The effect of anatomical versus traditional joint placement on articulated ankle foot orthoses and the consequences on parameters of gait

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Abstract

Context: One in 800 children in the United States suffer from Cerebral Palsy or Down Syndrome and adults with impairments as a result of a cerebrovascular accident are estimated to be 800,000 every year. Individuals with impaired neuromuscular deficits in the lower limb benefit from the intervention of an ankle foot orthosis (AFO). In orthotics, the standard is to place the joints parallel to the medial malleolus on an articulated thermoplastic AFO using a nylon high strength inner core joint.

Objectives: The goal of this study was to determine the most optimal placement of the ankle joint, parallel to the medial malleolus or in accordance with the anatomical ankle joint, in an articulated ankle foot orthosis for simulating normal gait patterns.

Design: Each subject served as his or her own control and experimental group.

Setting: The study took place at Loma Linda University in Loma Linda, California.

Participants: The research team recruited 7 healthy young adults. There were 5 males and 2 females with a mean age of 24.0 ± 1.8 years and mean BMI of 28.4 ± 5.6 kg/m².

Intervention: Each subject received two articulated AFOs. The first having the ankle joints aligned in the traditional manner, in line with the medial malleolus, and the second with joints aligned in anatomical alignment. Subjects walked on a GAITRite floor mat with no AFO, with the traditional orthosis, and with the anatomically placed joints orthosis to give comparable quantitative data. The study took place over an 8-week period with 4 visits every 2 weeks.

Outcome Measures: The GAITRite measured velocity, cadence, step length, percent of single limb support (SLS), and degree of toe in and toe out.

Results: The distribution of the outcome variables was approximately normal (p > 0.05). Using non-parametric statistics, there was a significant difference in mean velocity in the anatomical
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joint placement compared to baseline ($p = 0.02$). Also, a significant difference in mean right side step length in the anatomical joint placement compared to baseline ($p = 0.02$) as well as mean left side step length in the anatomical joint placement compared to baseline ($p = 0.018$).

Additionally, the mean single limb support on the right between all three joint placements held a significant difference ($p = 0.05$).
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The effect of anatomical versus traditional joint placement on articulated ankle foot orthoses and the consequences on parameters of gait

Introduction

 Individuals with impaired neuromuscular deficits in the lower limb benefit from the intervention of an ankle foot orthosis (AFO) (Graham, 2013; Middleton, Hurley, & McIlwain, 1988). One in 800 children, and 4 in 1,000 live births represent new cases of Down Syndrome and Cerebral Palsy, respectively, each year in the United States. Adults impaired after cerebrovascular accident are estimated to be 800,000 every year, with the amount of new cases increasing steadily (Prevention, 2015). Children with these diagnoses and adults who have suffered neuromuscular impairment are some of the individuals who benefit from wearing an AFO (Carlson, Vaughan, Damiano, & Abel, 1997; Chisholm & Perry, 2012; V. Pardo, 2015). An AFO is an external device designed to encumber the posterior portion of the lower leg, just below the knee, to the dorsum of the foot and toes, and to be used in concert with closed-toe footwear. Various designs exist in AFO production to compensate for the weakness or loss of musculature, with options in materials ranging from: leather and metal, carbon, and most commonly, thermoplastics, both with and without articulation (Danielsson & Sunnerhagen, 2004). Thermoplastic AFO with articulation is one of the most commonly prescribed lower limb orthoses, thus, attention should be considered on joint placement during fabrication to maximize gait efficiency (Fan Gao, 2012; van Swigchem, Roerdink, Weerdesteyn, Geurts, & Daffertshofer, 2014).

