Iranian Rehabilitation Journal, Vol. 13, Issue 4, Winter 2015

Original Article

The Effect of Modified Floor Reaction Ankle Foot Orthoses on Walking Abilities in Children with Cerebral Palsy

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Objectives: This study was designed to evaluate the effectiveness of a modified Floor Reaction Ankle Foot Orthosis (FRAFO) design on gait performance in children with cerebral palsy.

Methods: Eight children with cerebral palsy wore a modified FRAFO bilaterally for six weeks. Motion analysis was used to assess the immediate effectiveness of the orthosis on improving gait and also following six weeks of gradual orthosis use. Primary outcome measures were walking speed, cadence and stride length, plus hip, knee and ankle joint ranges of motion. A paired T test was used to compare primary outcome measures.

Results: Cadence, stride length and walking speed were all significantly increased when the children wore the modified FRAFO (P = <0.001for speed and stride length and p=0.005 for cadence). The children demonstrated a statistically significant reduction in ankle ROM when using the modified FRAFO. The mean knee joint ROM was increased from 36.5±13.32 degrees when walking with an orthosis at baseline to 43.5±1.19 degrees when walking with an orthosis after six weeks of use. Children with the modified FRAFO also had decreased hip flexion angle at initial contact and an extension shift during stance phase following 6 weeks of orthosis use compared to when initially donning it.

Discussion: Children with cerebral palsy can benefit from an improvement in gait parameters when walking with a modified FRAFO.

Key words: walking, modified FRAFO, cerebral palsy, temporal spatial parameters, kinematics, orthoses

Submitted: 18 October 2015
Accepted: 24 November 2015

Introduction

Cerebral palsy (CP) is one of the most common causes of abnormal gait in children (1). CP has a prevalence of 1.5 to 2.5 per 1000 children in the USA (2). Diplegia is the most common type of CP with an incidence rate of 32% (3). Diplegic gait is characterized as being a low-speed gait due to weakness and spasticity in the lower limbs (4). Walking is an important function (5), and pathologies such as CP can have a detrimental effect on the functional performance of the individual (6). Improved walking ability is a key purpose for the treatment of gait abnormalities in children with CP (7). A wide range of orthoses such as rigid ankle foot orthoses (AFOs) (8) , dynamic AFOs (9), floor reaction AFOs (10) and lycra garments (11) have all been shown to improve walking in these children. Limitation of normal tibial rotation over the weight-bearing foot is a disadvantage of wearing a solid AFO during ambulation, as this causes decreased ankle dorsiflexion and early heel rise during stance phase if it is not tuned correctly (12,13). Hinged AFOs with plantar flexion-stop ankle joints have been recommended by clinicians to decrease plantar flexion during gait (14), but these types of AFO have been shown to not significantly affect the knee position during walking in CP children(15). Floor reaction AFOs (FRAFOs) are normally of the solid type with an anterior trim line at the ankle and therefore fix the ankle in an appropriate position as dictated by the clinician to optimize gait parameters. They are prescribed to reduce excessive knee flexion during stance phase of gait in children with CP. Lucareli et al (10) demonstrated that FRAFOs provide externally applied forces to produced less knee flexion by altering the ground reaction force

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(GRF) vector in the sagittal plane, and do so by preventing ankle dorsiflexion motion. Rogozinski in evaluation of the effect of a FRAFO in children with CP (n=27) also demonstrated that it produced reduced knee flexion during stance phase (16). Owen et al. detailed an algorithm to improve lower limb kinematics in children with CP by optimizing the sagittal plane angle of the ankle in an AFO and for the designing, aligning and tuning of AFO-footwear combinations (17). Bahramizadeh et al. introduced a new design of a modified FRAFO (18), which allowed gradual adjustment of the fixed ankle joint position in order to potentially alter the knee flexion experienced during crouch gait. The evaluation of this orthosis on postural control in children with spastic cerebral palsy demonstrated that it may improve the alignment of the knee, but does not improve postural control in children with CP.

