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Original Article

Influences of Changes in the Level of Support and Walking Speed on the H Reflex of the Soleus Muscle and Circulatory Dynamics on Body Weight-supported Treadmill Training: Investigation in Healthy Adults

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Abstract. [Purpose] To investigate the therapeutic usefulness of treadmill walking using a body weight support device (BWS), changes in circulatory dynamics and muscle activities with various levels of support were investigated. [Subjects and Methods] The subjects were divided into 3 groups: 20% BWS, 40% BWS, and full body weight (FBW). The subjects walked at maximum and normal speeds. Under each condition, H and M waves and skin temperature before and after walking and changes in the heart rate during walking were measured. [Results] The heart rate continued to increase after 3 minutes of FBW at the maximum walking speed, but a steady state was reached after 3 minutes under the other walking conditions. Regarding skin temperature, no significant difference from that at rest was noted 30 minutes after walking at the normal speed, but it was significantly higher than that at rest at 30 minutes after walking at the maximum speed. The H/M ratio was significantly higher after walking at the maximum walking speed in the FBW and 20% BWS groups compared with the 40% BWS groups. [Conclusion] Treatment with 40% BWS at the maximum walking speed was safe for the circulatory system and may be effective in elevating the skin temperature for a prolonged period compared with the effects of the other walking conditions at normal speed.
Key words: Body weight support, Walking speed, Skin temperature

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INTRODUCTION

Many studies on treadmill walking using a body weight support (BWS) device for patients with dysbasia have recently been reported. Werning[1)] and Dietz[2)] reported its usefulness in improving the walking ability of spinal cord injury patients in 1992 and 1994, respectively, and walking speed-increasing and walking ability-improving effects were suggested. Studies on patients with hemiplegia[3–6)], orthopedic disease[7, 8)], cerebral palsy[9)], and Parkinson's disease[10, 11)] have also been reported, and body weight support treadmill training (BWSTT) is now widely applied.

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The motor-physiological influence of BWSTT has also been investigated mainly in healthy subjects and stroke patients. Ohata et al.[12)] performed electromyographic analysis of the lower limbs in BWSTT and observed that the action potential of the lower limb muscles decreased as the level of support increased. A decrease in oxygen intake has also been reported as a marked BWSTT-induced change. Colby et al.[13)] reported that 20% and 40% body weight support decreased oxygen consumption by 6% and 12%, respectively. In a study using evoked electromyography reported by Osaka et al.[14)], the maximum amplitude ratio of the H and M waves of the soleus muscle (H/M ratio) decreased after walking at 4 km/hour with and without support, and no significant difference was noted between the 2 groups. Since a decrease in the H/M ratio reflects the inhibition of spasm, the introduction of BWSTT may be useful for hemiplegia patients[14)]. Although changes in the H/M ratio with an increase in walking speed have not yet been clarified, the effectiveness of high-speed treadmill training in improv-

Table 1. Subjects' characteristics

Characteristics	FBW (n = 15)	20% BWS (n = 15)	40% BWS (n = 15)	p
Age (y)	25.6 ± 4.1	26.8 ± 6.0	27.1 ± 6.8	0.565 [b]
Sex (M/F)	12 / 3	11 / 4	10 / 5	0.711 [a]
Height (cm)	169.7 ± 7.2	169.7 ± 9.4	170.0 ± 10.9	0.992 [b]
Weight (kg)	61.8 ± 8.9	63.7 ± 10.2	62.6 ± 12.7	0.775 [b]
BMI (kg/m^2)	21.4 ± 2.6	22.1 ± 2.6	21.4 ± 2.1	0.439 [b]
Normal walking speed (km/h)	3.15 ± 0.61	3.04 ± 0.94	3.02 ± 0.95	0.344 [b]
Maximum walking speed (km/h)	5.68 ± 0.72	5.26 ± 0.79	5.16 ± 0.90	0.090 [b]

Values are presented as the mean ± SD or n of subjects.
[a]χ^2 test, [b]one-way analysis of variance. There was no significant difference among the three groups in each parameter.
F, female; M, male; BMI, body mass index; FBW, full body weight; BWS, body weight support

ing the walking speed was noted in preceding studies on BWSTT for patients with diseases accompanied by paralysis and articular disease, such as hemiplegia and orthopedic disease[3–8]. On the other hand, an increase in the H/M ratio suggests the facilitation of motor cells in the spinal cord, which may be desirable to increase muscle strength for healthy individuals[15, 16].

