PRESCRIPTION OF ANKLE-FOOT ORTHOSES FOR CHILDREN WITH CEREBRAL PALSY

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ABSTRACT

Purpose: Ankle foot orthoses (AFOs) are frequently prescribed to address gait impairments for children with cerebral palsy (CP). Successful treatment with AFOs depends on optimal prescription, matching the design of the brace to the individual child's physical impairments; however, research evidence does not exist to help health care professionals decide on the best AFO design to meet each child's needs. Therefore, this thesis explored current AFO prescription practices, and aimed to improve evidence to assist clinicians in making prescription decisions for children with CP.

Methods and Results: To examine the experiences and perspectives of clinicians on AFO prescription for children with CP, we conducted focus groups and semi-structured interviews with 32 clinicians who were involved with AFO prescription for children with CP in five Canadian rehabilitation facilities. Using Interpretive Description as a framework for analysis, we identified three categories from the data: 1) What is made, 2) How it is used, and 3) Factors that support or challenge outcomes. Throughout the interviews, the theme of prescription as a collaborative, iterative, and individualized process emerged.

To explore evaluation and clinical decision-making practices of physical therapists for AFO prescription and follow-up, we invited Canadian physical therapists (PTs) working with children who have CP to complete an online survey. Sixty completed responses were received. Three researchers conducted a conventional content analysis to examine the open-ended responses, and descriptive statistics were used to summarize the closed-ended responses. Three themes were identified: 1) Focus on impairment level measures, 2) Inconsistent practices between PTs, and 3) Lack of confidence/knowledge about casting positions and AFO types.

To investigate the effects of individualizing the angle of the ankle in the AFO on walking mechanics and function, gait biomechanics were studied in ten children with CP. Fifteen typically-developing children provided normative data. Using three-dimensional gait analysis, kinematics and kinetics were compared between the child's usual AFO(s) and AFOs that were fabricated with an ankle angle that was individualized for each child. Net responses to the individualized ankle angle were positive for 60% of limbs, negative for 40%. The greatest benefits were observed at the knee, suggesting that this may be a beneficial approach to orthotic intervention for some children with CP.

Conclusions: There is limited understanding of how AFOs are prescribed for children with CP in Canada. This thesis highlights the importance of multidisciplinary collaboration, objective evaluation, and individualized clinical problem-solving to facilitate the evolution of the AFO prescription from a medical directive to an orthotic device that optimally benefits the child. This is the first step toward the development of guidelines to help clinicians improve AFO prescription for children with CP.

PREFACE AND AUTHOR CONTRIBUTIONS

I, Kyra Kane, was the primary author of all the chapters contained in this thesis. Chapters 3 and 4 are manuscripts that have been published in peer-reviewed academic journals, and chapter 5 will be submitted for publication to an appropriate peer- reviewed academic journal. Author contributions have been discussed and agreed upon.

Chapter 3 is a manuscript that was published in *Physiotherapy Theory and Practice*. It was co-authored by Dr. Patricia Manns, Dr. Joel Lanovaz, and Dr. Kristin Musselman. I designed the research question, collected and analyzed the data, and prepared the manuscript under their guidance. Dr. Musselman and Dr. Manns assisted with data collection, analysis, and in reviewing the manuscript. Dr. Lanovaz assisted with analysis and manuscript revisions.

Chapter 4 is a manuscript that was published in *Physical and Occupational Therapy in Pediatrics*. It was co-authored by Dr. Joel Lanovaz, and Dr. Kristin Musselman. I designed the research question, recruited participants, collected and analyzed the data, and wrote the manuscript with their feedback. Dr. Lanovaz and Dr. Musselman assisted with data analysis and manuscript revisions.

Chapter 5 will be revised for submission to a peer-reviewed journal. This manuscript will be co-authored with Dr. Musselman and Dr. Lanovaz. I designed the research question, lead participant recruitment and data collection, performed most of the data processing and analysis, and wrote the manuscript, with their direction and feedback. Dr. Lanovaz assisted with data collection, and data processing. All co-authors were involved in research design and analysis, and contributed to reviewing the chapter.

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DEDICATION

To: 1) The gap between what we know and what we feel; and

2) The memory of the Saskatchewan Transportation Company.