Despite these known advantages in walking with FRAFOs in situ, more evidence is needed to show the influence of FRAFOs on walking ability in children with CP over longer periods. Therefore, the aim of this study was to evaluate the influence of a modified FRAFO on walking ability in children with CP over a period of six weeks.

Methods

Eight children with CP aged between 5 and 12 years (mean 9.6 ± 3.84 years) participated in this study. Their demographics are shown in table (1).

Table1. Demographics of the children who participated in this study

Participant	Gender	Age (Year)	Weight (kg)	Height (m)	BMI (kg/m^2)	GMFCS
1	Female	12	28.9	1.22	19.41	3
2	Male	11	23.2	1.18	16.66	3
3	Male	13	46.8	1.27	29.01	3
4	Male	7	21.3	1.16	15.82	1
5	Female	6	15.2	1.03	14.32	2
6	Female	8	20.7	1.06	18.42	2
7	Female	8	19.8	1.09	16.66	1
8	Male	10	22.4	1.12	17.85	2
Mean± SD		9.37±2.503	24.78±9.675	1.14±0.081	18.51±4.522	

* *BMI= Body mass index, GMFCS= Gross motor function classification system score*

Children were included in this study if they suffered from CP and could walk unsupported over a distance of at least 5m. They were excluded if they had history of using an orthosis previously, or having had received Botulinum toxin injections or orthopedic surgery in the 12 months prior to the study. All the children received their regular rehabilitation during the period of this study, which was continuously delivered during the period of orthosis use by an experienced therapist. The therapy provided included sagittal plane stretching of the structures affecting the ankle and knee. In addition, balance and standing and walking exercises with and without the orthosis being worn were performed. Each child was evaluated at a similar time of the day by the same assessor to reduce any order effects at the follow up evaluation.

The modified FRAFOs (figure 1), were custom moulded from a negative cast using 3mm copolymer polypropylene. The proximal part of the brace extended to 2cm below the fibular head and its footplate extended past the distal aspect of the toes (20). A Vicon Digital Motion Capture System with a frequency of 100 HZ (Oxford Metrics, UK) was used for capturing the locations of the reflective markers that were placed on the orthosis. Retro-reflective markers were utilised in the lower extremity and the pelvis based on the conventional gait model. Markers were placed bilaterally over the position of the anterior superior iliac spines (ASIS), over the sacrum, greater trochanter, the middle of the thigh, the lateral condyle of the femur, the middle of leg, plus on the calcaneus and the first and fifth metatarsals. Markers were placed on the outer-surface of the orthotic ankle joints to mimic the position of the malleoli as closely as possible, as it was not possible to adhere them directly onto the skin in this case. The calcaneal marker was placed to delineate the position of the calcaneal tuberosity by adhering it to the AFO thermoplastic superstructure.

Gait parameter data were calculated under three test conditions; walking without the orthosis at baseline and also with the orthosis in situ to measure its immediate effect, as well as after six weeks of gradual orthosis use (Figure 2). The children were asked to eventually wear the orthosis six hours a day. However, to enable gradual adjustment to wearing an orthosis, parents were asked to ensure that the orthosis was only initially worn for one hour daily and to increase this to six hours per day within the first two weeks of the intervention period. During the gait analysis testing, all the children practiced walking along a 6m long walkway whilst wearing the orthosis to habituate them to the test protocol, and then asked to walk five times along the walkway during data acquisition. The resulting data were calculated by averaging data from both left and right sides for the five walks with the orthosis. Orthoses were used bilaterally by all subjects.

