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Full length article

## Full length foot orthoses have an immediate treatment effect and modify gait of children with idiopathic toe walking

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### ABSTRACT

**Background:** There remains a substantial lack of evidence to support the use of foot orthoses as a conservative treatment option for idiopathic toe walking (ITW). Encouraging heel contact during gait is one of the primary goals of most interventions in paediatric ITW.

**Research Question:** Does the combined treatment of high-top boots and orthoses increase the number of heel contacts during gait and change spatio-temporal gait parameters?

**Methods:** This within subject designed randomised controlled trial recruited fifteen children diagnosed with ITW (n = 10 males). They were fitted with bilateral custom made rigid contoured carbon fibre foot orthoses placed inside high-top boots. To analyze the effect of this treatment, heel contacts and spatio-temporal parameters measured by an 8.3 m Gaitrite® mat were compared to barefoot walking and shod walking.

**Results:** An immediate increase in heel contact (p = 0.021) was observed in the combined treatment only. Gait changes included a large increase in stride time in the combined treatment condition compared to barefoot walking (p = 0.006). This was associated with a decrease in the percentage of swing phase in the gait cycle (p < 0.010), an increase in stance phase (p < 0.010) and an increase in double support time (p < 0.001).

**Significance:** These results suggest the hardness and thickness of the shoe and stiffness of the orthosis midsole may lead to improved local dynamic stability and foot position awareness with increased sensory feedback provided through the entire length of the foot. Further research is indicated to validate this treatment option on long term outcomes in this population group.

### 1. Introduction

Toe walking is a common pattern observed in young children learning to walk. Children are diagnosed with idiopathic toe walking when they have no pathological diagnosis, and are otherwise considered healthy. These children continue to demonstrate an absence of heel strike during the initial contact phase of gait. Idiopathic toe walking (ITW) is considered a diagnosis of exclusion after the age of three years, with little understood about the pathophysiology of this condition [1–3]. Children diagnosed with ITW can often appear to normalize their gait when they have sufficient active dorsiflexion range for walking [4].

Persistence of ITW has been linked to decreased ankle range of motion and ankle joint stiffness [5]. Treatment methods for ITW have predominantly been conservative to maintain calf length, and include

passive stretching, serial casting and Botulinum toxin injections [3]. Where a severe contracture develops, surgical intervention may be required [6,7]. Suggestions that the gains with conservative treatment regressed on average after two years of treatment have been made in a recent systematic review [3]. However surgical management appears to maintain ankle dorsiflexion range of motion up to three years post-surgery [6]. There appears to be no one treatment that has demonstrated long term success in treating ITW gait.

The ability to maintain passive ankle range of motion through childhood in children with ITW is unknown. Conservative management to date, has not included long-term foot orthoses prescription. There has been the suggestion that using a foot orthosis prior to the prescription of an ankle foot orthosis (AFO) may be beneficial in maintaining heel contact in the short term over and above treatment with only footwear [8]. An ITW management protocol by the Cincinnati

**Abbreviations:** ITW, idiopathic toe walking; WBL, weightbearing lunge; AFO, articulated foot orthosis

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Children's Hospital recommends articulated AFOs as the preferred conservative option for children with sufficient calf length [9]. While this treatment protocol is freely available online and recommends a conservative and pragmatic treatment approach based on evidence, there is limited information on how it was developed.

Another management approach is to combine full length rigid contoured carbon foot orthoses with a high-top boot with stiff soles. This treatment is prescribed within our clinics (authors JM and CW) for children diagnosed with ITW who have at least 10° of non-weight bearing passive dorsiflexion range at the gastrocnemius and soleus muscles. This combined treatment is initiated as early as possible and continued as an on-going management plan while calf length is maintained. The clinically observed improvement in gait and the on-going adherence to the treatment provides anecdotal evidence of the treatments efficacy. However, no research has been conducted to determine how this intervention affects gait. Therefore, the aim of this study was to determine the difference between barefoot, preferred footwear and combined treatment of footwear and orthoses on heel contact, spatio-temporal parameters of gait in children diagnosed with ITW.

## 2. Method

### 2.1. Design

This study was a within subject design randomised controlled trial as per a published study protocol [10]. Prospective trial registration was completed with the Australian New Zealand Clinical Trial Registry: ACTRN12612000975897. All parents provided written consent and children assented to participation. This research was approved by the Human Research Ethics Committee of Monash Health (12102B).