The standard in orthotic fabrication for joint placement is to place the medial artificial joint at the apex of the medial malleolus, parallel to the floor, with the lateral artificial joint parallel, and the joints perpendicular to the line of progression (Fan Gao, 2012). The talocrural
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Joint is comprised of the tibia, fibula, and talus, and is responsible for sagittal plane movement: dorsiflexion and plantarflexion. However, the talocrural joint is not perfectly parallel, as the lateral malleolus is distal and posterior to the medial malleolus. Many joint options are available, such as: metal, nylon, and thermoplastic; the Tamarack joint, which has a high-strength inner core that provides consistent, smooth articulation, and high durability. Because of the popularity of the joint, it is available in children and adult sizes. Due to the anatomical structure of the ankle joint and the contrasting orthotic joint placement on an AFO, it is evident that more anatomical joint placement, in this case, aligned to the talocrural joint, may benefit individuals who require an AFO (Fan Gao, 2012).

Different AFO designs and materials selection exist for differing pathological indications. Conventional design of AFOs use leather and metal, fixed permanently to a shoe, and is indicated for patients with flaccid equinus, or inability to adequately dorsiflex the foot during mid-swing of the gait cycle, coupled with fluctuating edema (T. Kobayashi, 2011). Additionally, individuals who may need a highly durable AFO, regardless of device weight, could benefit from a conventional AFO. A solid AFO is a non-articulated design of thermoplastic material with Velcro strapping over the anterior tibia, with trimlines typically encompassing or bisecting the malleoli (T. Kobayashi, 2011). It is designed for an individual with flaccid equinus and who is at risk for injury or falls due to medial-lateral instability of the foot-ankle complex (Mulroy, Eberly, Gronely, Weiss, & Newsam, 2010). A posterior leaf spring AFO is similar in appearance to a solid AFO, but it has more liberal trimlines, with both malleoli unenclosed; it is typically used for an individual with solely flaccid equinus, as the reduced material provides greater medial-lateral freedom of movement. The articulated, also referred to as hinged, AFO provides a more natural gait pattern, and is intended for individuals with flaccid equinus with minor to moderate
medial-lateral instability at the foot-ankle complex, with a knee extensor strength of 3+/5, using
the modified Oxford Scale for manual muscle testing (Buckon et al., 2004; Mulroy et al., 2010;
Romkes & Brunner, 2002; Teasell, McRae, Foley, & Bhardwaj, 2001). Articulated AFOs are
commonly prescribed to patients who have suffered cerebrovascular accident (CVA), children
with Cerebral Palsy (CP), and others with musculo-neurological deficits (Graham, 2013;
Middleton et al., 1988; Romkes, Hell, & Brunner, 2006; Sienko Thomas, Buckon, Jakobson-
Huston, Sussman, & Aiona, 2002; V. Pardo, 2015).

Every individual has a gait pattern specific to them, with deviations from the optimum
resulting in increased energy expenditure, risk of falls, and an uncosmetic appearance. An
individual responds to an AFO depending on the type of AFO and the selected trimlines of the
footplate by the orthotist (Fatone, Gard, & Malas, 2009). The length of the footplate determines
how many rockers, or rollover phases, of the gait cycle will be achieved (Fatone et al., 2009;
Fatone & Hansen, 2007a, 2007b). Options include: full length to the distal ends of the toes,
length to the sulcus, and length to the metatarsal heads. Individuals with cerebral palsy and post
cerebrovascular accident hemiplegia present with a plantarflexion dominant ankle position with a
lack of volitional dorsiflexion and an equinovarus position (Graham, 2013; V. Pardo, 2015).
This limitation, coupled with other possible comorbidities, results in a plantarflexed ankle
position during mid-swing, dramatically increasing the risk of falls and resulting in
compensatory movements at the proximal musculature. An AFO provides a three point force
system to maintain the ankle in a neutral position during mid-swing, and prevents the forefoot
from collapse at initial contact to loading response. A hinged AFO with a plantarflexion stop
assists individuals with maintaining a dorsiflexed position without negatively limiting mobility
(Fatone et al., 2009; Simons, van Asseldonk, van der Kooij, Geurts, & Buurke, 2009). The
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Hinged AFO has been shown to significantly increase velocity, stride length, step length, and single limb support in children with cerebral palsy, as compared to no orthotic intervention (White, Jenkins, Neace, Tylkowski, & Walker, 2002).