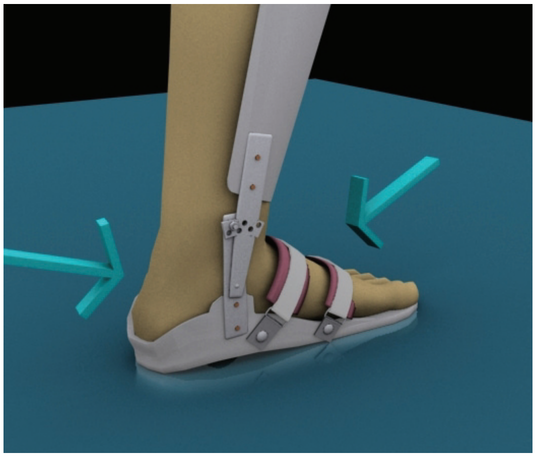


Fig 1. Views of the modified FRAFO introduced by Bahramizadeh et al (17).

The assessments were performed in the Biomechanics Laboratory of the Department of Ergonomy at the University of social welfare and rehabilitation sciences. The parents and children who volunteered for the study and were allowed to exit from the study at any time. Prior to the study, the parents read and approved a statement acknowledging informed consent. The Ethics Committee of the University of social welfare and rehabilitation sciences approved this study. The differences for each test parameter were calculated based on the means and SDs at baseline and at the six week post- intervention point. The Kolmogorov Smirnov test was use to examine the normality of the variables. The results indicated a normal distribution of the data. A paired T test was used to compare data obtained at baseline when walking both with and without orthoses to measure their immediate effect, and also at six weeks post-intervention when wearing the orthoses. SPSS statistical analysis software (Version16) was used for data analysis. The level of significance was set at 0.05.

Results

AFO parameters - The mean ankle angle set within the AFO (AAAFO) during the walking trials for all the subjects was 7 degrees of dorsiflexion with a range of between 6-10 degrees (table 2).

Table 2. Mean ankle angle within the FRAFOs

Subject number	AAAFO (degrees of dorsiflexion)
Subject 1	6
Subject 2	6
Subject 3	8
Subject 4	6
Subject 5	6
Subject 6	8
Subject 7	10
Subject 8	6
Mean	7

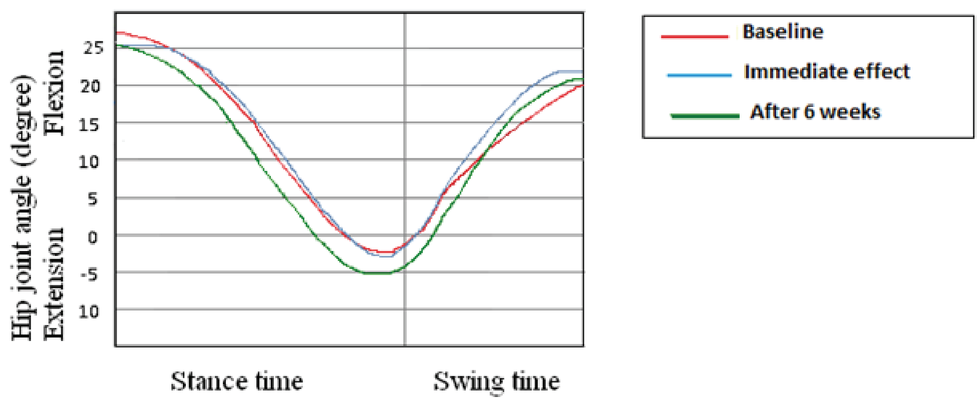
Tempero-distance parameters- The mean walking speed, stride length and cadence at baseline (without an orthosis) and when initially wearing FRAFOs, plus after having worn the orthoses for 6 weeks are shown in Table (3). Stride length and walking speed were both significantly increased when the children wore the modified FRAFOs for the six-week period when compared to its initial donning (P=<0.001 for walking speed, P=0.017 for stride length).