According to a report from the Japanese Society of Thermology[17], changes in the skin temperature after exercise are strongly correlated with muscle blood flow and are useful in evaluating the microcirculation. The gastrocnemius muscle is appropriate for blood flow evaluation using thermography because it shows a strong reaction to exercise load and the muscle mass is relatively large[18]. Thus, to investigate differences in muscle blood flow among various BWSTT patterns, we measured blood flow in the gastrocnemius muscle using thermography.

No consensus has been reached with regard to the treatment protocol and indications of BWSTT, and at present, they vary depending on the individual. However, for application of BWSTT to actual clinical cases, it is necessary to clarify the physiological effect. In this study, we compared the circulatory dynamics, skin temperature, and H/M ratio between BWSTT and full-body-weight treadmill training (FBWTT) in healthy adults with the aim of collecting basic information to establish a treatment protocol for BWSTT.

SUBJECTS AND METHODS

The subjects were 45 healthy adults with no past medical history of neurological, orthopedic, or cardiopulmonary functional abnormality (33 males and 12 females, mean height of 169.8±9.1 cm, mean body weight of 62.7±10.5 kg, mean age of 26.5±5.7 years).

Written informed consent was obtained from all the subjects.This study was performed after approval by the Ethics Committee of our hospital (approval number 24005). No potential conflicts of interest were disclosed.

For body weight support, a harness-type device (BDX-UWSZ, Biodex Unweighting System, SAKAI Medical Co., Ltd.) was used. For the exercise, a treadmill (BDX-GTM3, Biodex Unweighting System, SAKAI Medical Co., Ltd.) was used. The trunk above the femoral region was covered with a vest that comes exclusively with this device, and this vest was lifted using wire to decrease the body weight loaded on the lower limbs while walking.

The weight load during walking was set at the full body weight (FBW) and 20% and 40% body weight support (20% and 40% BWS, respectively). The 45 subjects were randomly allocated to these weight load conditions (FBW, 20% BWS, and 40% BWS groups; 15 subjects each) by employing envelope methods (Table 1). Two conditions were used for the walking speed: the subjects were encouraged to continue walking as fast as possible, which was designated as the maximum walking speed under one condition (Max), and to walk as usual, designated as the normal walking speed (Normal) under the other condition. All subjects walked barefoot at a constant speed under each condition.

The subjects walked under the Max and Normal conditions in random order. The experiment was performed under one condition per day, and a 2-day or longer interval was set between the experiments. The walking time was 6 minutes in all 3 groups, and changes in the heart rate and systolic blood pressure during walking were measured to judge whether respiratory and circulatory reactions reached a steady state under each walking condition. In addition, the amplitudes of the H and M waves of the soleus muscle, H/M ratio, and skin temperature were measured before and after walking under each condition. To eliminate confounding factors, the maximum amplitude and skin temperature were measured under double-blinded conditions for the examiner and subjects.

For measurement of the systolic blood pressure and heart rate, a noninvasive blood pressure monitor (BP-203, A&D Company, Colin Med. Tech.) and a heart rate monitor (RS100TM, Polar) were used. Measurement was performed in a standing position, and the blood pressure in the right brachial artery was measured. The systolic blood pressure (SBP), heart rate (HR), and double product (DP = SBP × HR) were determined within 30 seconds or less before walking and at 3 and 6 minutes of walking.

