



Original Article

The effects of forward and backward walking according to treadmill inclination in children with cerebral palsy

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Abstract. [Purpose] This study investigated the effects of forward and backward walking using different treadmill incline positions on lower muscle activity in children with cerebral palsy, to provide baseline data for gait training intensity. [Subjects and Methods] Nineteen subjects with cerebral palsy walked forward and backward at a self-selected pace on a treadmill with inclines of 0%, 5%, 10%, and 15%. Activation of the rectus femoris, biceps femoris, tibialis anterior, and lateral gastrocnemius was measured using surface electromyography during the stance phase. [Results] As treadmill incline increased during forward walking, muscle activation of the paralyzed lower limbs did not significantly change. However, as treadmill incline increased during backward walking, rectus femoris activation significantly increased and a significant difference was found between treadmill inclines of 0% and 10%. A comparison of backward and forward walking showed a significant difference in rectus femoris activation at treadmill inclines of 0%, 5%, and 10%. Activation of the tibialis anterior was only significantly higher for backward walking at the 10% gradient. [Conclusion] Backward walking may strengthen the rectus femoris and tibialis anterior in walking training for cerebral palsy. Gradient adjustment of the treadmill can be used to select the intensity of walking training.

Key words: Cerebral palsy, Backward walking, Muscle activation

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INTRODUCTION

Cerebral palsy is a disease of permanent disabilities with permanent problems related to engaging in activities, postural development, and movement resulting from a nonprogressive lesion in an immature brain that occurs before, during, or after birth¹⁾. Therefore, rehabilitation for children with cerebral palsy has traditionally focused on improving the gross motor skills, strengthening of the muscles, and the use of assistive equipment. However, current neurological rehabilitation focuses on motor learning by utilizing the concept of neuroplasticity²⁾. Smiana et al. reported that repetitive gait training was more effective in improving gait speed, stride length, and joint kinematics than traditional physical therapy in children with cerebral palsy³⁾. Traditional treadmill gait training, which is one type of commonly used repetitive gait training, improves motor learning and lower limb muscle strength, activates locomotor control systems, and enables children to experience the habits and task-specific gait behaviors that affect functional ability^{4, 5)}. Among the possible training elements, backward gait training on a treadmill occurs in a direction that is opposite to forward gait training, but is regulated by the same central pattern generator mechanism; therefore, it might be presented as a therapeutic intervention method for improving forward gait ability⁶⁾. Unlike forward gait, backward gait has no heel contact during the early stance phase; consequently, it might minimize stress to the lower limb joints by avoiding rapid weight load during the early phase⁷⁾. In addition, motor units are recruited more effectively⁸⁾, and adequate stress is provided to the lower limb joints, increasing the strength and balance abil-

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ity of muscles near the knee joints⁹). One study, showed that when healthy school-aged children engaged in backward gait, their sense of balance improved¹⁰; moreover, backward gait at the same speed consumed more oxygen, increased metabolic rate, and enhanced cardiovascular function compared to forward gait¹¹). Recent research on children with cerebral palsy showed that backward gait training positively affected children with spastic hemiplegia¹²). While research on backward gait training on a treadmill is ongoing¹³), only a few studies have examined the effects of gait direction and changes in the treadmill gradient in children with cerebral palsy. Therefore, this study aimed to provide basic data to determine variables of gait training intensity on a treadmill by comparatively analyzing forward and backward gait at different treadmill gradients; the effect on muscle activity of the paretic side lower limbs was evaluated during the stance phase.

SUBJECTS AND METHODS

Nineteen subjects diagnosed with spastic cerebral palsy were selected for this study (Table 1). The criteria for selection of the subjects were as follows: Gross Motor Function Classification System (GMFCS) levels I–III; age 10 to 25; Modified Ashworth Scale (MAS) levels 1–2; ability to walk 10 m backward using an assistive gait device; and ability to follow verbal instructions.

The criteria for exclusion are as follows: inability to walk independently walk; neurological or orthopedic surgery related to cerebral palsy within the prior six months; uncontrollable seizures, or visual, auditory, or perception difficulty.