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LIST OF ABBREVIATIONS

3DGA	Three-dimensional gait analysis
10mFWT	10-meter walk test at fastest speed
10mSSWT	10-meter walk test at self-selected speed
AFO	Ankle-foot orthosis
AA-AFO	Angle of the ankle in the AFO
AFO-FC	AFO-footwear combination
CI	Confidence interval
CP	Cerebral palsy
DF	Dorsiflexion
EVGS	Edinburgh Visual Gait Score
GMFCS	Gross Motor Function Classification System
GRF	Ground reaction force
GRFv	Ground reaction force vector
GVS	Gait Variable Score
IC	Initial contact
iAA-AFO	Individualized angle of the ankle in the AFO
MTP	Metatarsophalangeal
PBS	Pediatric Balance Score
PF	Plantarflexion
PT	Physical therapist/physiotherapist, physical therapy/physiotherapy
ROM	Range of motion
TD	Typically-developing
TMSt	Temporal midstance
STROBE	STrengthening the Reporting of OBservational studies in Epidemiology.
SVA	Shank to vertical angle

GLOSSARY

Ankle-foot orthosis: an orthosis that spans the ankle and foot segments of the body

Equinus gait: One of the most common gait patterns associated with CP (the most common according to Cornell, 1995); an inefficient toe-walking pattern associated with ankle plantarflexor muscle tightness and spasticity.

Gait quality: The extent to which the gait pattern deviates from normal (Lord, Halligan, & Wade, 1998).

Gross Motor Function Classification System (GMFCS): An internationally-recognized system for classifying children based on their functional motor abilities (Palisano et al., 2007).

International Classification of Functioning, Disability and Health (ICF): An internationally-recognized framework for measuring health and disability, classifying health and health-related domains, and that provides a common language for this discussion (World Health Organization, 2016a).

Orthosis: An “externally applied device used to modify the structural & functional characteristics of the neuromuscular & skeletal system” (ISO, 1989).

Shank to vertical angle (SVA): The angle between the anterior tibia and vertical in the sagittal plane.

Temporal Midstance (TMSt): The temporal midpoint of the stance phase (i.e., 30% of the gait cycle or 50% of the time interval from initial contact to toe off) (Gibson, et al., 2006).

Trim-lines (of an AFO): Refers to the way the plastic of the orthosis is trimmed during fabrication. For example, trim lines may alter the stiffness of the brace and the motion it allows. By locating the edge of the AFO (i.e., the trim lines) anterior to the malleoli, less sagittal plane ankle motion will be allowed and the ankle and knee will be more stable; more dorsiflexion and plantarflexion will be allowed if the trimlines are posterior to the malleoli (Supan, 2008). Locating the trimlines distal to the metatarsophalangeal joints will prevent extension while locating them proximally will allow more extension.

CHAPTER 1: INTRODUCTION, PURPOSE, AND OBJECTIVES

Rehabilitation for children with neurological conditions such as cerebral palsy (CP) frequently focuses on optimizing gait quality in order to improve gait efficiency and appearance and to reduce musculoskeletal strain. It is common practice for ankle-foot orthoses (AFOs) to be prescribed to address these aims. AFOs can influence joint motion and loading patterns by compensating for motor impairments -- such as poor motor control, and plantarflexor muscle spasticity, inflexibility, and weakness – that are prevalent in this population.

The success of AFO intervention relies on *individualized* prescription of the AFO design, delivering an orthosis that is well matched to the child's specific motor impairments (Davids, Rowan, & Davis, 2007; Harlaar et al., 2010). However, conventional AFO recommendations tend to be generalized, based on simplified biomechanical descriptions of various brace categories (e.g., hinged AFOs, solid AFOs) (Davids et al., 2007; Novacheck, 2008), and broad CP subtypes (e.g., unilateral CP/hemiplegia, bilateral CP/diplegia or quadriplegia) and gait pattern (e.g., equinus, crouch gait) (Rodda & Graham, 2001; Rodda, Graham, Carson, Galea, & Wolfe, 2004; Sutherland & Davids, 1993). AFO prescription is often based on trial and error, and lacks specificity, as there is little evidence to guide the selection of the most suitable AFO design for each individual child (Morris, Bowers, Ross, Stevens, & Phillips, 2011).

