

The Effectiveness of the Use of Custom-Made Foot Orthotics on Temporal-Spatial Gait Parameters in Children With Spastic Cerebral Palsy

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Abstract

This study examined the effects of custom-made foot orthotics on the temporal-spatial gait parameters in children with cerebral palsy. Twenty spastic bilateral cerebral palsy (spastic CP) children (11 boys and 9 girls) participated in this study. GAITRite was used to examine the velocity, cadence, step length differential, step length, stride length, stance time, single support time, double support time, base of support, and toe angle while walking with and without foot orthotics. The differences in temporal-spatial parameters were analyzed using paired t-test. The significance level was set at .05. The velocity, cadence, both step lengths, both stride lengths, both bases of support and right toe angle significantly increased when the children with spastic CP with foot orthotics compared to without foot orthotics ($p < .05$). The step length differential between the two extremities, left stance time and left single support time, significantly decreased with foot orthotics ($p < .05$). Right stance time, right single support time, both double support times and left toe angle showed little change ($p > .05$). This study demonstrated that foot orthotics were beneficial for children with spastic CP as a gait assistance tool.

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Key Words: Cerebral palsy; Foot orthotics; Temporal-spatial gait parameters.

Introduction

Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attribute to non-progressive disturbance that occurred in the developing fetal or infant brain (Rosenbaum et al, 2007). Spastic CP, which is the most common form in CP, show a variety of abnormal gaits such as crouch, equinus, and scissor gait (Himmelman et al, 2005). The different gaits are due to musculoskeletal system deformation, limited ranges of motion of joints, inadequate movement between joints resulting from spasticity, or muscle weakness (Gage, 2004). And

weight bearing pressure is concentrated on the fore-foot region; this causes foot deformity and difficulty in the balance and support of the ankle joint (Flett, 2003). Furthermore, the stride and step length are functionally short and their time related elements decrease. Therefore, spastic CP may have difficulty in walking independently at home or in community environments (Pirpiris et al, 2003).

Conservative methods for improving gait in children with spastic CP include physical therapy, orthoses, and gait assistance equipment (Ubhi et al, 2000). Ankle-foot orthosis (AFO) has been utilized to prevent foot and ankle deformation and provide ankle stability for children with CP (Morris, 2002). So nu-

merous studies apply AFOs to children with spastic CP to determine muscle activity or changes in joint angles that occur during walking. However, AFOs have been suggested main orthoses for CP children with an equinus deformity caused by severe spasticity (Radtka et al, 1997). AFOs provide assistance during gait since deformed feet and ankles are limited when AFOs are worn so that stability can be felt. Despite the diverse forms of AFOs, they affect only some muscle activities or changes in joint angles during walking and do not significantly affect functional changes in gait, such as the temporal-spatial variables of gaits (Abel et al, 1998).

Foot orthotics is a medical tool that is used to improve foot functions and prevent or correct foot deformation (Wu, 1990). This is more commonly known as a functional insole or correcting insert by aligning and supporting the feet. When foot orthotics is inserted, pressure on the foot is distributed and the sole contact surfaces are widened. This improves sole sensation and stability, and reduces medial or lateral rotation of the feet (Landorf and Keenan, 2000). Therefore, foot orthotics is applied to diverse cases, ranging from those who have special diseases of the feet to those who need orthopedic management because of leg deformation or leg length difference seen in climbers and athletes (Coughlin et al, 1995; Hawke et al, 2008). Although foot orthotics has many benefits on gait, few studies have been done for children with CP.

Likewise, children with spastic CP without an equinus deformity who have independent walking level may need an assistive device to increase sta-

bility of foot and ankle. In the present study, foot orthotics was used by children with spastic CP to examine the effects of foot orthotics on gait through changes in temporal-spatial gait parameters and using foot orthotics as a gait assistance tool would be applicable to children with CP. The present study also would provide a basic information for application of foot orthotics to children with CP.