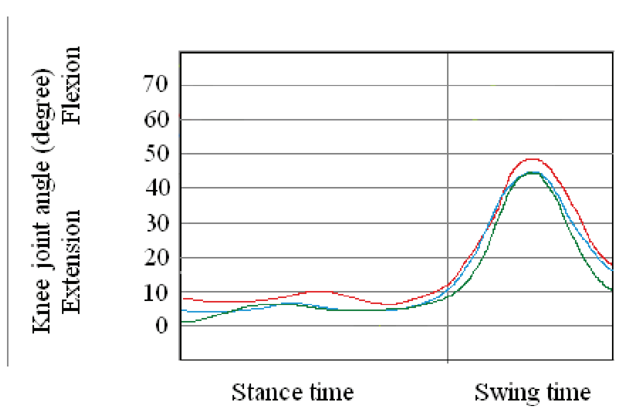
Table 3. Mean and standard deviation of walking speed, stride length and cadence in children with CP at baseline (with and without an orthosis), plus following 6 weeks of gradual increase of orthosis use.

Test Parameters	Without an orthosis (at baseline)	With an orthosis (at baseline)	With an orthosis (after 6 weeks)	P 1	P2	P3
Speed(m/s)	0.31 ± 0.03	0.42±0.029	0.45 ±0.02	<0.001	<0.001	<0.001
Stride length (m)	41.25 ± 2.60	49.87±3.04	50.62± 3.20	<0.001	<0.001	0.197
Cadence(steps/min)	44.50 ± 4.37	51.37±4.56	53.25 ± 4.27	0.026	0.005	0.054

P1: Comparison between baseline (no orthosis) and the immediate effect of orthosis use at baseline
P2: Comparison between baseline (no orthosis) and with an orthosis after 6 weeks of use
P3: Comparison between orthosis provision at baseline and after 6 weeks of orthosis use

Range of motion (ROM) parameters - The children demonstrated statistically significant reductions in ankle ROM when using the modified FRAFO after the six-week habituation period compared to wearing it at baseline. Push-off in the pre-swing phase was limited by the orthosis resulting in reduced plantar flexion which reduced the overall ankle ROM (p=0.075). Mean dorsiflexion was also significantly reduced (table 4). After having worn a modified FRAFO for 6 weeks, knee flexion at initial contact was decreased compared to when initially worn. The mean knee joint ROM was increased from 36.5±13.32 degrees when walking with an orthosis at baseline to 43.5±1.19 degrees when walking with an orthosis after six weeks of use. This increase occurred because the knee was significantly more maximally extended during stance after six weeks of orthosis use (6 deg., p=0.001). Children with the modified FRAFO also had decreased hip flexion angle at initial contact and an extension shift during stance phase following 6 weeks of orthosis use compared to when initially donning it. The mean sagittal plane flexion/extension plots for the hip, knee and ankle are shown in figure (2).





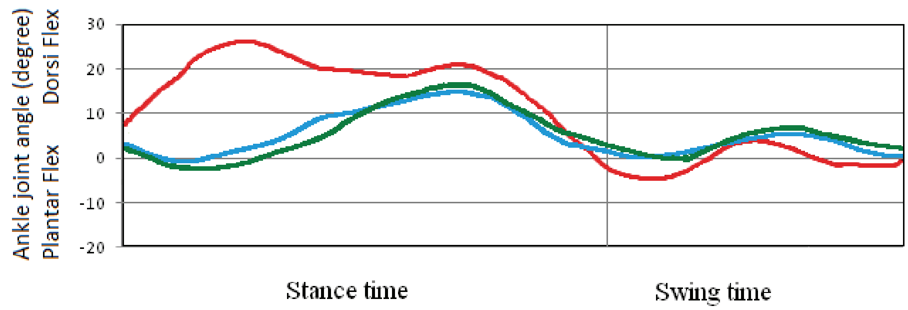


Fig 2. Sagittal plane motion of hip, knee and ankle joints in the study population.

