Effects of Hinged Ankle Foot Orthoses on the EMG of Children with Spastic Hemiplegia during a Step-up Task

Amber Davey, Marie Blackmore, Beverly Jepson & Geoff Strauss

This research was undertaken by Amber Davey in partial fulfilment of the Honours course in the Bachelor of Science (Physiotherapy) at Curtin University of Technology. We gratefully acknowledge the assistance of the children who participated, their parents, and the therapists from The Centre for Cerebral Palsy in helping to recruit participants. We also thank Paul Davies for analysing the EMG data.

ABSTRACT

Purpose: To determine the effect of a hinged ankle foot orthosis (HAFO) on muscle activity and temporal features of a step-up.

Methods: Four children with spastic hemiplegic cerebral palsy (who habitually wore HAFOs) completed a step-up whilst barefoot and when wearing their HAFO. The step-up was performed with both their unaffected and affected leg leading. Electromyography (EMG) timing and amplitude and time taken to complete the task were recorded.

Results: Whilst wearing the HAFO: the amplitude, duration and timing of EMG was reduced in both legs; time taken to complete the task was affected; the percentage of total time in hemiplegic single limb stance was decreased, whilst double limb stance was increased.

Conclusion: The prescription of HAFOs should involve ongoing evaluation of the effect of the AFO on both gait and functional tasks relevant to the individual. Interventions complementing the use of HAFOs should include strengthening exercises for both lower limbs.

INTRODUCTION

"Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation" [1] and is the result of damage to the developing brain. The impairments associated with CP are primarily motor but may include sensory, cognitive, behavioural, perceptual and communicative. The condition is non-progressive, yet it may change as the impairments interact with motor development.

Spastic type CP is characterised by muscle spasticity and imbalance, and accounts for 85-95% of all cases. Spasticity is defined as a velocity dependent increase in muscle tone[1] due to tonic stretch reflex hyperactivity. Hemiplegia (unilateral involvement) affects 30-40 % of all cases of CP [2]. Children with spastic hemiplegic CP have a pathological gait pattern, primarily due to muscle spasticity and weakness. Other gross motor tasks are also affected, but less is known about the impact of spasticity on these.

In the lower limbs, spasticity is usually present in the triceps surae, hamstrings, hip flexors and adductors [3]. Although the degree to which gait is altered by these impairments is highly individualised, there are characteristics which are typically present [3]. Tightness in the spastic triceps surae musculature combined with weakness in tibialis anterior (dorsiflexor) creates plantarflexion at the ankle (known as equinus). At initial contact this results in a flat foot, toe or forefoot first contact instead of the normal heel strike[3]. Foot clearance in swing is also reduced. Another primary impairment of gait for the child with spastic hemiplegic CP is poor stability in stance on their affected limb. Additionally, stride length is decreased and walking velocity and energy efficiency are reduced [3].

An ankle foot orthosis (AFO) is a mechanical device which may be prescribed to assist the normalisation of gait. A hinged AFO (HAFO) encompasses the posterior surface of the lower leg from just below the knee to the tips of the toes, covering the malleoli (see Figure 1). It is fitted to the limb with straps across the anterior aspect. It aims to prevent abnormal motion at the ankle without completely immobilising the joint. It is blocked at or near plantargrade so that plantarflexion is prohibited, whilst ankle dorsiflexion is freely permitted through the hinge. It is widely reported that HAFOs significantly improve ankle kinematics in children with hemiplegia[4]. However there is little consensus regarding the effect of AFOs on more proximal joints and results vary between the hemiplegic and diplegic CP populations. Although AFOs do not encompass the knee joint, some changes in knee excursion are exhibited and may be compensatory [5] or attributable to the action of the biarticular gastrocnemius [3].

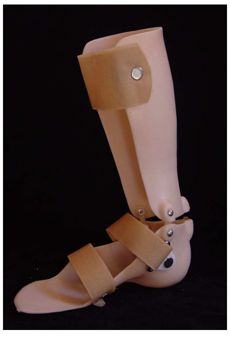


Figure 1: Hinged Ankle Foot Orthosis

AFOs also improve the temporal parameters of gait [4]. Their effect is well documented for children with spastic diplegic CP. However limited evidence exists for the hemiplegic population. Studies which investigated a mixed population of children with hemiplegic or diplegic CP, found that whilst wearing the HAFO, stride length is increased when compared to barefoot walking; yet children with diplegic CP show no significant improvement when compared to shoes[4].

As muscle spasticity is the primary impairment for these children, the effect of the HAFO on muscle activity is of interest to clinicians. However few studies have investigated possible changes in muscle activity and timing (measured via EMG) with the use of AFOs in children with CP. Those that do exist focus only on gait, and when studying the hemiplegic population measure only the affected leg.

Children with hemiplegic CP wearing the HAFO have shown decreased tibialis anterior muscle activity in early to mid swing compared with the barefoot condition [6]. The authors suggested that differences in muscle activity in children with CP may be explained not only by the presence of spasticity in the muscles themselves, but also by attempts to compensate for abnormal gait patterns. This finding requires further investigation, as the possibility of AFOs affecting both spastic and pathologically normal muscles is yet to be determined. This study also found knee extensor and hamstring muscle activation of the affected leg was corrected towards normal, whilst the HAFO was being worn. These results are corroborated by the findings of Romkes et al [7] of decreased activation of the hamstrings and quadriceps during the swing phase of gait. Both studies measured the influence of the HAFO on only the affected leg of children with mild CP.