Methods

Subjects

Twenty children with spastic CP (11 boys, 9 girls) participated and ranged in age from 5 to 15 years (Table 1). Children were recruited randomly by two physiotherapists who had more than five years of clinical experiences from local pediatric center for rehabilitation in Pohang city. Inclusion criteria were as follows: 1) Spasticity of the children classified into Grade 1 or Grade 2 using the Modified Ashworth Scale (MAS) measurement (Fosang et al, 2003). 2) Children had to be classified as level 1 or level 2 according to the Gross Motor Function Classification System (GMFCS). These individuals were selected because they were limited in travelling long distances or in some environments but still could walk independently (Rosenbaum et al, 2002). 3) Children needed to have a level of cognition that was necessary for understanding instructions (SystemSM WeeFIM, 1998). 4) Children had not undergone surgery or an operation during the past year and for the duration of the study.

Table 1. Characteristics of the subjects

(N=20)

Variable	Mean±SD ^a	Range
Age (yrs)	10.2±3.5	5.0~15.0
Height (cm)	135.2±19.6	103.0~158.0
Weight (kg)	30.1±11.9	14.0~50.0
Foot length (mm)	199.2±40.9	110.0~240.0
Foot width (cm)	10.2±2.2	6.0~14.0
MAS (grade 1/grade 2) ^b	10/10	

^amean±standard deviation, ^bmodified Ashworth scale.

Experimental method

Researcher explained the purpose and meaning of the experiment to the children and their parents. Then informed consent was obtained from patients, and assent was also given by the children. After informed consent had been obtained, measurements were taken of height, weight, foot length, and foot width for the purpose of collecting basic data to prepare for the gait tests. The children with spastic CP stood in front of a GAITRite board, which was 4.5 m long, and then performed at self-selected comfortable speed along the walkway after a command to start was given. That is because the previous study has shown that the self-selected comfortable speed is associated with discrimination of potential for rehabilitation (Bowden et al, 2008). The other reason to use the self-selected speed can be that it is for functional ambulation in patients (Goldi et al, 1996). During the gait test, the children were instructed to walk by themselves without the application of foot orthotics first. This provided a base-line information in comparisons of the other experimental conditions. Data for three walks that were performed well, which was defined as the children not leaving the walkway, were selected and averaged. After taking a rest for five minutes, the children walked on the walkway with foot orthotics and in the same manner as before.



Figure 1. Custom-made foot orthotics.

Measurement tools

Foot orthotics

In the present study, the insoles applied were custom-made foot orthotics that were molded to fit the shapes of individual, and were dispensed to the children. Foot orthotics was made of polyurethane (PU) and equipped with high density repulsive elastic pads, cup soles for supporting the arch, and low elasticity pads and polymer gel that were used to absorb impact on the heels (Figure 1). The foot orthotics was made by alFOOTs¹⁾ using the following identical procedure: 1) Measurement and assessment of the feet, 2) Casting: feet shape molding using Pedilen foam²⁾, 3) Preparation of positive plaster models, 4) Plaster model revision: checking for any compressed region or sensitive region, 5) Shell production: modeling using thermoplastic plastic, 6) Posting and grinding: finishing and alignment adjustment, 7) Covering.

GAITRite system

To examine changes in the temporal-spatial gait parameters, a GAITRite system³⁾ which is an equipment that can sense pressure from the feet during walking, was used to collect data. The GAITRite is an equipment that is useful as a clinical assessment tool because the degree of asymmetry of the lower



Figure 2. GAITRite system.

1) OrthoComTM, alFoods Co., Ltd., Seoul, Korea.
2) Pedilen[®] foams, Otto Bock Health Care, Salt Lake City, U.S.A.
3) GAITRite System, CIR Systems Inc., CA, U.S.A.

extremities can be seen using spatial parameters, such as step length. Lower extremity disorders can be assessed using temporal parameters, such as support time and velocity. After which, gait interventions can be digitized using the equipment (Kressing et al, 2004). The GAITRite is an electronic gait board that is 4.5 m long and .9 m wide (Figure 2). On this board, 13,824 sensors, which are .6 cm in diameter, are vertically arranged along the walking path at intervals of 1.27 cm. This is done so that information on temporal-spatial parameters can be collected from these sensors. Out of the total length of the gait board, a 3.6 m long and .61 m wide area on the center is an active region where the sensors recognize pressure and the loads imposed by the feet of the children during walking are collected at a sampling rate of 90 Hz/sec. The information is sent to the computer through a series of interface cables. The collected information on temporal-spatial parameters was processed using the GAITRite system ver. 3.8 software.