The purpose of this study was to determine the differences in gait when able-bodied individuals use articulated AFOs with traditional parallel joint alignment compared to non-parallel anatomical joint alignment. Outcome measures will include assessment of gait parameters: cadence, velocity, toe-in, step length, stride length, and single limb support. It is hypothesized that the hinged AFO with anatomical joint placement will provide improved gait parameters than the hinged AFO with standard parallel joint placement.

This study aimed to establish a standard for articulated AFO joint placement, specific to the Tamarack joint. The fabrication guidelines for parallel joint placement are subjective among orthotists and technicians, and are unnatural compared to the ankle, specifically the talocrural joint. Subjects were recruited to wear a custom fabricated, thermoplastic, articulated AFO with the standard parallel joint placement compared to a second AFO with an anatomical joint placement to determine differences in the parameters of gait. Parameters of gait assessed included: stride length, step length, cadence, velocity, toe-in, and percentage of single limb support.

Methods

Subjects

The subjects (n = 7) for this study were healthy individuals who served as both the control and experimental group. Subjects were recruited by word of mouth at the Loma Linda University campus from the Orthotics and Prosthetics department and surrounding community.
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Subjects included were 5 males and 2 females with a mean age of 24.0 ± 1.8 years and an average body mass index of 28.4 ± 2.1 kg/m².

Individuals were questioned and excluded if they had any of the following conditions: (1) any physical disability or injury affecting the spine or lower extremity that would prohibit a natural gait pattern and (2) joint fusion, stiffness, or abnormality.

Informed consent was done in a quiet group setting, removed from distractions, with all questions directed towards two investigators. Each participant was given time to read the informed consent and investigators answered questions to satisfaction. Subjects were asked to provide their demographic data, including: age, gender, weight and height to determine the appropriate thickness of plastic necessary for the individual. Additionally, any prior history of lower extremity orthopedic injury was taken. The Institutional Review Board of LLU approved all procedures.

Outcome Measures

**GAITRite by CIR Systems Inc.** Outcome measures of velocity, cadence, step length of the right foot, step length of the left foot, single limb support of the right foot, single limb support of the left foot, toe in on the right, and toe in on the left were determined using the GAITRite floor mat and GAITRite software version 4.7 (CIR Systems Inc., Sparta, New Jersey). The GAITRite is an FDA registered system, CE certified with ISO standard compliant, and the gold standard of temporospatial gait analysis. The stated spatial accuracy of the GAITRite is ±0.5 (±1.27cm) and the temporal accuracy is ±1. The system measures an individual’s cadence and the parameters of their steps using the platinum GAITRite walkway SN:Q229 (CIR systems Inc., Peekskill, NY; Zografou Athens, Greece). This electronic walkway records the gait cycle
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via pressure activated sensors. The data collected is then sent to a computer interface called the platinum GAITRite interface 485 VER.F.

**QTS Infrared Oven by PDQ.** The plastic used in creating the ankle foot orthoses can be quickly heated to high temperatures, allowing the process of thermoforming the plastic to the mold easier through a blister or drape molding process. This will assist in maintaining the shape of the subjects’ leg. The oven can reach a maximum temperature of 450°F/243°C, with an automatic shut-off feature if the temperature exceeds 500°F/260°C. The oven also has options for a single or three phase wiring system. The single phase wiring diagram operates between 208-240 volts, and the three phase wiring diagram operates between 380-400 volts.

**Trautman Floor Carver.** Primarily used in the modification process of the ankle foot orthosis; that included grinding and smoothing down the plastic according to the specified trimlines. It ran off of a dual speed motor with 60Hz, 115 volts, and 3500/1760 RPM. An attached floor pedal that was connected to the trautman by cable was the main method of turning it on or off when needed.