### 2.2. Participants and setting

The children were recruited from the Victorian Paediatric Rehabilitation Service Toe Walking Clinic, Melbourne, Australia. Children aged between 4 and 10 years diagnosed with ITW during a multidisciplinary assessment by a medical specialist, physical therapist and podiatrist, with a minimum of 15° of ankle range of motion as measured with the straight leg position of the weight bearing lunge test [11] were included in this study.

Children were ineligible to participate if they were diagnosed with a medical condition known to cause toe walking gait or had previously been treated for ITW with surgical Achilles tendon lengthening, Botulinum toxin-A, serial casting or had previous treatment with full length orthoses within the past 12 months.

### 2.3. Measurements

The age, gender, height and weight were recorded for all participating children. Gait measures were recorded on the GaitRite® (CIR Systems Inc. Havertown, PA, USA), an 8.3 m long electronic walkway system. This system has excellent reliability in recording heel strike and spatio-temporal gait measures in children [12].

The primary outcome measure was bilateral heel strike. Secondary outcome measures included weight bearing lunge (WBL) tests with leg straight and knee bent, gait velocity, cadence, stride length and time, stride width, stance and swing percentage, foot progression angle and double support time.

The WBL test [11] is a measure used to determine available ankle dorsiflexion with high intra-rater reliability [13] that has been utilized within the ITW population previously [14]. These measures were taken by a single investigator with the TiltMeter App on an iPhone [13], which was calibrated prior to each gait session. The child placed their hands on the wall and their right leg placed behind them as far as they could, with heel flat on the floor, their foot perpendicular to the wall and their knee straight. This was repeated with the knee bent. Measures



Fig. 1. Carbon fibre full length foot orthosis.

were taken for the right leg only due to high correlation between left and right limb measures and the symmetrical nature of ITW gait [15,16].

### 2.4. Gait conditions

All children participating in the trial were tested walking at their preferred pace along the GaitRite® mat under the same three conditions:

- Condition 1: Barefoot.
- Condition 2: Wearing usual school or play footwear. An investigator laced the children's footwear to ensure they were secure.
- Condition 3: Wearing custom made rigid contoured carbon fibre foot orthoses (Fig. 1) placed inside Nike AIR FORCE 1 high-top boots. This shoe was chosen for its stiff and flat sole and minimal toe clearance. To reduce variability, all children wore the same type of footwear and the orthoses were fabricated with a secure fit in length and width into the footwear by the manufacturer. The orthoses were manufactured by an external company from a plaster cast impression taken by the podiatrist (JM) up to three weeks prior to testing. The plaster cast impressions were taken non-weight bearing with the foot held in subtalar neutral. The orthoses and shoes were dispensed on the day of data collection.

### 2.5. Procedure

The baseline WBL tests were recorded prior to gait testing. There was a one-meter space at the start and end of the GaitRite® mat for the children to accelerate or decelerate. Children were shown and encouraged to complete a finger-thumb motor apposition task whilst walking at a self-selected speed for each of the gait conditions. This task was introduced to minimize any thoughts of gait pattern change [17]. Two walking trials for each condition were collected. The WBL tests were repeated between each condition to determine if any condition affected ankle range of motion.

### 2.6. Analysis

The data were analyzed using Stata v.13 [19]. Randomisation of gait conditions was undertaken through a balanced Latin-square design [10]. Each participant completed each condition only once, in two consecutive trials, for a total of six walking trials. Descriptive statistics were used to describe variables in means (SD) or frequency (%). All foot strikes were manually counted by the investigators. The foot strikes were captured from the GaitRite sensor pads and heel and toe initial contacts were identified based on the captured image. A full foot strike was counted if there was an observed full foot print with initial heel strike. A partial foot strike was counted if there was a midfoot or forefoot initial contact. Aggregate participant data of heel and toe initial contacts were used for analysis. Percentage of initial toe contacts and change in initial toe contacts percentage between barefoot and footwear and barefoot and footwear with orthoses were calculated for each participant. Prior to the extraction of spatio-temporal measures from GaitRite® for secondary analysis, all initial toe contacts were removed. The data were then analyzed for normality [20]. One-sample *t*-test determined there were no statistical differences ( $p > 0.05$ ) between all left and right limbs for all spatio-temporal parameters, and ankle range of motion values. Linear regression analyses were used to determine any difference in outcome measures between Condition 1

versus Condition 2 and Condition 1 versus Condition 3. Data were clustered within individual participants and robust variance estimates used to account for the within-subject nature of these data.