Looking beyond gait tasks, children with CP typically show delayed or limited gross motor development [1]. A concern of clinicians prescribing AFOs is the effect they may have on a child's functional ability including their involvement in activities of daily living, many of which require balance. Some studies have analysed the contribution of AFOs to gross motor skill achievement in children with CP, but it is rarely the focus of research. As such, limited evidence exists suggesting AFOs may benefit gross motor function, and conversely that wearing an AFO may indeed make some balance tasks more difficult. The long-term effect of habitual AFO use on motor development is yet to be studied.

Using the Gross Motor Functional Measure (GMFM) to evaluate ability shows that children with diplegic CP benefit from the use of HAFOs during functional tasks [8, 9], yet the hemiplegic population does not. Buckon et al [10] reported no significant differences in GMFM scores when children with hemiplegic CP wore the HAFO, compared to either barefoot or wearing shoes alone. Evidently, children with hemiplegia do not gain additional gross motor function by utilising AFOs.

Buckon et al [9] found that despite no improvement in the GMFM scores for children with hemiplegic CP, there was a significant increase in Gross Motor Performance Measure scores, suggesting that their quality of performance increased but they did not gain additional function when wearing the HAFO, compared to the barefoot condition.

Researchers fail to agree on whether HAFOs benefit individual functional tasks for children with diplegic CP and their effect on the hemiplegic population remains largely unexplored. Park et al [11] and Wilson et al [12] found HAFOs were beneficial during a sit-to-stand transfer, in a young spastic diplegic population (aged 2-6 years). Total time taken to complete the task was reduced and both kinematic and kinetic measurements trended towards normal. Meanwhile, in a similar population it was found that children who were able to complete a sit-to-stand transfer barefoot, within 1 standard deviation of normal time, were less efficient when wearing the HAFO[12, 13]. This suggests that children with milder presentations of CP may find the HAFO detrimental to functional tasks.

Kott and Held [14] found HAFOs to be ineffective in upright functional skills in an older (aged 5-19) predominantly diplegic population. One study investigated a population of children with hemiplegic CP [15] and found stair locomotion was not impeded by the HAFO in children who could reciprocally stair climb barefoot. When wearing the HAFO, many children were even able to keep up with their peers without CP when climbing stairs.

No studies have investigated the effect of HAFOs on muscle activity during functional tasks, in children with spastic hemiplegic CP. Nor have they measured the effect of the HAFO on muscle activity in the unaffected leg.

In the present study, a step-up task is used (movement of both feet, one at a time, from ground level to a step). The study aimed to determine the effect of the HAFO, during a step-up task: on total time and single limb stance and double limb stance ratios; on the amplitude and timing of EMG in the gastrocnemius, tibialis anterior, hamstrings and quadriceps muscles; and on the contraction duration of these muscles in both the affected and unaffected legs of children with spastic hemiplegic CP.

METHODS

Design

The study involved four case studies. The independent variable was the AFO condition: HAFO (with shoes) versus barefoot. The dependent variables included muscle activity (magnitude and timing of gastrocnemius, tibialis anterior, hamstrings and quadriceps measured via EMG) and temporal characteristics of the step-up (total time to complete the task and single limb support to double limb support ratio).

Participants

Children with cerebral palsy receiving therapy from The Centre for Cerebral Palsy, Western Australia who appeared to meet the selection criteria were identified from the Centre's database. Identified families were mailed an invitation, information sheet and consent form, and contacted the researchers to enrol in the study.

Inclusion criteria for participation were: a diagnosis of spastic hemiplegic CP; current use of a hinged ankle foot orthosis unilaterally; aged between 5 and 18 years and the ability to understand instructions. Functional homogeneity of the group was controlled as each child was also required to be able to step-up a 15cm high step independently. The exclusion criterion was any lower limb surgical procedure in the previous 12 months.

Instrumentation

The equipment used included the Motion Analysis System (VICON: Los Angeles, CA, USA), an AMT-8 EMG capture system (BORTEC: Calgary, Alberta, CANADA), 610mm x 610mm and 1220mm x 610mm force platforms (AMTI: Mass, USA), 1.5cm diameter retro-reflective spherical markers (VICON: Los Angeles, CA, USA), 3cm diameter self-adhesive monitoring electrodes with soft cloth tape and solid gel (3M Red Dot: Minneapolis, MN, USA) a Model G200 goniometer (Whitehall Manufacturing: CA, USA), a non-slip 15 centimetre high step and the participant's own HAFO.

Procedures

All activities were performed in the School of Physiotherapy's Movement Analysis Laboratory at Curtin University of Technology, under the supervision of a fourth year Bachelor of Science (Physiotherapy) Honours student. Each participant attended one two hour session.

An explanation of the procedures was given and written consent was gained from the participant's parents, who were present throughout testing. Data collected for the purpose of participant description included a short parent interview to determine the surgical, Botox-A and orthotic history of each child. Spasticity of the lower limb muscles was measured by the Modified Ashworth and the Modified Tardieu Scales[16]. A Gross Motor Functional Classification System (GMFCS) level [17] and Gage gait classification [3] was also recorded.

Spherical retro-reflective markers required for kinematic data collection were placed according to standard principles [18]. Optical capture occurred at one hundred frames per second (100Hz), using a 10 camera system.

Disposable self adhesive electrodes were positioned following the SENIAM guidelines for collection of EMG data [19] (at 1000Hz). Prior to application, the identified area of skin was cleaned with an alcohol wipe.

Two electrodes were placed over the muscle bellies of gastrocnemius, tibialis anterior, vastus lateralis and semitendinosis, following palpation during resisted contraction. The electrodes were attached to a portable, battery powered unit, housed in a small backpack, worn by the child and EMG was captured (simultaneously to motion analysis) for the identified muscles of both legs.