Temporal-spatial gait parameters

The definitions of the temporal-spatial parameters of gait used in the present study are as follows (Kirtley, 2006).

- 1) Velocity: value obtained by dividing the walked distance by the time spent
- 2) Cadence: the number of steps per unit time
- 3) Step length: distance from the heel of a foot to the heel of the other foot
- 4) Stride length: distance from the heel of a foot to the heel of the same foot in the next step
- 5) Stance time: time to support the weight from the time when the heel of a foot is in contact with the ground to the time when the toes are taken off the ground
- 6) Single support time: time during which one leg is in contact with the ground
- 7) Double support time: time during which both legs are in contact with the ground
- 8) Base of support: the step width between the

two feet

- 9) Toe angle: the angle made by the direction of progress and the major axis of the foot

Statistical Analysis

Statistical analysis of collected data were conducted using SPSS ver. 18.0 software. Differences in the temporal-spatial gait parameters of between with and without foot orthotics were compared using paired t-test. The significance level was set at $\alpha=.05$.

Results

Changes in the temporal-spatial gait parameters

Using the GAITRite, the temporal-spatial gait parameters were measured with and without foot orthotics and the measured values were compared. According to the results, the velocity, cadence, left/right step length, left/right stride length, left/right base of support, and right toe angle of gait increased during walking with foot orthotics compared to without foot orthotics ($p<.05$). The step length differential, left stance time and left single support time significantly decreased with foot orthotics ($p<.05$). On the other hand, right stance time, right single support time, left/right double support time and left toe angle showed little change ($p>.05$) (Table 2).

Discussion

In the present study, custom-made foot orthotics that fit an individual's feet were made for children with spastic CP to assist gait and data were obtained during walking with and without foot orthotics using a GAITRite. Walking with self-selected speed on the GAITRite reflected a patient's functional ambulation, although the gait could be influenced by subjective and environmental factors

Table 2. Temporal-spatial gait parameters changes with and without foot orthotics (N=20)

Parameters	Without foot orthotics		With foot orthotics		
		Mean±SD	Mean±SD	t	p
Velocity (cm/sec)		54.34±20.30	62.90±26.35	3.16	<.05
Cadence (steps/min)		100.88±29.43	105.65±28.78	1.60	<.05
Step length differential (cm)		7.55±6.85	4.95±3.74	2.25	<.05
Step length (cm)	R ^a	33.66±13.05	36.24±13.65	2.04	<.05
	L ^b	31.60±10.23	34.84±11.43	2.22	<.05
Stride length (cm)	R	64.77±24.64	71.62±24.65	2.19	<.05
	L	67.27±20.78	71.55±24.10	1.86	.07
Stance time (sec.)	R	.93±.54	.86±.46	1.45	<.05
	L	.93±.55	.84±.44	1.62	<.05
Single support time (sec.)	R	.41±.20	.38±.07	1.17	.12
	L	.42±.21	.35±.06	1.72	<.05
Double support time (sec.)	R	.53±.50	.52±.49	.38	.35
	L	.53±.52	.53±.51	.10	.45
Base of support (cm)	R	8.08±5.25	10.80±5.33	2.31	<.05
	L	7.92±5.21	10.79±5.62	2.39	<.05
Toe angle (°)	R	4.44±10.28	8.29±6.02	2.59	<.05
	L	6.76±10.31	8.54±7.62	1.00	.16

^aright, ^bleft.

(Goldie et al, 1996). The data were analyzed and the following results were obtained.