The skin temperature measurement conditions were controlled at an atmospheric temperature of 24±0.2 °C and humidity of 50±2%. The subjects wore short pants with both legs exposed, and were sufficiently acclimated to the room temperature at rest for 40 minutes. For measurement and re-

Table 2. Results for SBP, HR, and DP

Walking condition	Speed	Parameter	Rest	3 min	6 min
FBW	Normal	HR (beats/min)	82.6 ± 12.5	94.3 ± 6.0*	93.7 ± 5.2*
		SBP (mmHg)	120.1 ± 13.0	129.4 ± 12.9	132.3 ± 12.3*
		DP (beats×mmHg)	9.9 ± 2.0	12.2 ± 1.7*	12.4 ± 1.5*
	Max	HR (beats/min)	78.6 ± 11.4	94.9 ± 13.1*	109.5 ± 13.1*#
		SBP (mmHg)	120.3 ± 8.5	129.1 ± 9.4*	134.1 ± 6.9*
		DP (beats×mmHg)	9.5 ± 1.6	12.3 ± 2.3*	14.7 ± 2.0*#
20% BWS	Normal	HR (beats/min)	74.3 ± 9.8	89.5 ± 12.0*	90.9 ± 11.3*
		SBP (mmHg)	117.8 ± 9.5	127.0 ± 11.3*	128.0 ± 9.2*
		DP (beats×mmHg)	8.8 ± 1.5	11.4 ± 2.2*	11.7 ± 2.0*
	Max	HR (beats/min)	78.2 ± 12.6	101.6 ± 13.9*	104.0 ± 15.1*
		SBP (mmHg)	117.9 ± 11.5	127.7 ± 10.2*	131.0 ± 7.2*
		DP (beats×mmHg)	9.2 ± 1.9	13.0 ± 2.4*	13.7 ± 2.4*
40% BWS	Normal	HR (beats/min)	76.2 ± 6.2	89.1 ± 6.9*	91.7 ± 9.2*
		SBP (mmHg)	118.9 ± 13.2	127.7 ± 13.4	129.0 ± 11.7
		DP (beats×mmHg)	9.0 ± 1.1	11.4 ± 1.3*	11.8 ± 1.5*
	Max	HR (beats/min)	72.7 ± 10.5	92.1 ± 15.9*	99.7 ± 16.3*
		SBP (mmHg)	119.8 ± 15.6	129.9 ± 13.2	133.7 ± 12.9*
		DP (beats×mmHg)	8.7 ± 1.8	11.9 ± 2.3*	13.4 ± 3.2*

Values are presented as the mean ± SD. *p <0.05 vs. rest; #p <0.05 vs. 3 min.
FBW, full body weight; BWS, body weight support; SBP, systolic blood pressure; HR, heart rate; DP, double product

cording, a thermography device (Handy Thermo TVS–200 ME, Nippon Avionics Co., Ltd., Tokyo, Japan) was used. The skin temperature was measured on the posterior surface of the gastrocnemius muscle of the left crus. A rectangular frame with sides of 1/2 the width of the popliteal fossa and 2/3 of the major axis of the crus was set on the gastrocnemius muscle, and the mean skin temperature in the frame was automatically measured under the following conditions: temperature step, 0.4–0.8 °C; temperature range, 6.4 °C; temperature step display, 16 steps; and number of frame additions, 32. Measurement was performed at rest, immediately after the completion of walking, and every 10 minutes for 30 minutes after the completion of walking. In addition, the rate of change in the skin temperature ([skin temperature after walking − skin temperature before walking]/ skin temperature before walking × 100) was calculated.

For the measurement of H and M waves, an evoked electromyograph (Viking IV P 233 MHz, Nicolet) was used. After acclimation for a specific time using a plate electrode through the right soleus muscle, the impedance was adjusted to 5 kΩ or lower using a skin preconditioning agent (skinPure, Nihon Kohden, Tokyo, Japan). The negative electrode was fixed to the lateral side of the soleus muscle belly at about 1/3 from the periphery of the crus, and the positive electrode was fixed to the Achilles tendon. Both electrodes were fixed using tape, and left on the leg until the completion of measurement after walking. H and M waves were measured in the prone position. Regarding the stimulation conditions, the stimulus intensity was set at an intensity maximizing the amplitude, and the duration was 0.2 ms. The tibial nerve was continuously stimulated 16 times through the right popliteal fossa with constant current rectangular waves at a stimulus frequency of 1 Hz and an intensity of about 1.1–1.2 times higher than the threshold of the H/M waves. The amplitudes of 16 waveforms (from the baseline to negative peak) were individually determined and averaged. Measurement was performed at rest and 5 minutes after the completion of walking. In addition, the rate of change in the H/M ratio (H/M ratio after walking − H/M ratio before walking] / H/M ratio before walking × 100) was calculated after FBW, 20% BWS, and 40% BWS. To measure stable H waves, the subjects closed their eyes and mentally counted numbers to block visual stimulation.