Participants were randomly allocated the barefoot or AFO condition first. Randomisation occurred immediately prior to the trials (i.e. after participant descriptor measures had been taken). Each child wore their own HAFO provided by the Centre for Cerebral Palsy, custom made and fitted by the same orthotist. The children wore their regular footwear with the HAFO.

Each step-up trial consisted of a step up onto a 15 centimetre block. The child was requested to step up with one foot at a time, at a self-selected speed. The preferred foot was noted. The child was then required to complete the step-up, leading with the non-preferred foot. Three complete, representative trials were collected on both legs for each participant in each condition. (i.e. total of twelve trials collected).

The step up was divided into 7 phases – preparation, leading flexion, leading extension, weight shift, trailing flexion, trailing extension and stabilisation (see Table 1). Single limb stance includes the flexion/extension phases for either leg, whilst double limb stance is comprised of preparation, weight shift and stabilisation.

Table 1: Phases of the step-up

Phase	Start position	End position
Preparation	Both feet in contact with ground, child stationary	Last point of ground contact of leading foot (recognised by force platform)
Leading flexion	Leading foot off	Leading leg maximum hip flexion
Leading extension	Maximum hip flexion	First foot contact on step
Weight shift	Step contact	Last point of ground contact of trailing foot (recognised by force platform)
Trailing flexion	Trailing foot off	Trailing leg maximum hip flexion
Trailing extension	Maximum hip flexion	Trailing leg first foot contact on step
Stabilisation	Step contact	Both feet rested on top of step, child stationary

An analysis of each child's performance was provided to their principal physiotherapist at The Centre for Cerebral Palsy with consent from the parent/caregiver.

Data reduction

The median of the three trials for each condition (chosen by median time taken to complete the task) was used for data analysis. Time was analysed as total time (sec) and normalised to 100 percent. EMG data was demeaned and rectified to Root Mean Square, filtered through a 4^{th} order Butterworth lowpass filter with a cut-off frequency of 8Hz. A muscle was considered to be active when its activity exceeded 4 standard deviations above the mean EMG amplitude during quiet double limb stance, in each condition.

RESULTS

Four children participated in the study. Participants ranged in age from 6 to 14 years (mean = 11.31, SD = 3.01) and had been wearing HAFOs for 4 to 9 years (mean = 6.25, SD = 2.22). The participants' functional level were classified as GMFCS level I (n = 4). No child had received Botox during the last 2 years. Participant descriptors are summarised in Table 2.

Table 2: Participant characteristics

Participant	A	B	C	D
Age (yrs)	11.5	14.1	6.1	10.3
Sex	Male	Female	Female	Male
HAFO (yrs)	7.5	7	5	6
GMFCS*	1	1	1	1
Gage†	II	III	II	II
Tone (affected leg) ‡				
Gastrocnemius	R_1 10pF	R_1 10pF	R_1 5dF	R_1 0dF
	R_2 20dF	R_2 10dF	R_2 20dF	R_2 5dF
	MAS§ 1	MAS 2	MAS 1+	MAS 1
Hamstrings	R_1 50F	R_1 85F	R_1 60F	nil
	R_2 30F	R_2 20F	R_2 10F	
	MAS 1	MAS 2	MAS 1+	MAS 0

* Gross Motor Functional Classification Scale

† Gage Classification of Gait

‡ R_1 = onset of first resistance to rapid passive movement,
R_2 = end of range

§ MAS = Modified Ashworth Scale

All children preferred to perform the step-up with their unaffected leg leading. Therefore the results are presented with the affected leg trailing during the step up task. The non-preferred method of stepping up with the hemiplegic leg leading is described last, and only briefly, as the aim of this study was to analyse a functional everyday task which these children would choose to undertake.

Time

Table 3 shows the total time taken to complete the step-up and the percentage of total time for each phase, when each child was barefoot and wearing their HAFO. Two children took longer to complete the task when wearing the HAFO whilst the other two took longer barefoot. This increased total time was largely due to longer preparatory phases in both cases (Participants 2 and 4). An increased preparation phase accompanied by a decreased weight shift duration (measured as a percentage of total time) was common to 3 participants. Participant 1 spent double the percentage of time in preparation when in the HAFO, yet spent half as much time (in seconds) in the weight shift phase. Thus weight shift was completed by 54% of total time in both conditions. Similarly, Participant 4 spent 39% of total time whilst wearing the HAFO in the preparation phase (compared to just 4% whilst barefoot), yet the stabilisation phase commenced at a similar percent of total time in both the AFO and barefoot conditions (84% and 81% respectively).

Table 3: Time Taken to Complete Step-up

Participant 1:

	Time (s)		Percent of total		Cumulative percent	
	Barefoot	HAFO	Barefoot	HAFO	Barefoot	HAFO
Preparation	0.21	0.35	10.29	20.23	10.29	20.23
Lead Flexion	0.31	0.26	15.20	15.03	25.49	35.26
Lead Extension	0.24	0.15	11.76	8.67	37.25	43.93
Weight Shift	0.34	0.17	16.67	9.83	53.92	53.76
Trail Flexion	0.37	0.35	18.14	20.23	72.06	73.99
Trail Extension	0.17	0.12	8.33	6.94	80.39	80.92
Stabilisation	0.40	0.33	19.61	19.08	100.00	100.00
TOTAL	2.04	1.73	100.00	100.00		

Participant 2:

	Time (s)		Percent of total		Cumulative percent	
	Barefoot	HAFO	Barefoot	HAFO	Barefoot	HAFO
Preparation	1.02	1.6	26.34	34.04	26.34	34.04
Lead Flexion	0.33	0.29	8.53	6.17	34.87	40.21
Lead Extension	0.18	0.16	4.65	3.40	39.52	43.62
Weight Shift	0.99	0.68	25.59	14.47	65.11	58.09
Trail Flexion	0.42	0.56	10.86	11.91	75.96	70.00
Trail Extension	0.24	0.19	6.20	4.04	82.17	74.04
Stabilisation	0.69	1.22	17.83	25.96	100.00	100.00
TOTAL	3.87	4.7	100.00	100.00		

TABLE 3 (cont): Time Taken to Complete Step-up

Participant 3:

	Time (s)		Percent of total		Cumulative percent	
	Barefoot	HAFO	Barefoot	HAFO	Barefoot	HAFO
Preparation	1.25	0.839	47.35	36.34	47.35	36.34
Lead Flexion	0.41	0.31	15.53	13.43	62.88	49.76
Lead Extension	0.20	0.21	7.58	9.09	70.45	58.86
Weight Shift	0.16	0.17	6.06	7.36	76.52	66.22
Trail Flexion	0.27	0.31	10.23	13.43	86.74	79.64
Trail Extension	0.16	0.12	6.06	5.20	92.80	84.84
Stabilisation	0.19	0.35	7.20	15.16	100.00	100.00
TOTAL	2.64	2.31	100.00	100.00		

Participant 4:

	Time (s)		Percent of total		Cumulative percent	
	Barefoot	HAFO	Barefoot	HAFO	Barefoot	HAFO
Preparation	0.07	1.28	4.24	39.14	4.24	39.14
Lead Flexion	0.26	0.31	15.76	9.48	20.00	48.62
Lead Extension	0.31	0.29	18.79	8.87	38.79	57.49
Weight Shift	0.20	0.16	12.12	4.89	50.91	62.39
Trail Flexion	0.34	0.52	20.61	15.90	71.52	78.29
Trail Extension	0.15	0.18	9.09	5.50	80.61	83.79
Stabilisation	0.32	0.53	19.39	16.21	100.00	100.00
TOTAL	1.65	3.27	100.00	100.00		

Time (s) in single limb stance (on the affected and unaffected leg) and percentage of total time for both single and double limb stance periods are summarised in Table 4. All participants spent a reduced percent of total time in affected single limb stance when wearing the HAFO, whilst the total double limb stance percentage was increased in 3 participants.

Table 4: Single and Double Limb Stance Time

Participant 1:

	Time (s)		Percent of total	
	Barefoot	AFO	Barefoot	AFO
Affected SLS*	0.55	0.41	26.96	23.70
Unaffected SLS	0.54	0.47	26.47	27.17
Total SLS	1.09	0.88	53.43	50.87
Total Time	2.04	1.73	100.00	100.00

Participant 2:

	Time (s)		Percent of total	
	Barefoot	AFO	Barefoot	AFO
Affected SLS	0.51	0.45	13.18	9.57
Unaffected SLS	0.66	0.75	17.06	15.96
Total SLS	1.17	1.20	30.24	25.53
Total Time	3.87	4.70	100.00	100.00

Participant 3:

	Time (s)		Percent of total	
	Barefoot	AFO	Barefoot	AFO
Affected SLS	0.61	0.52	23.12	22.52
Unaffected SLS	0.43	0.43	16.29	18.62
Total SLS	1.04	0.95	39.39	41.14
Total Time	2.64	2.31	100.00	100.00

Participant 4:

	Time (s)		Percent of total	
	Barefoot	AFO	Barefoot	AFO
Affected SLS	0.57	0.60	34.55	18.35
Unaffected SLS	0.49	0.70	29.70	21.41
Total SLS	1.06	1.30	64.24	39.76
Total Time	1.65	3.27	100.00	100.00

Peak EMG

Peak EMG and the time (in seconds and as a percent of total time) at which it occurred are summarised in Table 5, for each child in both conditions. Whilst wearing the HAFO, 13 of the 16 affected muscles displayed reduced peak EMG values, the most consistent of which was tibialis anterior (n=4). This peak EMG amplitude occurred in the same or earlier phase during the step-up in 12 of the 16 affected muscles. Similar results were seen in the unaffected leg: reduced peak EMG amplitude and earlier onset of peak EMG (in 10 and 14 of the 16 unaffected muscles respectively), when the AFO was worn on the affected side.

Table 5: Peak Electromyography (EMG) and Time of Occurrence

Participant 1:

	Peak EMG (x 10^{-3})		Percent of total time		Phase	
	Barefoot	AFO*	Barefoot	AFO	Barefoot	AFO
Leading gastrocnemius	0.224	0.276	48.34	63.93	Weight Shift	Trail Flexion
Leading tibialis anterior	0.618	0.714	43.56	44.97	Weight Shift	Weight Shift
Leading hamstrings	0.370	0.368	12.00	21.33	Lead Flexion	Lead Extension
Leading quadriceps	0.903	0.644	71.27	48.73	Trail Flexion	Weight Shift
Trailing gastrocnemius	0.338	0.327	48.39	45.55	Weight Shift	Weight Shift
Trailing tibialis anterior	0.257	0.056	58.24	45.90	Trail Flexion	Weight Shift
Trailing hamstring	0.385	0.468	53.76	55.95	Weight Shift	Trail Flexion
Trailing quadriceps	0.351	0.486	75.56	47.40	Trail Extension	Weight Shift

Participant 2:

	Peak EMG (x 10^{-3})		Percent of total time		Phase	
	Barefoot	AFO	Barefoot	AFO	Barefoot	AFO
Leading gastrocnemius	0.485	.539	35.59	32.04	Lead Extension	Preparation
Leading tibialis anterior	0.848	.457	44.40	33.13	Weight Shift	Preparation
Leading hamstrings	1.097	1.230	1.99	33.36	Preparation	Preparation
Leading quadriceps	2.458	2.217	43.96	36.30	Weight Shift	Lead Flexion
Trailing gastrocnemius	0.101	0.365	51.67	14.70	Weight Shift	Preparation
Trailing tibialis anterior	1.091	0.123	1.99	19.36	Preparation	Preparation
Trailing hamstring	1.030	0.224	1.99	21.94	Preparation	Preparation
Trailing quadriceps	1.151	0.251	1.99	21.34	Preparation	Preparation

TABLE 5 (cont): Peak Electromyography (EMG) and Time of Occurrence

Participant 3:

	Peak EMG (x 10^{-3})		Percent of total time		Phase	
	Barefoot	AFO	Barefoot	AFO	Barefoot	AFO
Leading gastrocnemius	0.096	0.075	46.86	29.10	Preparation	Prep
Leading tibialis anterior	0.252	0.207	74.62	49.20	Weight Shift	Lead Flexion
Leading hamstrings	0.069	0.097	50.34	35.25	Lead Flexion	Preparation
Leading quadriceps	0.131	0.140	74.66	62.49	Weight Shift	Weight Shift
Trailing gastrocnemius	0.328	0.248	70.57	59.33	Weight Shift	Weight Shift
Trailing tibialis anterior	0.177	0.144	46.59	26.55	Preparation	Preparation
Trailing hamstring	0.127	0.089	62.54	65.61	Lead Flexion	Weight Shift
Trailing quadriceps	0.042	0.034	56.74	84.84	Lead Flexion	Trail Extension

Participant 4:

	Peak EMG (x 10^{-3})		Percent of total time		Phase	
	Barefoot	AFO	Barefoot	AFO	Barefoot	AFO
Leading gastrocnemius	0.162	0.005	43.52	23.64	Weight Shift	Preparation
Leading tibialis anterior	1.011	0.004	41.94	1.99	Weight Shift	Preparation
Leading hamstrings	0.145	0.002	2.79	2.39	Preparation	Preparation
Leading quadriceps	0.467	0.002	49.03	4.59	Weight Shift	Preparation
Trailing gastrocnemius	0.254	0.002	42.06	4.19	Weight Shift	Preparation
Trailing tibialis anterior	0.236	0.002	3.21	4.16	Preparation	Preparation
Trailing hamstring	0.100	0.002	79.33	4.25	Trail Extension	Preparation
Trailing quadriceps	0.267	0.005	40.55	62.97	Weight Shift	Trail Flexion

*Ankle foot orthosis

Muscle contraction duration

Figure 2 represents all muscles undertaking the same activity, as trailing leg during the step-up. This has been chosen as it is the preferred pattern of movement for children with hemiplegic CP. Contraction duration (measured as a percent of total time) and muscle activity timing are depicted. Due to technical difficulties during data collection, complete EMG data is only available for participants 1 and 3. Whilst wearing the HAFO Participant 1 had a reduced duration of muscle contraction in the affected gastrocnemius, tibialis anterior and quadriceps muscles; muscle contraction duration was also reduced in the unaffected leg in these same muscles, whilst the HAFO was worn. Participant 3 had reduced contraction durations of their affected tibialis anterior and quadriceps, whilst the contraction durations in their unaffected leg were reduced in tibialis anterior and hamstring muscles.

Figure 2: Affected v Unaffected Trailing Leg (AFO and Barefoot)