Based on the comparisons of the measured tempo-spatial gait parameters, the velocity, cadence, both step lengths, both stride lengths, both bases of support and right toe angle of gait significantly increased during walking with foot orthotics compared to without foot orthotics, with $p < .05$ considered statistically significant. Step length differential, left stance time and left single support time significantly decreased. However, right stance time, right single support time, both double support times and left toe angle did not show any statistically significant differences.

The temporal-spatial gait parameters refer to velocity, cadence, and stride length. These three parameters are basic parameters for the assessment of functional gait (Sekiya and Nagasaki, 1998). With regard to the correlation between these parameters, Grieve and Ruth (1966) stated that if one parameter

increased, then other parameters would linearly increase. In the present study, the three parameters increased together so there was a functional improvement of gait. Also velocity and step length are closely related to each other and the increase in velocity can be identified from an increase in step length (Gage and Russman, 1991). Also the primary effect of foot orthotics is a correction or supporting of the foot and ankle. This has secondary effects on all planes through the coupled dynamics of lower extremity. By shifting gait to more normal gait pattern, and positioning joints more functionally, orthotics can change overall gait efficiency as well as correcting ankle and foot kinematics. Gage et al (2009) has also demonstrated that the gait speed increased with improving foot alignments. Buckon et al (2004) revealed that while part of the efficiency improvements could be attributed to improvements in gait pattern, a significant portion was due to an increase in walking velocity. In a study by Eisenhardt

et al (1996), it was reported that when the stability of the feet decreased, a compensation strategy would be used to achieve balance by increase the base of support and support time. But the present study demonstrated that the increase of base of support with foot orthotics. In diplegic CP, motor deficits and spasticity typically produce a walking pattern characterized by poor ankle position and floor contact. The pattern has exaggerated knee flexion, increased hip adduction and internal rotation (Cherng et al, 2007). Therefore in the present study, an increase of base of support may be caused by reduced hip adduction pattern with supporting foot and ankle (Krebs et al, 2002). Also the stance time shortened along with increased velocity or stability (Kirtley et al, 1985). Relationships between speed and the temporal parameters demonstrated that stance duration was stride time multiplied by 71 and double support duration was stride time multiplied by 41. And stance duration was double support time plus 100 divided by 2. These suggest that as speed increases, the double support time along with stance duration decreases but not always the single support time increases (Blanc et al, 1999). Thus, the result of increasing gait speed without double support time suggests that temporal parameters in the present study would be influenced by stability of foot and ankle rather than increase gait speed only. In the present study, the step length differential between the two lower extremities decreased significantly with foot orthotics. This means that the symmetry of the gait improved because, as noted by Dewar and Judge (1980), there was a decrease in step length differential, which is a useful element in assessing the improvement of symmetry among temporal-spatial parameters of gait. In the case of children with spastic CP, as the degree of spasticity is higher, the more internal rotation of the hip joint occurs. This restricts the movement of the knee and ankle joint and causes deviation, which results in in-toeing gait (Inan et al, 2009). This misalignment has a bad influence on femoral anteversion in conjunction with

tibial torsion from foot and ankle conversely (Gage and Russman, 1991). Fortunately, such lever-arm dysfunction is commonly correctable with appropriate orthopedic devices such as AFOs, foot orthotics and inserted wedges. Foot orthotics correct the foot alignment by reducing the excessive knee flexion, hip adduction and hip internal rotation, in turn, play an important role in gait (Gage et al, 2009). Also foot orthotics is advantageous because it provides stability to the subtalar joint through lateral weight distribution to rotate the toe angle laterally (Kakihana et al, 2005). This is because in-toeing is often compensated by an excessive pronation in the subtalar joint, a patellar instability, and a hip internal rotation caused by muscle imbalance in children with spastic CP (Nakajima et al, 2009). Thus, correcting foot and ankle alignment with foot orthotics resulted in an increase of the foot progression angle in the present study. Also among the children with spastic CP of the present study, 9 of 10 MAS level 2 patients with higher degree of spasticity, who also showed larger medial rotation of the right toe angle because they were affected more by spasticity on the right side, showed significant increases in lateral rotation angles after applying foot orthotics.