Fourteen children were calculated as an appropriate sample size to achieve 82% power to detect an effect size of 0.833, alpha criterion of 0.05. This effect size was calculated based on increasing the initial heel contact proportion from 0.5 to 0.7 (SD = 0.24) and a correlation between pre and post intervention assessment of 0.5 [6]. Recruitment of 15 participants enabled a balanced Latin-square randomisation sequence.

### 3. Results

There were 15 children (n = 10, 67% male) recruited. The children ranged in age from four to nine years, with a median of 6 years and mean (SD) of 5.93 (1.83) years. Height ranged from 101.0 to 151.1 cm with a median of 115.6 cm, mean (SD) of 120.03 (13.76) cm. Weight ranged from 16.2 to 43.1 kg with a median of 22.4 kg, mean (SD) of 24.84 (8.20) kg. All children were observed to toe walk intermittently during familiarization of procedures within the gait laboratory environment. All children completed the full number of walking trials and there were no adverse events. All data were normally distributed.

When children walked barefoot, their rate of heel strike was 64%. This increased slightly to 68% in the footwear only condition. There was large variability within the group consistent with the large standard deviation (Table 1). The combined treatment resulted in a significant increase of heel strikes in 89% of steps taken, leading to important changes in the spatio-temporal parameters of gait. There was a difference in heel strike between the barefoot condition versus combined treatment (p = 0.021), with more heel strikes observed during the combined treatment condition. There were no differences in full foot strikes between the barefoot and footwear conditions (p > 0.05). Table 2 displays individual participant data. There were three (20%) children that had no initial toe contacts in any condition despite observation of toe walking during walking about the gait laboratory. A small number of children increased their toe walking when in footwear (n = 4, 27%) and with footwear and orthoses (n = 3, 20%).

The children increased their gait velocity in the footwear only condition compared to barefoot (p = 0.015) due to a significant increase in stride length (p < 0.001). This increase in gait speed was not observed between other conditions (Table 3). The children increased their stride length from barefoot walking to walking with the combined treatment (p < 0.001), but at a reduced cadence (p = 0.005), therefore there was no significant change in gait velocity.

Stride time was increased in the footwear only condition compared to barefoot (p = 0.025) and further increased in barefoot versus combined treatment (p = 0.006). This large increase in stride time in the combined treatment condition was associated with a decrease in percentage of swing phase in the gait cycle (p < 0.010), an increase in stance phase (p < 0.010) and an increase in double support time (p < 0.001) equating to an increase from 20.90 percent of the gait cycle to 23.47 percent of the gait cycle in double support. These changes were not apparent in the barefoot versus footwear only conditions.

All other gait variables showed little difference between each condition. No changes were observed in ankle range of motion between

**Table 1**  
Primary outcome of initial heel contacts versus initial toe contacts for each condition.

	Barefoot steps Mean (SD) N =	Footwear only Mean (SD) N =	Footwear with orthoses Mean (SD) N =	Heel strike: Barefoot vs Footwear Coef, [95%CI], p	Heel strike: Barefoot vs Combined treatment Coef, [95%CI], p
Heel	22.50 (12.61)	21.21 (10.40)	26.36 (3.75)	15.02, [-14.07, 44.11], 0.285	25.96, [4.51,47.42], 0.021
Toe	12.45 (11.85)	10.29 (16.22)	3.33 (3.44)		

**Table 2**  
Primary outcome of initial heel contacts versus initial toe contacts in each condition for individual participants.