**Southern Prosthetic Supply (SPS) Materials Supplier.** All materials and supplies used in the casting and fabrication process were ordered from Southern Prosthetic Supply (SPS) based in Alpharetta, Georgia, with the exception of shoes, which were purchased from a local superstore.

**SPSS Statistical Analysis Software.** Data was then analyzed using IBM SPSS 21.0 statistical software (IBM Corporation, Armonk, New York, United States). Measures included: velocity (cm/sec), cadence (cm/sec), step length (cm), percent single limb support (%GC), and toe in (deg). Data were analyzed using parametric and nonparametric tests. The parametric one-
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sample Kolmogorov-Smirnov test and nonparametric Wilcoxon signed ranks test and Friedman test were used. Significance was set at $p \leq 0.05$.

Procedures

![Figure 1. Timeline of procedures.](image)

<table>
<thead>
<tr>
<th>Wearing Schedule</th>
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</thead>
<tbody>
<tr>
<td><strong>Sunday</strong></td>
</tr>
<tr>
<td><strong>Week 1</strong></td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
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<tr>
<td><strong>Week 3</strong></td>
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<tr>
<td><strong>Week 4</strong></td>
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<tr>
<td><strong>Week 5</strong></td>
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<tr>
<td><strong>Week 6</strong></td>
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<tr>
<td><strong>Week 7</strong></td>
</tr>
<tr>
<td><strong>Week 8</strong></td>
</tr>
</tbody>
</table>

**You will also receive a reminder text messages on the following days you are suppose to wear the AFO’s**

![Figure 2. Wearing schedule of anatomical and parallel AFOs.](image)
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Visit 1

Subjects arrived in the Gait Lab at Loma Linda University East Campus Hospital. Subjects were asked to sit in a chair, cotton stockinette was applied to the right leg of the subject, and a cutting strip was inserted inside the stockinette, directly against the skin. The investigator used an indelible marking pencil to identify bony prominences: medial malleolus, lateral malleolus, head of first metatarsal, head of fifth metatarsal, base of fifth metatarsal, and the fibular head. Four inch fiberglass was used to cast the subjects’ limb, with room temperature water being used to start the curing process. The ankle and foot were held in subtalar neutral, with 0 degrees of dorsiflexion while the fiberglass cured. Once the limb was casted and the fiberglass was cured, the cast was removed with a cast saw and scissors. The subject was then asked to perform a baseline walk, with shoes, along the GaitRite floor mat.

2 week period between visits

During this two week period, the fiberglass cast was filled with plaster of paris and then modified. There were build-ups of 1/8” on the medial and lateral malleoli, base of the fifth metatarsal, head of the first metatarsal, and the navicular tuberosity, to prevent any impingement and maintain skin integrity during the use of the AFO. Once the plaster mold was smoothed, it was re-wrapped in fiberglass to create a duplicate mold since each subject served as their own control and experimental group. The plastic used was polypropylene, thickness 3/16 of an inch, and it was heated to 380 degrees fahrenheit. The AFOs were vacuum formed and left to cool at room temperature for at least 1 hour, or until cool to the touch. The plastic device was cut off of the plaster model, with trimlines following standard orthotics procedure. For the traditionally aligned joints, the AFO was cut in a straight line in accordance with the placement of the medial malleolus. For the anatomically aligned joints, the AFO was cut in a diagonal manner, the
medial side being more proximal than the lateral side. The footplate was trimmed at the sulcus, to allow for a more comfortable fit into the subjects' shoes. The anterior opening of the AFO was trimmed 1.5 inches medial to the tibia and 1.5 inches lateral to the tibia, totaling 3 inches. A velcro anterior calf strap was riveted to the proximal portion of the AFO. An ankle strap was not included because the subjects’ shoe will serve to hold their foot securely in the AFO. Subjects’ shoe size was acquired at the initial visit and investigators purchased identical athletic shoes for each subject to create uniformity in measurements; the brand of shoe used was Starter.