Table 4. Sagittal plane lower limb kinetics results

Joint	Test Parameters	Without orthosis (Base line)	With orthosis (Immediate effect)	With orthosis (After 6 weeks)	P 1	P2	P3
Hip joint	Total ROM(deg)	29.37± 0.51	28.25±1.28	30.5± 1.19	0.038	0.065	0.023
	Maximum flexion(deg)	27±1.06	25.62±1.06	25±0.75	0.004	<0.001	0.250
	Maximum extension(deg)	2.5±0.75	2.62±0.51	5.5±0.92	0.685	<0.001	<0.001
Knee joint	Total ROM(deg)	39± 1.30	36.5±13.23	43.5± 1.19	<0.001	0.161	0.599
	Maximum extension (deg)	8±0.75	4.5±0.92	2±0.75	<0.001	<0.001	0.001
	Maximum flexion (deg)	47±1.19	45.62±1.18	45.5±0.75	0.036	<0.001	0.649
Ankle joint	Total ROM of joint(deg)	30.37± 1.40	16.12±1.72	14.5±1.19	<0.001	<0.001	0.075
	Maximum plantarflexion (deg)	5.25±.03	2.75±0.70	1.62±0.74	<0.001	<0.001	0.026
	Maximum dorsiflexion (deg)	25.12±1.24	13.37±1.59	11.62±3.66	<0.001	<0.001	0.307

P1: Comparison between baseline and immediate effect of orthoses using
P2: Comparison between baseline and with orthoses after 6 weeks using
P3: Comparison between immediate effect of orthoses using and with orthoses after 6 weeks using

Discussion

As the aim of this study was to evaluate the effect of a modified FRAFO on the temporal spatial parameters and kinematics of walking in children with CP, the mean ROM in all three lower limb joints was reduced when walking with the FRAFOs in situ. Motion patterns of the hip and ankle joints when walking with the orthosis were similar to that of normal walking. The FRAFO restricted ankle joint movement as expected during ambulation, and also reduced the equinous (plantarflexed) position at initial contact. Based on these findings, the function of this orthosis could improve the child's push off, and so could have indirectly affected the knee and hip joint movements. This could also be increased by the increased lever-arm of the orthosis in foot region. The modified FRAFO resulted in a better foot prepositioning for initial contact and control of ankle equines during stance and swing, although previous studies have not reported this with this type of orthosis previously(21-24). In addition, despite the limited structure of AFOs and DAFOs (25), the movement patterns of the hip joint may be changed by alteration of knee and ankle position in children with CP (3, 26). The results of this study demonstrated that a FRAFO can reduce maximum knee flexion angle in children with CP during walking by influencing it to be relatively extended, and also induce a more extended knee during mid stance. Plantar flexion/ knee extension imbalance causes a crouched position in these patients because of spasticity of some lower limb muscles, and lengthening of mono-articular muscles. The GRF passes behind knee joint in these children during stance phase due to reduced muscle power being available in these children, and they are not able to correct this position. Similar results were reported in a previous study with a FRAFO(10, 19). Additional time of orthosis wear to facilitate more adaptation may improve the knee joint ROM or pattern beyond the six week time frame chosen for this study. In this study we used an orthosis without reinforcement at the ankle, and we propose that this effect should be evaluated in further studies.

Children suffering from CP have a significantly shorter stride length than normal. The FRAFO significantly increased stride length and cadence and therefore confirmed the results from previous studies (4, 27). The effective role of a FRAFO in controlling ankle equinous, and a reduction in knee flexion may prove useful in prevention of muscle weakness in these patients. The fact that the ankle position could be altered meant that a more bespoke orthosis could be utilized to improve the motion of the more proximal lower limb joints of the children with CP included in this study. The alterations to hip and knee motion were small and can be accounted for by the motion analysis technique utilised. The small sample size, lack of kinetic evaluation of walking parameters and postural evaluation of these children with the FRAFO are limitations of this study. Therefore, future research would be beneficial with these included.

Conclusion

Previous studies on children with CP have reported that improvements in walking could be produced through the application of a modified FRAFO (18). The findings of this study demonstrated that a modified FRAFO was an effective method for addressing gait parameters and improving hip, knee, ankle joint ROMs in the children studied following a six-week habituation period, and gave the authors encouragement to analyse the longer-term effects of such an orthosis on the gait of children with crouch-type gait.

Funding - This material was based on work supported by the Deputy of Research and Technology of the University of social welfare and rehabilitation sciences (grant number 92.801.1.21369).

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