One of the most general objectives of physical therapists for CP patients is to improve gaits so that they are close to normal gait. To this end they apply diverse orthoses, physical therapy, and gait assistance devices. Waters and Mulroy (1999) presented five elements for approaching normal gaits: stability in stance, clearance in swing, preposition of the foot in terminal swing, adequate step length, and energy conservation. Conditions that are necessary for all these five elements include the balance and stability of the same leg or the other leg that supports the weight during gait and appropriate positions and alignment of the feet.

During body movements, foot orthotics can add balance by increasing the stability of the side that bears the weight by normalizing foot alignment and widening sole contact area (Landorf and Keenan,

2000) According to the results of the present study, foot orthotics could improve gait function since stability, balance, and symmetry were improved through changes in the temporal-spatial gait parameters. Therefore, foot orthotics is useful as a gait assistance tool that can be used by children with spastic CP to improve their gait.

Limitations of the present study include the small number of subjects and the fact that changes in temporal-spatial gait parameters are not sufficient to represent gait analysis. Therefore, future studies should examine diverse aspects of gait, including muscle activity, kinematic and kinetic variables through a larger number of study subjects.

Conclusion

The present study examined the effects of foot orthotics applied to children with spastic CP for whom AFOs had been mostly prescribed. The purpose of this study was to collect basic data and present foot orthotics as a viable gait assistance tool for children with CP. To accomplish this, the effects of foot orthotics was examined through changes in temporal-spatial gait parameters using a GAITRite. According to the results, the velocity, cadence, both step lengths, both stride lengths, both bases of support, and right toe angle of the gait increased during walking with foot orthotics when compared to without foot orthotics, with $p < .05$ being defined as statistically significant. Step length differential, left stance time and left single support time decreased significantly. As such, the researchers determined that foot orthotics positively affects gait and can be used as a gait assistance tool for children with spastic CP.

References

Abel MF, Juhl GA, Vaughan CL, et al. Gait assess-

ment of fixed ankle-foot orthoses in children with spastic diplegia. *Arch Phys Med Rehabil.* 1998;79(2):126-133.

Blanc Y, Balmer C, Landis T, et al. Temporal parameters and patterns of the foot roll over during walking: Normative data for healthy adults. *Gait Posture.* 1999;10(2):97-108.

Bowden MG, Balasubramanian CK, Behrman AL, et al. Validation of a speed-based classification system using quantitative measures of walking performance poststroke. *Neurorehabil Neural Repair.* 2008;22(6):672-675.

Buckon CE, Thomas SS, Jakobson-Huston S, et al. Comparison of three ankle-foot orthosis configurations for children with spastic diplegia. *Dev Med Child Neurol.* 2004;46(9):590-598.

Cherng RJ, Liu CF, Lau TW, et al. Effect of treadmill training with body weight support on gait and gross motor function in children with spastic cerebral palsy. *Am J Phys Med Rehabil.* 2007;86(7):548-555.

Coughlin MJ. Roger A. Mann award. Juvenile hallux valgus: Etiology and treatment. *Foot Ankle Int.* 1995;16(11):682-697.

Dewar ME, Judge G. Temporal asymmetry as a gait quality indicator. *Med Biol Eng Comput.* 1980;18(5):689-693.

Eisenhardt JR, Cook D, Pregler I, et al. Changes in temporal gait characteristics and pressure distribution for bare feet versus various heel heights. *Gait Posture.* 1996;4(4):280-286.

Flett PJ. Rehabilitation of spasticity and related problems in childhood cerebral palsy. *J Paediatr Child Health.* 2003;39(1):6-14.

Fosang AL, Galea MP, McCoy AT, et al. Measures of muscle and joint performance in the lower limb of children with cerebral palsy. *Dev Med Child Neurol.* 2003;45(10):664-670.

Gage JR, Russman BS. *Gait Analysis in Cerebral Palsy.* Cambridge University Press, 1991:101-117.

Gage JR. *The Treatment of Gait Problems in Cerebral Palsy:* Mac Keith Press, 2004:382-397.