Visit 2

Each subject was fitted with a traditionally aligned articulated AFO. Shoes were provided by the investigators to the subjects, to be worn with the AFO. Any modifications necessary, such as grinding, smoothing, and/or flaring out areas of the AFO, were made to ensure comfort and compliance. Subjects were given the AFO to take home and asked to wear it according to the wearing schedule provided. Five days prior to the third visit subjects were asked to start a wearing schedule, as illustrated in Figure 2. The first day subjects wore the AFO for 1 hour, the second day 2 hours, the third day 4 hours, the fourth day 6 hours, and the day before the appointment for 8 hours.

Visit 3

Subjects were asked to walk on the GAITRite floor mat while wearing the parallel AFO. Data were collected and recorded for analysis and comparison. Subjects were then fit with the anatomically aligned AFO and asked to wear it according to the same wearing schedule as the prior.
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Visit 4

Subjects were asked to walk on the GAITRite floor mat with the anatomically aligned AFO.

Statistical Analysis

General characteristics of the subjects were summarized using frequencies and relative frequencies for categorical variables and mean±SD for quantitative variables. The normality of the outcome variables were examined using one-sample Kolmogorov-Smirnov test. Changes in mean outcome variables (velocity, cadence, length of each step at the right side, length of each step at the left side, percent single limb support at the right side, percent single limb support at the left side, toe in at the right side and toe in at the left side) between baseline (before using orthoses), while using ankle foot orthosis in the parallel joint placement, and while using the device with anatomical joint placement were examined using the Friedman test. Further changes between any two positions were assessed using the Wilcoxon signed rank test. The level of significance was set at p ≤ 0.05.

Results

Seven subjects, mean age 24.0 ± 1.8 years and mean body mass index (BMI) 28.4 ± 5.6 kg/m² participated in the study (Table 1). There were 5 male subjects in this study, comprising 71.4% of the total subject count. The distribution of the outcome variables was approximately normal (p > 0.05). Because of the small sample size, changes in the outcome variables were examined using non-parametric statistics. Changes in outcome variables by joint placement are displayed in Table 2.

Results indicated that velocity, step length, and single limb support time improved when wearing the anatomical AFO. There was a significant difference in mean velocity in the
anatomical joint placement compared to baseline (131.0 ± 14.2 vs 114.7 ± 12.4, p = 0.02) (Table 3). The percentage of velocity increased a total of 14.0% (Table 3) in comparison to baseline values. Furthermore, significant differences were found when comparing the changes in mean right side step length when wearing anatomical joint placement compared to baseline (74.2 ± 9.9 vs 65.3 ± 5.4, p = 0.02) (Table 3). The mean value of right side step length increased by 13.6% when wearing anatomical AFO compared to baseline walk.

Referring to Table 2, there was also a significant difference in left and right step length between baseline, anatomical joint placement, and parallel joint placement. Single limb support time between all three joint placements held a significant difference. When wearing anatomical AFOs participants took larger step lengths than at baseline and with parallel aligned joints. Results have shown that anatomically placed joints improved efficiency and gait compared to no intervention and parallel placed joints.