Participant	% toe contacts barefoot	% toe contacts in footwear	% toe contacts in footwear and orthoses	% change of toe contacts between barefoot and footwear	% change of toe contacts between barefoot and footwear with orthoses
1	0%	0%	0%	0%	0%
2	0%	0%	31%	0%	> 100%
3	0%	0%	0%	0%	0%
4	19%	100%	0%	> 100%	-100%
5	19%	8%	0%	-58%	-100%
6	0%	4%	4%	> 100%	> 100%
7	55%	100%	6%	81%	-89%
8	4%	0%	6%	-100%	50%
9	6%	0%	3%	-100%	-50%
10	0%	6%	19%	> 100%	> 100%
11	100%	0%	0%	-100%	-100%
12	15%	3%	0%	-80%	-100%
13	45%	0%	0%	-100%	-100%
14	61%	0%	0%	-100%	-100%
15	0%	0%	0%	0%	0%

each condition.

### 4. Discussion

The purpose of this study was to determine the difference between barefoot, preferred footwear and combined treatment of footwear and orthoses on heel contact and spatio-temporal parameters of gait in children diagnosed with ITW. In 89% of steps taken in the combined treatment condition a heel strike was evident. This was associated with an increase in stride time, a decrease in the percentage of swing phase, an increase in stance phase and time spent in the double support phase.

Interestingly children responded differently to the conditions. Some increased their toe walking with footwear or footwear and orthoses. It is unknown why the response was different for these children. This may highlight the variability in presentation of this population.

Children walked faster with shoes compared to barefoot walking. This is consistent with earlier studies [21–24] however in this study, the increase in gait speed was achieved primarily by increasing stride length, rather than maintaining a fixed ratio between cadence and stride length to increase speed [22,23,25].

In barefoot walking, children with ITW demonstrated significantly different stride length and velocity compared to shod walking. This was a similar finding to a past study on toe walking gait [26]. The addition of shoes led to stride length and velocity parameters reaching age appropriate values, which is again similar to other studies investigating the impact of footwear on ITW gait [22,25].

With the combined treatment of footwear and full-length orthoses, velocity was reduced compared to shod walking, but the increase in stride length was maintained. The reduction in gait speed was due to a decrease in cadence. This was associated with a significant increase in stride time and double support phase. As highlighted in the most recent systematic review on the impact of footwear on children’s gait [21], this increase in double support phase may suggest subtle modifications in

**Table 3**  
Secondary outcome measures of spatial (or distance) and temporal (or timing) parameters of gait and ankle ranges of movement. WBL = weight bearing lunge.

Variable	Barefoot Mean (SD)	Footwear only Mean (SD)	Footwear and Orthotics Mean (SD)	Barefoot vs Footwear Coef, [95%CI], p	Barefoot vs Combined treatment Coef, 95%CI, p
Right stride length (cm)	89.85 (9.71)	109.77 (14.17)	106.72 (12.41)	19.92, [12.12,27.71], < 0.001	16.87, [10.03,23.70], < 0.001
Right stride width (cm)	9.23 (1.56)	9.10 (1.23)	9.55 (1.42)	-0.13, [-1.06,0.81], 0.774	0.32, [-0.60,1.24], 0.467
Right stance (%)	58.70 (1.64)	58.93 (1.64)	60.32 (2.06)	-2.64, [-10.60,5.32], 0.489	-3.26, [-10.30,3.77], 0.337
Right swing (%)	41.30 (1.60)	41.05 (1.63)	39.69 (2.05)	-0.25, [-1.34,0.85], 0.637	-1.61, [-2.78, -0.45], 0.010
Gait velocity (cm/s)	110.88 (13.78)	128.15 (17.63)	118.35 (22.05)	17.28, [3.86,30.70], 0.015	7.47, [-5.47,20.41], 0.236
Cadence (steps/min)	149.48 (16.30)	141.58 (19.00)	133.13 (17.73)	-7.89, [-17.16,1.38], 0.089	-16.35, [-26.89, -5.82], 0.005
Right foot toe in/toe out angle (°)	-1.69 (4.65)	0.29 (3.63)	-1.49 (3.75)	1.99, [0.17,3.80], 0.034	1.90, [0.42,3.77], 0.042
Right stride time (s)	0.67 (0.19)	0.75 (0.18)	0.81 (0.18)	0.08, [0.00, 0.16], 0.044	0.14, [0.045, 0.23], 0.004
Right double support time (s)	0.14 (0.04)	0.15 (0.05)	0.19 (0.06)	0.01, [-0.02, 0.04], 0.340	3.93, [0.02, 0.08], 0.002
WBL (straight) (°)	21.11 (3.57)	21.95 (3.80)	21.92 (3.58)	0.55, [-1.13, 2.24], 0.414	0.84, [-0.23, 1.91], 0.102
WBL (bent) (°)	25.88 (4.91)	26.56 (4.93)	26.64 (4.50)	0.38, [-1.99, 2.75], 0.680	0.68, [-1.38, 2.73], 0.450