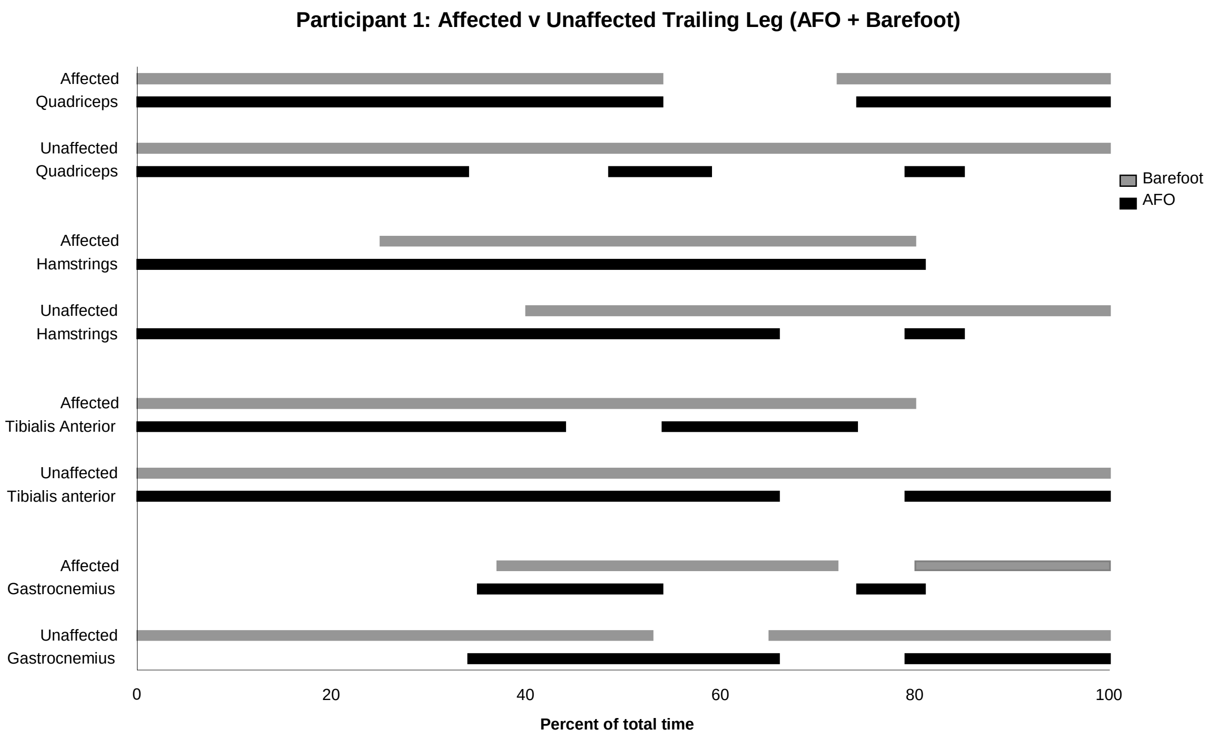
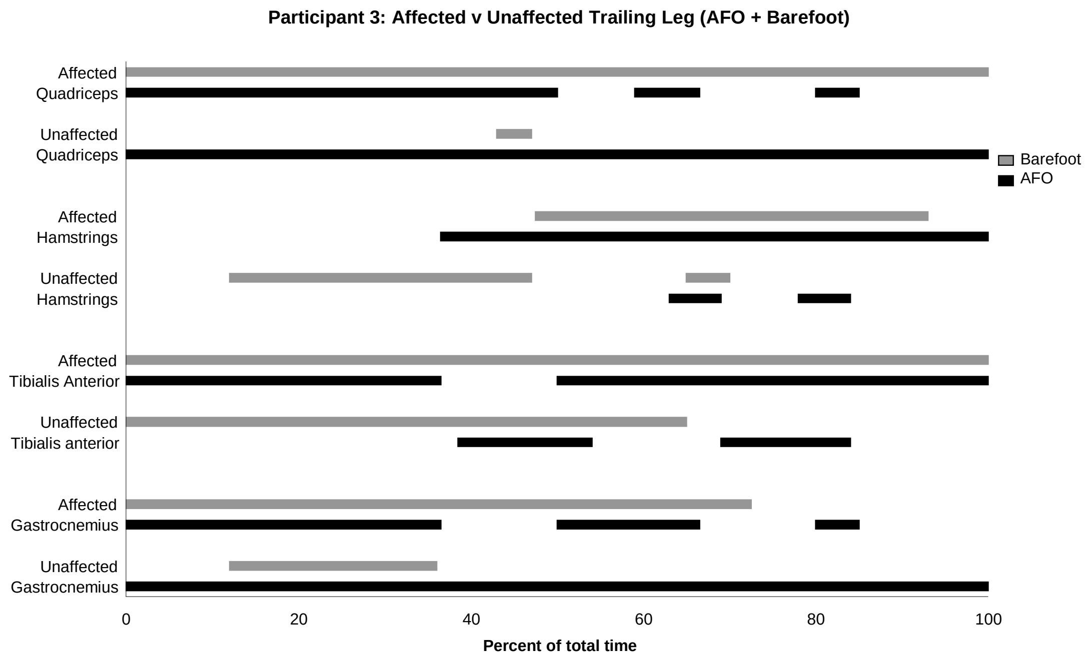


Figure 2 (cont): Affected v Unaffected Trailing Leg (AFO and Barefoot)



Muscle activity timing

Both participants had altered timing (periods when the muscle was active) in all muscles, in both the affected and unaffected legs in both conditions (see Figure 2).

Muscle co-activation was defined as phases when both the agonist and antagonist within a muscle couple (ie gastrocnemius and tibialis anterior or hamstring and quadriceps) were active simultaneously. Both participants showed reduced co-activation in their affected tibialis anterior and gastrocnemius whilst wearing the HAFO, compared to barefoot. Participant 3 also had reduced co-activation in the affected quadriceps and hamstrings couple when wearing the HAFO. However, whilst wearing the HAFO, the results for the unaffected leg varied - Participant 1 had reduced co-activation for both muscle couples, whilst Participant 3 had increased.

Non-preferred step-up

As previously mentioned, all children preferred to step-up leading with their unaffected leg. However, for the purposes of testing, the children were also required to step-up leading with their affected (and non-preferred) leg, in both the AFO and barefoot condition. When stepping up barefoot, with their affected leg leading, there was an increased peak EMG in both the affected and unaffected legs (in 27 out of a possible 32 instances). Evidently, the children were forced to increase the muscle contraction amplitude in order to complete this task successfully.

DISCUSSION

This study has found the HAFO affects time taken and muscle activity of children with spastic hemiplegic CP during a step-up task.

Time

Haideri et al [13] found that children who were able to sit-to-stand within 1 standard deviation of normal whilst barefoot, took longer to complete the task when wearing the HAFO. With few results and without normal data, the present study cannot confirm this same trend, though the child with the most mild presentation of CP (Participant 4) had an increased total time whilst wearing the HAFO.

All children spent less time in single limb stance on their affected leg when wearing the HAFO. In similar populations, studies on gait have found single limb stance time increases[20] or is unchanged[7] when children wear an AFO, compared to barefoot. A number of reasons could account for the reduced time observed in this study. Whilst wearing the HAFO, proprioception is altered (compared to barefoot), ankle strategies (which are used to maintain balance in this age group) may be inhibited by the AFO and other compensatory mechanisms (eg toe clawing) are no longer able to be utilised for balance. Whilst these are also true for gait, the periods of single limb stance in a step-up may be more demanding than those in gait. During single limb stance in the step-up, the child's centre of mass shifts superiorly, as well as forwards, providing additional challenge to balance. There is also little forward momentum during a step-up, thus single limb stance must be more controlled. Further research investigating the effect of HAFOs on single limb stance is required.