### Table 1. Mean (SD) of Demographics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Gender (%)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>71.4</td>
<td></td>
<td>28.6</td>
</tr>
<tr>
<td>Age (year)</td>
<td>24 (1.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>84.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>196.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>28.4 (5.6)&lt;br&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Mean (SD) of gait outcomes based on joint alignment (baseline, parallel & anatomical)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Parallel</th>
<th>Anatomical</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (cm/sec)</td>
<td>114.7 (12.4)</td>
<td>119.2 (17.2)</td>
<td>131 (14.2)</td>
<td>0.05</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>105.6 (11.0)</td>
<td>102.6 (10.8)</td>
<td>106.2 (4.8)</td>
<td>0.57</td>
</tr>
<tr>
<td>Step Length R (cm)</td>
<td>65.3 (5.4)</td>
<td>69.0 (5.7)</td>
<td>74.2 (9.9)</td>
<td>0.002</td>
</tr>
<tr>
<td>Step Length L (cm)</td>
<td>65.5 (6.4)</td>
<td>70.0 (5.0)</td>
<td>74 (8.3)</td>
<td>0.01</td>
</tr>
<tr>
<td>Percent SLS R (%GC)</td>
<td>38.3 (1.5)</td>
<td>35.8 (3.6)</td>
<td>37.1 (1.8)</td>
<td>0.05</td>
</tr>
<tr>
<td>Percent SLS L (%GC)</td>
<td>38.0 (1.4)</td>
<td>37.9 (2.0)</td>
<td>37.7 (1.8)</td>
<td>0.86</td>
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<tr>
<td>Toe In R (deg) median (min, max)</td>
<td>3.5 (-2, 6.5)</td>
<td>1.0 (-3, 6)</td>
<td>2.5 (-1.5, 4.5)</td>
<td>0.96</td>
</tr>
<tr>
<td>Toe In L (deg) median (min, max)</td>
<td>-0.5 (-7, 2)</td>
<td>-1 (-7.5, 5.5)</td>
<td>-2.0 (-7.5, 4)</td>
<td>0.89</td>
</tr>
</tbody>
</table>
### Table 3. Mean (SD) and percent change of gait outcomes based on joint alignment (baseline, anatomical)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Anatomical</th>
<th>% Change</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (cm/sec)</td>
<td>114.7 (12.4)</td>
<td>131 (14.2)</td>
<td>14.0%</td>
<td>0.02</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>105.6 (11.0)</td>
<td>106.2 (4.8)</td>
<td>0.56%</td>
<td></td>
</tr>
<tr>
<td>Step Length R (cm)</td>
<td>65.3 (5.4)</td>
<td>74.2 (9.9)</td>
<td>13.6%</td>
<td>0.02</td>
</tr>
<tr>
<td>Step Length L (cm)</td>
<td>65.5 (6.4)</td>
<td>74 (8.3)</td>
<td>12.9%</td>
<td>0.02</td>
</tr>
<tr>
<td>Percent SLS R (%GC)</td>
<td>38.3 (1.5)</td>
<td>37.1 (1.8)</td>
<td>0.3%</td>
<td>0.03</td>
</tr>
<tr>
<td>Percent SLS L (%GC)</td>
<td>38.0 (1.4)</td>
<td>37.7 (1.8)</td>
<td>0.8%</td>
<td>0.69</td>
</tr>
<tr>
<td>Toe In R (deg) median (min, max)</td>
<td>3.5 (-2, 6.5)</td>
<td>2.5 (-1.5, 4.5)</td>
<td>-28.5%</td>
<td>0.93</td>
</tr>
<tr>
<td>Toe In L (deg) median (min, max)</td>
<td>-0.5 (-7, 2)</td>
<td>-2.0 (-7.5, 4)</td>
<td>-300%</td>
<td>0.87</td>
</tr>
</tbody>
</table>

### Table 4. Mean (SD) and percent change of gait outcomes based on joint alignment (baseline, parallel)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Parallel</th>
<th>% Change</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (cm/sec)</td>
<td>114.7 (12.4)</td>
<td>119.2 (17.2)</td>
<td>3.90%</td>
<td>0.61</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>105.6 (11.0)</td>
<td>102.6 (10.8)</td>
<td>-0.28%</td>
<td></td>
</tr>
<tr>
<td>Steps Length R (cm)</td>
<td>65.3 (5.4)</td>
<td>69.0 (5.7)</td>
<td>5.66%</td>
<td>0.02</td>
</tr>
<tr>
<td>Steps Length L (cm)</td>
<td>65.5 (6.4)</td>
<td>70.0 (5.0)</td>
<td>6.87%</td>
<td>0.04</td>
</tr>
<tr>
<td>Percent SLS R (%GC)</td>
<td>38.3 (1.5)</td>
<td>35.8 (3.6)</td>
<td>-6.53%</td>
<td>0.04</td>
</tr>
<tr>
<td>Percent SLS L (%GC)</td>
<td>38 (1.4)</td>
<td>37.9 (2.0)</td>
<td>-0.26%</td>
<td>0.87</td>
</tr>
<tr>
<td>Toe In R (deg) median (min, max)</td>
<td>3.5 (-2, 6.5)</td>
<td>1.0 (-3.6)</td>
<td>-71.40%</td>
<td>0.60</td>
</tr>
<tr>
<td>Toe In L (deg) median (min, max)</td>
<td>-0.5 (-7.2)</td>
<td>-1(-7.5, 5.5)</td>
<td>-100%</td>
<td>0.92</td>
</tr>
</tbody>
</table>