The measured values are presented as the mean±standard deviation. Subjects' characteristics were analyzed using one-way analysis of variance, with the level of support as a dependent variable. For the nominal scale, the χ^2 test was used. One-way analysis of variance of the skin temperature was performed with the walking condition as a factor, that of SBP, HR, and DP was performed with the time as a factor, and that of the evoked muscle potential was performed with the walking condition as a factor. In the subsequent analysis, the Bonferroni test was used for intragroup comparison, and Tukey's HSD post hoc test was used for intergroup comparison[19]. For comparison of the H- and M-reflex amplitudes and H/M ratio between before and after walking, the paired t-test was used. SPSS Statics 21 was used for the statistical analysis and the significance level was set at less than 5%.

RESULTS

Under the FBW Max conditions, HR significantly increased until 6 minutes, not reaching a steady state at 3 minutes (Table 2). Under the other walking conditions, HR

Table 3. Serial changes in the skin temperature with each motor task

Walking condition	Speed	Before	After	10 min	20 min	30 min
FBW	Normal	29.0±0.5	30.1±0.5*	30.6±0.5*	30.4±0.4*	29.7±0.4
	Max	29.0±0.4	30.4±0.5*	31.8±0.4*	31.2±0.5*	30.9±0.5*
20% BWS	Norma	29.1±0.3	29.8±0.3*	30.5±0.6*	30.3±0.5*	29.7±0.6
	Max	29.3±0.5	30.8±0.6*	31.4±0.5*	31.1±0.6*	30.8±0.6*
40% BWS	Norma	29.3±0.5	29.7±0.6	30.0±0.5*	29.6±0.5	29.4±0.4
	Max	29.4±0.4	30.6±0.7*	31.4±0.5*	31.1±0.5*	30.5±0.6*

Values are presented as the mean ± SD. * p<0.05 vs. before
FBW, full body weight; BWS, body weight support

significantly increased in the first 3 minutes of walking, but there was no significant difference between HR at 3 and 6 minutes.

No significant change from the SBP before walking was noted at 3 minutes under the FBW Normal or 40% BWS Max conditions, but a significant difference was noted between the SBPs at rest and 6 minutes of walking. Under the FBW Max and 20% BWS Normal and Max conditions, the SBP significantly increased from that at rest in the first 3 minutes of walking, but no significant difference was noted between the SBPs at 3 and 6 minutes. Under the 40% BWS Normal conditions, no significant difference was noted in SBP among those at rest and 3 and 6 minutes of walking.

DP significantly increased under the FBW Max conditions until 6 minutes, not reaching a steady state at 3 minutes. Under the other conditions, DP significantly increased from that at rest in the first 3 minutes, but no significant difference was noted between the DPs at 3 and 6 minutes.

The skin temperature on the posterior surface of the crus significantly rose with time that at rest in the 10 minutes after walking under the Normal speed condition in all 3 groups and then decreased to a temperature not significantly different from that at rest at 30 minutes after walking (Table 3). Under the Max condition in the 3 groups, the skin temperature significantly rose from that at rest in the 10 minutes after walking, and the temperature at 30 minutes after walking was still significantly higher than that at rest. On comparison of the rate of change in the skin temperature, no significant difference due to the weight loading condition was noted at either the Max or Normal speed (Table 4).