Peak EMG

Previous studies have found that children with hemiplegic CP wearing HAFOs have reduced tibialis anterior peak EMG amplitude, in their affected leg during gait [6, 7]. This study confirms this is also true during a step-up task. Whilst wearing the HAFO, the child is not able to plantarflex past 90 degrees at the ankle. Tibialis anterior is no longer required to work against the spastic gastrocnemius to achieve plantargrade.

Both the affected and unaffected legs displayed reduced peak EMG when the HAFO was worn. If a similarly reduced workload exists during gait, it may explain some of the reduced energy cost of walking with HAFOs, compared to barefoot gait[4].

Whilst stepping up barefoot, with their affected leg leading (ie in the non-preferred pattern), peak EMG amplitude was increased. This heightened workload may be harnessed as a simple strengthening exercise, to challenge the muscles in both the affected and unaffected legs.

Contraction duration

The contraction duration was reduced in both affected and unaffected lower limb muscles, when the children were wearing HAFOs, most consistently in tibialis anterior. As equinus is now inhibited, tibialis anterior is no longer required to be active against the spastic gastrocnemius to achieve plantargrade. Thus tibialis anterior is able to exert more volitional control as a dorsiflexor, which has also been found during perturbed balance[21].

Timing of muscle activity

Muscle co-activity is increased in children with CP compared to age-matched peers[21]. Spasticity reduces the child's ability to selectively move, thus co-activation in the affected leg is used to achieve the desired outcome, and may overflow into the unaffected leg. The unaffected leg may also exhibit co-activity in an attempt to improve stability and compensate for the positioning of the affected leg[5]. Whilst wearing the HAFO, co-activity was reduced in the tibialis anterior and gastrocnemius coupling, of the affected leg, in both participants. Additionally, Participant 1 had reduced co-activation in all muscles of the unaffected leg, in this condition. Reduced co-activity may represent a pattern more similar to children without CP, though further study is required to confirm this.

A study investigating the effect of AFOs on perturbed balance found that children aged 3.5 to 15 years had an established pattern of muscle recruitment, which was basically unchanged by wearing an AFO[21]. Participant 1 has a similar pattern of recruitment within each muscle, evident visually in the affected and unaffected muscles whilst wearing the HAFO (see Figure 2). This pattern is not as apparent in Participant 3, who at 6 years old may have less established patterns of recruitment and may be less experienced with this task.

When wearing the HAFO, both participants recruited their hamstrings during affected leg single limb stance, which was earlier compared to barefoot. During perturbed bilateral standing, Burtner et al[21] found no change in the recruitment of the hamstring muscle. Thus the altered recruitment may be due to the increased requirements of dynamic single leg stance.

Clinical implications

The prescription of a HAFO must be based on ongoing evaluation of its effect on gait and the functional tasks pertinent to the individual. Whilst AFOs are known to benefit gait, they are regularly worn throughout the day when the child undertakes many other gross motor tasks. The clinician must evaluate the benefits of the AFO, but also be aware of any less desirable effects. By acknowledging any such disadvantages, the clinician is able to prescribe a complementary intervention program. Specifically, where the AFO inhibits muscles eg tibialis anterior and gastrocnemius, specific strengthening exercises should be prescribed. And in the child whose single limb balance is affected by the HAFO, the clinician may choose balance activities to be performed whilst wearing the HAFO, in addition to barefoot interventions.

Hell-vocke et al [6] suggested that pathological patterns of muscle activity in the affected leg are not only due to muscle spasticity, but are also compensations for abnormal positioning. The results of the unaffected leg in the present study support this theory, as there is little or no spasticity in this leg, yet muscle activity was altered by wearing a HAFO on the opposite limb.

Limitations and future research

The findings of this study cannot be generalised to all children with CP. The participants were few in number and technical difficulties further reduced some results. The participants comprised a specific group - children with spastic hemiplegic CP with GMFCS level 1. Additionally, despite attempting to control for functional differences, there were vast functional abilities evident. One child competed in mainstream sport, whilst another required standby assistance when required to step-up with their affected leg leading. Thus, clinicians should utilise outcomes from the child most similar in function, by consulting the participant descriptors. Future research should endeavour to include participants with similar functional abilities[22] and use classifications (eg GMFCS) as well as clinical measures (eg Modified Ashworth Scale) to describe individual participants. Thus the reader is assisted in recognising the abilities of participants and is able to appropriately transfer research outcomes to the clinic.

Methodological inconsistencies within research may make outcomes difficult to transfer to the clinical environment. There is no recognised standard for data reduction or for determining when a muscle is considered active, in this population. The debate regarding the necessity for EMG normalisation in participants with spasticity is also unresolved. Additionally, collected data may be compromised by the presence of the AFO eg non-uniform pressure on the gastrocnemius electrode, between the AFO and barefoot conditions, may affect accuracy. Standard guidelines are required to create consistency and ensure future studies are easily comparable.

Previous studies have compared the effects of AFOs to either barefoot or to wearing shoes[4]. However, the functional significance of wearing shoes alone should be considered – these children tend to wear their AFO with shoes or be barefoot. Thus the present study chose to analyse the more functional barefoot condition.

