Faul F, Erdfelder E, Lang AG, et al.: G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods, 2007, 39: 175–191. [Medline] [CrossRef]
32) Brodaty H, Mothakunnel A, de Vel-Palumbo M, et al.: Influence of population versus convenience sampling on sample characteristics in studies of cognitive aging. Ann Epidemiol, 2014, 24: 63–71. [Medline] [CrossRef]
33) Goyal K, Borkholder DA, Day SW: Dependence of skin-electrode contact impedance on material and skin hydration. Sensors (Basel), 2022, 22: 8510. [Medline] [CrossRef]
34) Lee MS, Paul A, Xu Y, et al.: Characterization of Ag/AgCl Dry electrodes for wearable electrophysiological sensing. Front Electron, 2022, 2.
35) Hwang IS, Lin CF, Tung LC, et al.: Responsiveness of the H reflex to loading and posture in patients following stroke. J Electromyogr Kinesiol, 2004, 14: 653–659. [Medline] [CrossRef]
36) Zehr EP, Stein RB: Interaction of the Jendrássik maneuver with segmental presynaptic inhibition. Exp Brain Res, 1999, 124: 474–480. [Medline] [CrossRef]
37) Christie AD, Inglis JG, Boucher JP, et al.: Reliability of the FCR H-reflex. J Clin Neurophysiol, 2005, 22: 204–209. [Medline]
38) Tucker KJ, Türker KS: Muscle spindle feedback differs between the soleus and gastrocnemius in humans. Somatosens Mot Res, 2004, 21: 189–197. [Medline] [CrossRef]
39) Cohen J: The t-test for means. In: Statistical power analysis for the behavioral sciences. Hillsdale: L. Erlbaum Associates, 1988, pp 19–66.
40) Antonenko D, Grittner U, Saturnino G, et al.: Inter-individual and age-dependent variability in simulated electric fields induced by conventional transcranial electrical stimulation. Neuroimage, 2021, 224: 117413. [Medline] [CrossRef]
41) Meunier S, Kwon J, Russmann H, et al.: Spinal use-dependent plasticity of synaptic transmission in humans after a single cycling session. J Physiol, 2007, 579: 375–388. [Medline] [CrossRef]
42) Pierrot-Deseilligny E, Bergego C, Katz R, et al.: Cutaneous depression of Ib reflex pathways to motoneurones in man. Exp Brain Res, 1981, 42: 351–361. [Medline]
43) Tamura K, Sugita S, Tokunaga T, et al.: TRPM8-mediated cutaneous stimulation modulates motor neuron activity during treadmill stepping in mice. J Physiol Sci, 2019, 69: 931–938. [Medline] [CrossRef]
44) Senoo J, Yoneda M, Niwa M: Study on heat conduction properties of clothing materials (part 1): measurement of effective thermal conductivity of fabrics. J Home Econ Jpn, 1985, 36: 241–250.
45) Senoo J, Yoneda M, Niwa M: Study on heat conduction properties of clothing materials (part 2): on effective thermal conductivity of fabrics containing water. J Home Econ Jpn, 1985, 36: 251–260.

46) Tang KM, Chau KH, Kan CW, et al.: Assessing the accumulated stickiness magnitude from fabric-skin friction: effect of wetness level of various fabrics. R Soc Open Sci, 2018, 5: 180860. [Medline] [CrossRef]
47) Arshi A, Jeddi AA, Katbab A: Frictional behavior of plain woven fabrics constructed from polyester and cotton yarns in different environmental conditions. J Eng Fibers Fabrics, 2012, 7: 155892501200700215.
48) Alexander CM, Stynes S, Thomas A, et al.: Does tape facilitate or inhibit the lower fibres of trapezius? Man Ther, 2003, 8: 37–41. [Medline] [CrossRef]
49) Alexander CM, McMullan M, Harrison PJ: What is the effect of taping along or across a muscle on motoneurone excitability? A study using triceps surae. Man Ther, 2008, 13: 57–62. [Medline] [CrossRef]
50) Casey E, Reese M, Okafor E, et al.: Influence of menstrual cycle and oral contraceptive phase on spinal excitability. PM R, 2016, 8: 860–868. [Medline] [CrossRef]