In the evoked muscle potential measurement, the H- and M-reflex amplitudes and H/M ratio significantly increased after walking under the FBW Max and 20% BWS Max conditions (Table 5). No significant difference was noted in the rates of change in the H/M ratio among the weight load conditions (FBW, 20% BWS, and 40% BWS) at the Normal speed (Table 4). At the Max speed, the rate significantly increased after walking under the 40% BWS conditions compared with those after walking under FBW and 20% BWS conditions.

DISCUSSION

The Max and Normal walking speeds were set by each subject in this study. The Normal walking speed was slower than that in preceding studies (4 km/hour)[14, 20] because most subjects felt that walking at 4 km/h or faster was too fast and differed from their natural walking. Kubo[21] reported that the normal walking speed on a treadmill is significantly slower than that on flat land due to the influence of sensation and familiarity. Finch et al.[22] also reported that the normal speed of BWSTT decreased as the level of support increased. In our study, the speed of BWSTT tended to decrease compared with that of FBWTT, but the difference was not significant.

Table 4. Rate of change in skin temperature and H/M amplitude

Parameter	Speed	Walking condition	Rate of change
Skin temperature	Normal	FBW	4.2 ± 1.2
		20% BWS	3.5 ± 1.4
		40% BWS	2.3 ± 1.3
	Max	FBW	7.8 ± 1.6
		20% BWS	7.1 ± 1.9
		40% BWS	6.9 ± 1.5
H/M amplitude	Normal	FBW	8.4 ± 1.6
		20% BWS	−3.5 ± 1.5
		40% BWS	1.9 ± 1.2
	Max	FBW	51.5 ± 14.4
		20% BWS	35.9 ± 10.5
		40% BWS	15.7 ± 8.5*#

Values are presented as the mean ± SD. *p <0.05 vs. FBW; #p <0.05 vs. 20% BWS.
FBW, full body weight; BWS, body weight support

Regarding the SBP, HR, and DP, HR and DP continued to increase after 3 minutes under the FBW Max conditons, but a steady state was reached by 3 minutes of walking under the other conditions. HR is widely used as an index of aerobic exercise in clinical physical therapy[23]. DP is strongly correlated with oxygen consumption of the myocardium and exponentially rises with a gradual increase in exercise. Thus, it is utilized as an index for indirect estimation of the load on the heart during exercise[24]. Generally, factors increasing the SBP and HR during exercise include an increase in venous circulation due to a reduction in the inspiratory intrathoracic pressure associated with muscle pumping and promoted ventilation and an increase in the cardiac output induced by sympatheticotonia. In a state-load exercise test, VO_2 reaches a steady state within 3 minutes when the load is smaller than the aerobic threshold (AT), and it

Table 5. The measurement results for H-wave amplitude, M-wave amplitude, and H/M ratio

Walking condition	Speed		H-wave amplitude (mV)	M-wave amplitude (mV)	H/M ratio (%)
FBW	Normal	Before	1.6 ± 0.4	6.2 ± 1.0	26.8 ± 9.1
		After	1.8 ± 0.6	6.5 ± 0.8	27.6 ± 10.7
	Max	Before	1.6 ± 0.4	6.2 ± 1.0	26.2 ± 8.0
		After	2.7 ± 0.6*	7.3 ± 1.4*	39.3 ± 14.3*
20% BWS	Normal	Before	1.0 ± 0.3	5.0 ± 0.8	21.4 ± 5.8
		After	1.2 ± 0.5	6.2 ± 1.0	20.1 ± 8.9
	Max	Before	1.1 ± 0.4	4.9 ± 0.7	22.8 ± 5.9
		After	2.0 ± 0.5*	6.8 ± 0.8*	30.0 ± 8.5*
40% BWS	Normal	Before	2.7 ± 0.6	7.1 ± 1.3	38.9 ± 10.4
		After	2.7 ± 0.7	7.0 ± 1.2	39.5 ± 11.1
	Max	Before	2.8 ± 0.7	7.0 ± 0.9	40.0 ± 10.1
		After	3.2 ± 1.0	7.1 ± 1.0	45.2 ± 11.1

Values are presented as the mean ± SD; * p<0.05 vs. before.
FBW, full body weight; BWS, body weight support

exceeds 0 (at 3–6 minutes) when the load is AT or greater[23]. Therefore, under the walking conditions other than FBW Max, the exercise load was lower than the AT and safe.