The step-up task has not previously been studied and no data is available for children without pathology. Therefore it can be difficult to interpret whether the effect of the HAFO is towards 'normal' or not. Though comparisons are able to be made to the unaffected leg, it is recognised that this pattern may not be the same as in the child without pathology.

Future research should continue to investigate the effects of AFOs on functional tasks other than gait. More investigations assessing muscle activity (in both lower limbs of children with hemiplegic CP) are also required. Specifically, the effect of the HAFO on the preparation and weight shift phases and foot clearance during a step up should be evaluated, as well as the effect on single limb stance. One study[14] found no significant difference in single limb stance (assessed during the Pediatric Balance Scale) in a heterogeneous population wearing a number of different

AFOs, compared to barefoot. However, further studies which investigate muscle activity in a more homogenous group would be beneficial.

CONCLUSION

The prescription of HAFOs should involve ongoing evaluation of the effect of the AFO on both gait and functional tasks relevant to the individual. Interventions complementing the use of HAFOs in children with spastic hemiplegic cerebral palsy should include strengthening exercises for both lower limbs.

REFERENCES

1. Rosenbaum, P., et al., *A report: the definition and classification of cerebral palsy April 2006.* Dev Med Child Neurol Supp, 2007. **109**: p. 8-14.
2. Stanley, F., E. Blair, and E. Alberman, *Cerebral Palsies: Epidemiology and causal pathways: Clinics in Developmental Medicine No 151*. 2000, London MacKeith Press.
3. Winters, T.F., Jr., J.R. Gage, and R. Hicks, *Gait patterns in spastic hemiplegia in children and young adults.* J Bone Joint Surg Am, 1987. **69**(3): p. 437-41.
4. Morris, C., *A review of the efficacy of lower-limb orthoses used for cerebral palsy.* Dev Med Child Neurol, 2002. **44**(3): p. 205-11.
5. Patikas, D., S. Wolf, and L. Doderlein, *Electromyographic evaluation of the sound and involved side during gait of spastic hemiplegic children with cerebral palsy.* Eur J Neurol, 2005. **12**(9): p. 691-9.
6. Hell-vocke, A., J. Romkes, and R. Brunner, *EMG analysis of leg muscles in hemiplegic children with and without hinged ankle-foot orthoses.* J Bone Joint Surg, 2003. **85**(B:SUPP III): p. 276.
7. Romkes, J., A. Hell, and R. Brunner, *Changes in muscle activity in children with hemiplegic cerebral palsy while walking with and without ankle-foot orthoses.* Gait Posture, 2006. **24**(4): p. 467-74.
8. Bjornson, K., et al., *The effect of dynamic ankle foot orthoses on function in children with cerebral palsy.* J Pediatr Orthop, 2006. **26**(6): p. 773-6.
9. Buckon, C.E., et al., *Comparison of three ankle-foot orthosis configurations for children with spastic diplegia.* Dev Med Child Neurol, 2004. **46**(9): p. 590-8.
10. Buckon, C.E., et al., *Comparison of three ankle-foot orthosis configurations for children with spastic hemiplegia.* Dev Med Child Neurol, 2001. **43**(6): p. 371-8.
11. Park, E., et al., *The effect of hinged ankle-foot orthoses on sit-to-stand transfer in children with spastic cerebral palsy.* Arch Phys Med Rehabil, 2004. **85**(12): p. 2053-7.
12. Wilson, H., et al., *Ankle-Foot Orthoses for Pre-ambulatory Children with Spastic Diplegia.* J Pediatr Orthop, 1997. **17**(3): p. 370-376.

13. Haideri, N., et al., *The Effects of Solid and Articulating Ankle Foot Orthoses During Sit-to-Stand in Young Children with Spastic Diplegia.* Gait Posture, 1995. **3**(2): p. 98.
14. Kott, K. and H. Held, *Effects of orthoses on upright functional skills of children and adolescents with cerebral palsy.* Pediatr Phys Ther, 2002. **14**: p. 199-207.
15. Sienko Thomas, S., et al., *Stair locomotion in children with spastic hemiplegia: the impact of three different ankle foot orthosis (AFOs) configurations.* Gait Posture, 2002. **16**(2): p. 180-7.
16. Morris, S., *Ashworth and Tardieu Scales: Their Clinical Relevance for Measuring Spasticity in Adult and Paediatric Neurological Populations.* Phys Ther, 2002. **7**(1): p. 53-62.
17. Oeffinger, D., et al., *Gross Motor Function Classification System and outcome tools for assessing ambulatory cerebral palsy: a multicenter study.* Dev Med Child Neurol, 2004. **46**(5): p. 311-9.
18. Davis, R., et al., *A gait analysis data collection and reduction technique.* Hum Mov Sci, 1991. **10**(5): p. 575-587.
19. Hermans, H., et al., *Development of recommendations for SEMG sensors and sensor placement procedures.* J Electromyogr Kinesiol, 2000. **10**(5): p. 361-363.
20. Balaban, B., et al., *The effect of hinged ankle-foot orthosis on gait and energy expenditure in spastic hemiplegic cerebral palsy.* Disabil Rehabil, 2007. **29**(2): p. 139-44.
21. Burtner, P.A., M.H. Woollacott, and C. Qualls, *Stance balance control with orthoses in a group of children with spastic cerebral palsy.* Dev Med Child Neurol, 1999. **41**(11): p. 748-57.
22. Figueiredo, E., et al., *Efficacy of Ankle-Foot Orthoses on Gait of Children with Cerebral Palsy: Systematic Review of Literature.* Pediatr Phys Ther, 2008. **20**: p. 207-223.