### Table 5. Mean (SD) and percent change of gait outcomes based on joint alignment (parallel, anatomical)

<table>
<thead>
<tr>
<th></th>
<th>Parallel</th>
<th>Anatomical</th>
<th>% Change</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (cm/sec)</td>
<td>119.2 (17.2)</td>
<td>131 (14.2)</td>
<td>9.89%</td>
<td>0.24</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>102.6 (10.8)</td>
<td>106.2 (4.8)</td>
<td>3.50%</td>
<td></td>
</tr>
<tr>
<td>Steps Length R (cm)</td>
<td>69.0 (5.7)</td>
<td>74.2 (9.9)</td>
<td>7.53%</td>
<td>0.05</td>
</tr>
<tr>
<td>Steps Length L (cm)</td>
<td>70.0 (5.0)</td>
<td>74 (8.3)</td>
<td>5.71%</td>
<td>0.18</td>
</tr>
<tr>
<td>Percent SLS R (%GC)</td>
<td>35.8 (3.6)</td>
<td>37.1 (1.8)</td>
<td>3.63%</td>
<td>0.40</td>
</tr>
<tr>
<td>Percent SLS L (%GC)</td>
<td>37.9 (2.0)</td>
<td>37.7 (1.8)</td>
<td>0.05%</td>
<td>0.24</td>
</tr>
<tr>
<td>Toe In R (deg) median (min, max)</td>
<td>1.0 (-3, 6)</td>
<td>2.5 (-1.5, 4.5)</td>
<td>150%</td>
<td>0.34</td>
</tr>
<tr>
<td>Toe In L (deg) median (min, max)</td>
<td>-1(-7.5, 5.5)</td>
<td>-2.0 (-7.5, 4)</td>
<td>-200%</td>
<td>0.68</td>
</tr>
</tbody>
</table>
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**Figure 1.** Mean & SD outcomes for velocity based on joint alignment (baseline, parallel, & anatomical)

**Figure 2.** Mean & SD outcomes for right step length based on joint alignment (baseline, parallel, & anatomical)

**Figure 3.** Mean & SD outcomes for left step length based on joint alignment (baseline, parallel, & anatomical)
**Figure 4.** Mean & SD outcomes for right single limb support based on joint alignment (baseline, parallel, & anatomical)

**Figure 5.** Mean & SD outcomes for cadence based on joint alignment (baseline, parallel, & anatomical)

**Figure 6.** Mean & SD outcomes for left single limb support based on joint alignment (baseline, parallel, & anatomical)
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Figure 7. Mean & SD outcomes for right toe in based on joint alignment (baseline, parallel, & anatomical)

Figure 8. Mean & SD outcomes for left toe in based on joint alignment (baseline, parallel, & anatomical)

Discussion

The current study examined whether ankle joint orientation on an articulated ankle foot orthosis affected a person’s ability to simulate natural gait patterns. The two different orientations were traditionally aligned, parallel to the floor according to the medial malleolus and perpendicular to the line of progression, and anatomically aligned, in accordance to the talocrural joint. Use of an AFO compared to no orthotic intervention was found to significantly improve velocity, stride length, step length, and single limb support in cerebral spastic children (White, Jenkins, Neace, Tylkowski, & Walker, 2002). Though our subjects were able-bodied individuals, our data supported these findings and demonstrated that single limb support,
velocity, and step length were found to increase significantly between the anatomical AFO and baseline.