In terms of the rate of change in the skin temperature, no significant difference was noted among the weight load conditions, FBW, 20% BWS, and 40% BWS, at either the Max or Normal speed, but the temperature at 30 minutes after walking at the Max speed was significantly higher than that at rest, showing that the temperature-elevating effect of the Max speed persisted longer than that of the Normal speed.

In a study using thermography reported by Mori et al.[25], repeated standing on the tips of the toes on one leg markedly elevated the temperature of the gastrocnemius muscle on the motion side. They also directly stimulated an exposed feline gastrocnemius muscle preparation to confirm this muscle contraction-induced muscle temperature elevation, and it was shown that the muscle temperature rose immediately after stimulation and returned to the previous temperature within about 30 minutes. In a study on the association between treadmill walking speed and lower limb muscle activity level using surface electromyography[26], no significant change due to alteration in the walking speed between 2 and 5 km/h was noted in the muscle discharge level, but significant increases were noted in the main muscles, such as the anterior tibial and gastrocnemius muscles, between 5 and 7 km/h, indicating that an inflection point of muscle activity during walking is present at about 5 km/h. In our study, the Max speed exceeded 5 km/h in all 3 groups, suggesting that this change in the speed increased the gastrocnemius muscle activity level and led to the persistently high skin temperature.

No heat production resulting from sweating, tremor, or muscle tissue occurs at a room temperature of about 25 °C. Using thermography, the sympathetic function can be examined in the temperature range of 20–30°C, and it has been reported to be useful in detecting abnormal sympathetic function accompanying pain[27]. Kanai et al.[28] randomly treated 69 patients with osteoarthritis of the knee using ultrasonic therapy and observed that the skin temperature at rest significantly rose with the improvement of symptoms. The mechanism of pain relief by skin temperature elevation is due to improvement of blood flow, and it is considered that an increase in muscle blood flow removes pain-inducing substances[29]. Therefore, the Max condition is effective in improving persistent pain after walking.

The H/M ratio increased after walking under the FBW and 20% BWS conditions at the Max speed, and the rate of change in the H/M ratio was significantly greater after walking under the FBW and 20% BWS conditions at the Max speed than under the 40% BWS conditions at the Max speed. These findings support those reported by Yanagisawa et al.[30]: the soleus muscle H/M ratio linearly increased immediately after exercise when the weight on the lower limb increased. M waves are complex waves induced by the excitement of α motor fibers, and they influence the size of H waves. Thus, the H/M ratio is considered to reflect changes in spinal cord α motor activity directly and accurately[31]. H waves decrease for about 60 seconds after muscular activity due to inhibition by antagonist muscle and an increase in input by interneurons, but both H waves and the H/M ratio increase with decreases in inhibition and input[14, 32]. In our study, the reciprocal inhibition during walking may not have influenced these parameters because measurement was performed 5 minutes after the completion of walking. In addition, it was clarified that an increase in the walking speed enhanced the excitability of spinal cord α motoneurons.

It was suggested that lower limb muscle tonus during walking training with BWS at the Max speed can be reduced by increasing the level of support. This condition may also be very safe for the circulatory system as well as effective in elevating the skin temperature compared with that under Normal speed conditions.

The skin temperature rose immediately after walking under the BWS Max conditions, but this was an immediate effect. To generalize the findings, it is necessary to investigate the long-term effect. In addition, to investigate the immediate effect in detail, investigation of kinesiological elements, such as muscle activity and articular movement, is necessary. We used the heart rate as an index of energy consumption, but we did not measure the oxygen intake. In preceding studies[33], the duration of H-reflex depression after exercise was markedly influenced by the level of muscle contraction force. We measured the evoked muscle potential 5 minutes after walking, but the validity of this time setting is unclear.

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