All the subjects understood the purpose of this study and gave written consent before participating, according to the ethical standards of the Helsinki Declaration. Ethical approval was given by the local university or hospital research ethics boards. All the subjects engaged in forward and backward gait at a self-selected pace. The treadmill gradients were 0%, 5%, 10%, and 15%, and the subjects walked for 30 seconds at each gradient. Whenever the gradient changed, the subjects rested for one minute in order to prevent muscle fatigue. In this study, gradient means the percentage of vertical distance against the horizontal distance. For example, a 10% gradient means climbing 10 m while walking 100 m. In order to identify the muscle activity of the lower limbs during the stance phase of forward and backward gait, wireless surface electromyography (EMG) (TeleMyo DTS, Noraxon Inc., USA) was used to collect data.

The electrodes were attached to the rectus femoris, biceps femoris, tibialis anterior, and lateral gastrocnemius, which play an important role in gait. For subjects whose lower limbs and upper and lower extremities were paralyzed, the electrodes were attached to their dominant paretic lower limb. The areas where the electrodes were attached were determined using the Surface Electromyography for the Non-Invasive Assessment of Muscles protocol¹⁴). The electrodes were attached at the middle area of the belly, where the muscles are most activated, through manual muscle testing. The sampling rate of the EMG signals was set at 1,500 Hz. The amplified waveforms were filtered with a band pass filter set at 40–400 Hz and a notch filter set at 60 Hz for removal of noise. All the EMG signals collected in this way were standardized using the root mean square (RMS). In order to obtain average values for the muscle activity of the paretic lower limb during the stance phase, six gait cycle amplitude, whose signal was correctly made in the footswitch while walking for 30 seconds at the angle gradient, was transformed into an effective value, and the obtained average values were comparatively analyzed. Considering that the subjects were children with cerebral palsy, this study selected and used standardized reference voluntary contraction (RVC) values. The reference values of RVC were measured with a standing posture as the standard, and the average values of activity measured during the stance phase while walking on an inclined treadmill were expressed as rates.

Statistical analysis was conducted using SPSS 20.0 for Windows. To identify the difference between forward and backward walking on a treadmill, a paired t-test was used. To evaluate muscle activity according to the four different treadmill inclines, statistical analysis with repeated one-way analysis of variance (ANOVA) was performed, with the Bonferroni correction for post hoc analysis. The significance level was set to $p < 0.05$ for the statistical analysis.

RESULTS

Changes in lower limb EMG signals occurred according to changes in the treadmill gradient during the forward and backward gait stance phase. During the forward gait stance phase, based on the treadmill gradients of 0%, 5%, 10%, and 15%, the lower limb EMG signal (% RVC) was not statistically significantly different for the tested muscles ($p > 0.05$) (Table 2). During the backward gait stance phase, based on gradients of 0%, 5%, 10%, and 15%, the muscle activity of the lower limbs was significantly different only for the rectus femoris ($p < 0.05$), and no significant difference was found for the biceps femoris, tibialis anterior, and lateral gastrocnemius ($p > 0.05$) (Table 3).

The lower limb EMG signals for forward and backward gait, were compared, based on changes in the treadmill gradient. According to the results of the paired t-test comparing the EMG signals for forward and backward gait, the rectus femoris showed a statistically significant difference at 0%, 5%, and 10% ($p < 0.05$), but there was no significant difference at the 15% gradient ($p > 0.05$). However, the backward gait tended to have higher EMG signals than the forward gait. The tibialis anterior activity showed a statistically significant difference at the 10% gradient ($p < 0.05$), but no significant difference was observed at the other gradients; however forward gait tended to exhibit higher EMG signals than backward gait. There was no significant difference between forward and backward gait at all treadmill gradients for the biceps femoris and lateral gastrocnemius ($p > 0.05$).

Table 1. General characteristics of subjects

Measurement	Pre-test
Age (years)	17.4 ± 4.5
Gender (male/female)	12/7
Height (cm)	159.4 ± 8.6
Weight (kg)	52.1 ± 12.2
GMFCS (I/II/III)	(16/0/3)

*p<0.05

Table 2. Comparison of muscle activity between each inclined treadmill during forward walking

Muscle	0%	5%	10%	15%	
FW	RF	235.2 ± 145	293 ± 242.2	317.1 ± 305.4	325.2 ± 314.1
	BF	259.1 ± 128.4	256.9 ± 118.5	261.6 ± 138.9	265.9 ± 143.4
	TA	217.6 ± 106.5	216 ± 97.4	238.1 ± 128.2	231.7 ± 111.4
	LGM	412.8 ± 600.9	290 ± 206.1	314.7 ± 242.5	343.4 ± 315.8