The results demonstrated a significant difference in step length and single limb support on the affected leg between the baseline walk and when wearing the AFOs. The significant difference in velocity is solely between the baseline measurements and the anatomical AFO measurements (Table 3). It was unexpected that velocity would increase for the AFO measurements being that it is an added weight to the lower extremity and a possible hindrance for able-bodied ambulators. A potential explanation is the change in walkway distance. The first baseline walk was in a small room, which required each subject to stop as soon as they stepped off the GAITRite walkway. The second and third walks, wearing AFOs, took place in a different room that allowed the subjects to continuously walk off of the walkway.

In total, step length, single limb support, and velocity all changed significantly with the anatomical AFO compared to baseline. The velocity increase for the anatomical AFO in comparison to the traditional AFO did support the hypothesis by showing an increase in fluid movement. By placing the mechanical joints according to the anatomical joints, subjects may have experienced less torsion at the talocrural joint due to the biomimetic nature of the AFO. Changes in step length and single limb support may also be related to the increased comfort of the anatomical AFO.

Toe in and toe out, cadence, single limb support of the unaffected leg may have held no difference between the three separate parameters due to its relation to gait habits rather than mechanical changes of the ankle. If the AFO was uncomfortable to the user, it may affect the percentage of single limb support on the affected leg and cadence.
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Previous research by Gao, et al, has demonstrated the importance of joint placement and alignment in AFO fabrication. In the coronal plane, it has been deemed essential to align the axis through the malleoli, as any anterior or posterior alignment could cause deviations in the mechanical properties of the material, namely the stiffness and resistance of the thermoplastic, which impairs AFO effectiveness and negatively affects gait patterns (Gao, Carlton, & Kapp, 2011; Gao & Kapp, 2012). The study observed the effectiveness of joint placement by placing an articulated AFO on a lower leg plaster mold and measuring the stiffness and resistance using a custom motorized device (Gao, Carlton, & Kapp, 2011). While there were no interaction between the human ankle and the mechanical joints, measurements of torque in various joint positions allowed for quantification of appropriate joint positioning. This study expanded on previous research by exploring the interaction between the human ankle and mechanical joint, as well as measuring the differences in joint placement in accordance to the talo-crural joint.

Similar to the study conducted by Gao, et al, investigators of this study established that the placement of the joint on the AFO plays a role in the efficiency of gait by measuring the resistance to natural gait in the quantified readings of velocity, single limb support on the affected leg, and step length. Although data was not significantly different from the anatomical to the parallel AFO, there were minor improvements in gait parameters.

Some potential limitations of the current study were present. First, the sample size was small with only 7 participants who were all able-bodied individuals and did not appropriately represent the potential population that this study sought to address. Second, due to the necessary time required to acclimate to the AFO, subject compliance was not guaranteed for using the AFO in accordance with the provided wearing schedule. In future studies, it is recommended that subjects be given the different AFOs in a randomized order, which may affect the variable...
readings of velocity, step length, and single limb support. Randomizing the order will decrease the chance of error due to subjects’ becoming accustomed to walking in AFO’s.

**Conclusion**

This study is relevant to the present day field of orthotics being that AFOs are the most frequently seen prescriptions in clinics. The goals of AFOs are to promote movement necessary for proper gait while ensuring that existing movements are not hindered. In clinical settings, practitioners have often placed the mechanical joints in accordance with the medial malleolus and while this may be effective in increasing the efficiency of gait, the application of this study to clinical setting may allow practitioners to better aid their patients in initiating normal gait patterns. By tackling this need in the rehabilitative setting, clinicians will initiate whole person care and allow patients to return to their activities of daily living and potentially decrease the need for additional help in movement. This, in turn, will increase patient morale and quality of life therefore leading to a higher possibility of overall device use and dedication to injury recovery.
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References


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*Journal of Neuroscience Nursing, 6*(4).


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