the gait pattern to improve local dynamic stability with shoes acting as a “sensory filter”. This was not evident in the shoe only condition in this study. However, the introduction of the combined treatment with a full length orthosis, and boot with a flat and stiff sole and minimal toe clearance, supports the theory that the hardness and thickness of the shoe midsole improves stability and foot position awareness [27]. Children with ITW in boots and full-length orthoses also had longer ground contact time and delayed toe-off. This would contribute to the increase in the double support phase which may reflect subtle changes in balance control [28]. The stable base of the orthoses and high-top boots are likely to influence this balance control and hence these findings may reflect subtle changes in local dynamic stability strategy.

There is limited documentation of the use of orthoses as a treatment for ITW. It is considered that increasing sensory stimulation increases support tone in the lower limbs during gait [29,30]. The companion study with this same population utilized multiple doses of whole-body vibration to determine the immediate and short-term impact on ITW [31]. Though this impact was not sustained at 20 min post the vibration protocol, the improvements in the number of heel contacts and the available ankle range of motion, support the theory that children with ITW may process sensory input differently to typically developing children [32].

Only one other study has utilized foot orthoses within a comparative effectiveness trial [33]. Children with ITW received either AFOs or foot orthoses with a rigid carbon fiber footplate and gait outcomes were compared. Their findings supported their hypotheses that the AFO is a mechanical treatment of equinus, maintaining 100% control of toe walking. However, there was no carryover effect when the AFO was removed. Children prescribed the foot orthoses however showed significant improvement compared to baseline results in shoe-only walking. This present study had similar findings. While not completely controlling toe walking, the use of a full length orthoses provided a more stable base of support. In contrast to the effectiveness trial, the full length orthoses used in this present study were molded through the midfoot and provided rear foot control, thereby modifying the plantar pressure distribution, sensory feedback, muscle activity and influencing foot alignment [34–36]. It is proposed that this provides not only a mechanism that physically reduces the child’s ability to toe walk but potentially provides additional sensory feedback reducing any underlying reason for toe walking potentially related to sensory seeking behaviors. The improvement in the number of heel contacts, stride time and double support time whilst wearing the full-length orthoses may be associated with the increased sensory feedback provided through the entire length of the foot.

This study was limited by the single assessment. It is unknown whether this combined treatment has long-term impact on the normalization of gait in children with ITW. By increasing the contact area of the plantar surface of the foot during gait and controlling the sensory input, the need to toe walk in the long term may be pacified but this theory needs further investigation. The results of this study are limited

to children with ITW with dorsiflexion range of at least fifteen degrees as measured by the WBL test and therefore are not relevant to children with less than this range. An additional limitation of this study was no differentiation of the contribution of the chosen footwear that the orthoses were manufactured to fit into. The Nike AIR FORCE 1 shoes were specifically chosen for their stiff and flat sole, combined with minimal toe clearance to encourage longer foot contact with the ground. This feature may also contribute to the reduced gait speed seen with the combined treatment; however, the manufacturing process of the orthoses required the shoes to be present at the lab for exact fitting of length and width. This limited the ability to test the features of the shoes prior to the orthoses being placed in situ. Further research should consider isolating this footwear for testing and blinding children to the presence of the orthoses within the shoes.

Future work needs to determine if or how the orthoses change the mechanics of gait, whether they are as effective in all shoe types and whether the orthoses should be considered a long-term treatment to aid the training of children with ITW toward a heel-toe gait pattern. Between subject designs are needed to examine the effects of these different intervention approaches for extended periods of time.

**5. Conclusion**

The combined treatment of a full-length foot orthosis with a high-top boot changed the gait of children with ITW. This treatment immediately reduced the occurrence of toe walking, and improved gait stability by increasing stride time and double support time.

**Conflict of interest statement**

The authors have no conflicts of interest relevant to this article to disclose.

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