- Gage JR, Schwartz MH, Koop SE, et al. The Identification and Treatment of Gait Problems in Cerebral Palsy. Mac Keith Press, 2009:327-348.
- Grieve DW, Gear RJ. The relationships between length of stride, step frequency, time of swing and speed of walking for children and adults. *Ergonomics*. 1966;9(5):379-399.
- Goldie PA, Matyas TA, Evans OM. Deficit and change in gait velocity during rehabilitation after stroke. *Arch Phys Med Rehabil*. 1996;77:1074-1082.
- Hawke F, Burns J, Radford JA, et al. Custom-made foot orthoses for the treatment of foot pain. *Cochrane Database Syst Rev*. 2008;16(3):CD006801.
- Himmelmann K, Hagberg G, Beckung E, et al. The changing panorama of cerebral palsy in Sweden. IX. Prevalence and origin in the birth year period 1995-1998. *Acta Paediatr*. 2005;94(3):287-294.
- Inan M, Altintas F, Duru I. The evaluation and management of rotational deformity in cerebral palsy. *Acta Orthop Traumatol Turc*. 2009;43(2):106-112.
- Kakahana W, Akai M, Nakazawa K, et al. Effects of laterally wedged insoles on knee and subtalar joint moments. *Arch Phys Med Rehabil*. 2005;86(7):1465-1471.
- Kirtley C, Whittle MW, Jefferson RJ. Influence of walking speed on gait parameters. *J Biomed Eng*. 1985;7(4):282-288.
- Kirtley C. *Clinical Gait Analysis: Theory and Practice*. Churchill Livingstone, 2006:15-37.
- Krebs DE, Goldvasser D, Lockert JD, et al. Is base of support greater in unsteady gait? *Phys Ther*. 2002;82(2):138-147.
- Kressig RW, Gregor RJ, Oliver A, et al. Temporal and spatial features of gait in older adults transitioning to frailty. *Gait Posture*. 2004;20(1):30-35.
- Landorf KB, Keenan AM. Efficacy of foot orthoses. What does the literature tell us? *J Am Podiatr Med Assoc*. 2000;90(3):149-158.
- Morris C. A review of the efficacy of lower limb orthoses used for cerebral palsy. *Dev Med Child Neurol*. 2002;44(3):205-211.
- Nakajima K, Kakihana W, Nakagawa T, et al. Addition of an arch support improves the biomechanical effect of a laterally wedged insole. *Gait Posture*. 2009;29(2):208-213.
- Pirpiris M, Trivett A, Baker R, et al. Femoral derotation osteotomy in spastic diplegia. Proximal or distal? *J Bone Joint Surg Br*. 2003;85(2):265-272.
- Radtka SA, Skinner SR, Dixon DM, et al. A comparison of gait with solid, dynamic, and no ankle-foot orthoses in children with spastic cerebral palsy. *Phys Ther*. 1997;77(4):395-409.
- Rosenbaum P, Paneth N, Leviton A, et al. A report: The definition and classification of cerebral palsy April 2006. *Dev Med Child Neurol Suppl*. 2007;109:8-14.
- Rosenbaum PL, Walter SD, Hanna SE, et al. Prognosis for gross motor function in cerebral palsy: Creation of motor development curves. *JAMA*. 2002;288(11):1357-1363.
- Sekiya N, Nagasaki H. Reproducibility of the walking patterns of normal young adults: test-retest reliability of the walk ratio (step-length/step-rate). *Gait Posture*. 1998;7(3):225-227.
- Ubhi T, Bhakta BB, Ives HL, et al. Randomised double blind placebo controlled trial of the effect of botulinum toxin on walking in cerebral palsy. *Arch Dis Child*. 2000;83(6):481-487.
- Waters RL, Mulroy S. The energy expenditure of normal and pathologic gait. *Gait Posture*. 1999;9(3):207-231.
- WeeFIM System clinical guide: Version 5.01. Buffalo, NY: Uniform Data System for Medical Rehabilitation. 1998.
- Wu KK. *Foot Orthoses: Principles and clinical applications*. Williams & Wilkins, 1990:353-357.
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