Table 3. Comparison of muscle activity between each inclined treadmill during backward walking

Muscle	0%	5%	10%	15%	
BW	RF	344.5 ± 249.1	386 ± 352.5	436.3 ± 402.3*	509.3 ± 830.6
	BF	254.3 ± 148.4	224.9 ± 107.8	254 ± 128.2	248.4 ± 131.8
	TA	276.3 ± 170.5	289.2 ± 243.4	276.3 ± 170.2	284.4 ± 226.6
	LGM	266.7 ± 131.5	293.2 ± 167.3	282 ± 148.4	279.9 ± 165.7

*p<0.05

DISCUSSION

This study was conducted in order to examine the effect that treadmill gradient and gait direction had on lower limb muscle activity in children with spastic cerebral palsy, and to provide basic data for determining appropriate gait training for these children. No significant difference in lower limb muscle activity was found based on changes in treadmill gradients during the forward gait stance phase; however, muscle activity had a tendency to increase in the rectus femoris, biceps femoris, and tibialis anterior. According to Lay et al., when a person climbs a slope, the moment of force of the hip joint extensor increases, and this increased counterforce of the hip joint extensor increases the muscle activity of the knee joint extensor¹⁵. Previous research has shown that the tibialis anterior had eccentric control of the load during the early stance phase; therefore, the load delivered from the increase in the gradient also increased, and the activity of the tibialis anterior increased¹⁶. The present study also showed a similar trend, but failed to obtain a significant value because the number of subjects in the study sample was small. In backward gait, only activity in the rectus femoris significantly increased based on the increase in the treadmill gradient. Engaging in an early knee flexing exercise during the supporting stage of backward gait is related to the role of weight absorption during the process of supporting the body after landing; therefore, backward gait can increase the strength of the quadriceps femoris muscle while decreasing the load of the knee joints during the stance phase. The present study obtained the same results¹⁷. Accordingly, this could be a therapeutic method for patients with hemiplegia accompanying hyper-extension. Changes in muscle activity according to changes in the gradient mean that the changes in the joint moment that occur in the lower limbs based on increases in the gradient are different; therefore different motor control strategies are needed. For example, as the gradient changes, the moment in each joint changes and the tensile force of the Golgi tendon organ changes; thus, information from the peripheral nerves enters the control system, triggering sufficient muscle activity of the lower limbs for a given task^{15, 18}. Previous studies comparing forward and backward gait have shown that the maximum extension muscle strength and activity tended to increase more after backward than after forward gait training¹⁹. The reason for this is that, during forward gait, the gastrocnemius is the driving force, but during backward gait, the rectus femoris, a knee extensor muscle, acts as the driving force¹⁷. In the present study, less muscle activity occurred in the lateral gastrocnemius during backward than during forward gait for all of gradients, but the activity of the tibialis anterior showed an opposite trend. This is thought to be because during backward gait, the gastrocnemius decreases ankle movement

during the early stance phase, and the tibialis anterior adjusts ankle movement with eccentric contraction²⁰). In addition, the results of the present study are consistent with findings presented in previous research, which found that during backward gait, the gastrocnemius no longer acts as a driving force²¹). Furthermore, as the treadmill gradient increases, the movement of the lower limb joints increases, which requires an increase in lower limb muscle activity. Moreover, a study that compared the biomechanical and physiological advantages of forward and backward gait, reported that the muscle activity in backward gait was higher than in forward gait, and the muscle activity of a longer lower limb was able to achieve higher strength²²). In a study that compared the activity of the quadriceps femoris based on exercise direction with treadmill gradients of 0%, 5%, and 10%, Han reported significant muscle activity differences based on exercise direction, which is consistent with the results of the present study²³).

Based on these results, backward gait training might be proposed as a method to minimize load to the knees and increase muscle strength resulting from isometric and uniaxial contraction of the quadriceps femoris during the stance phase. By increasing the treadmill gradient, it might be possible to adjust gait training to establish an appropriate intensity for children with cerebral palsy. This study had some limitations. First, the number of cerebral palsy children in the sample was small and it is difficult to generalize the results. Second, three-dimensional gait analysis was not performed; therefore, changes in the location of the joints were not known. Future research is necessary to examine joint location and plantar pressure changes in a greater number of spastic cerebral palsy children at different treadmill gradients.

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