While AFOs have demonstrated the potential to improve various aspects of walking (Figueiredo, Ferreira, Maia Moreira, Kirkwood, & Fetters, 2008; Morris et al., 2011), few studies present results that can be applied to improve our understanding of how to effectively individualize the orthotic type and design for each child (Bowers & Ross, 2009). Recently, it has been suggested that clinical prescription practices may not optimize the intervention's potential (Ries, Novacheck, & Schwartz, 2014, 2015), and that they may not be based on biomechanical rationale (National Health Service Quality Improvement Scotland, 2009). The literature's lack of attention to the individualization of AFO prescriptions may contribute to mixed results in some studies, and the current paucity of evidence-based clinical prescription guidelines.

An aspect of the AFO prescription that may be individualized is the angle of the ankle in an AFO (AA-AFO). The AA-AFO is conventionally set at 90˚, and there is a lack of clinical guidance for considering the severity of plantarflexor muscle tightness or the force required to sustain that angle. For example, "severe equinus" is listed as a contraindication for a solid AFO in one text (Beaman, Kalisperis, & Miller-Skomorucha, 2014), while another (Novachek et al., 2009) lists “severe spasticity” as an indication for solid AFOs. Neither define “severe” and neither discuss the AA-AFO as a consideration in the prescription. However, it has been suggested that a better match between the child and the orthosis may be achieved by individualizing the AA-AFO based on a physical assessment of the child’s foot and ankle that considers the measured length of the gastrocnemius muscle as a starting point (Owen, 2005, 2010). While it is likely that the AA-AFO influences the resultant gait pattern and ultimate success of the orthotic intervention (Eddison & Chockalingam, 2013; Jagadamma et al., 2015; Owen, 2014), clinicians lack research to support evidence-based prescription decisions regarding the AA-AFO.

The overarching aim of this thesis was to improve the evidence available to clinicians to guide AFO prescription for children with CP and contribute to the development of best practice guidelines for AFO prescription for this population. In order to identify a suitable focus for improving care, it was necessary to first examine current practice and identify strengths and challenges within this landscape. This thesis is comprised of three studies (Chapters 3-5). The objectives for each study and the hypotheses for study 3 are described below.

1.1 Clinician Experiences with Prescription of AFOs for Children with CP

The objective of this qualitative study was to explore clinician perspectives about the factors that influence AFO prescription for children with CP in Canada. A secondary aim was to compare the results with the current literature and provide recommendations for clinical practice.

1.2 Physical Therapists’ Use of Evaluation Measures to Inform AFO Prescription for Children with CP

In study 1, physical assessment emerged as an area that may be improved to benefit outcomes. Therefore, the purpose of this study was to gain an understanding of physical therapists’ (PTs’) evaluation practises for AFO prescription at both initial prescription and follow-up. Specifically, we hoped to improve our understanding of what is evaluated, how it is evaluated, and how evaluation informs prescription. As well, we aimed to provide recommendations to improve current practice by comparing our results with the published literature.

1.3: The effect of the AA-AFO on walking in children with CP

About half of children with CP use AFOs to improve their walking ability (Wingstrand, Hägglund, & Rodby-Bousquet, 2014). More evidence is needed to guide individualized AFO prescription decisions, based on biomechanical principles. The objective of this study was to compare conventional, community-prescribed AFOs with AFOs that were fabricated with individualized AA-AFOs based on clinical measures of the child's plantarflexor muscle state (as described by Owen, 2005, 2010). This comparison had two primary investigative aims:

1.3.1 Aim #1: gait mechanics

To investigate gait kinematics and kinetics during walking in children with CP and spastic equinus, comparing their usual AFOs with individualized AA-AFOs. The hypothesis was that, compared to their usual AFOs, the children with CP would have gait mechanics closer to typically developing children when the AA-AFOs were individualized to accommodate calf muscle tightness and stiffness.

1.3.2 Aim #2: functional mobility

To examine the effects of a child-specific, individualized AA-AFO on functional mobility. The hypothesis was that an individualized AA-AFO would not impair mobility compared to the child's usual AFO, and that children would perform similarly in tests of functional mobility wearing each orthosis.

Little is known about current AFO prescription practices; yet the success of this intervention rests on their efficacy. An understanding of current practices, treatment philosophies, and contributing factors is necessary to identify stakeholder needs, barriers, and gaps in evidence-based care, and will help to direct the focus of future research and clinical recommendations. This is the multi-faceted context in which evidence-based recommendations will be implemented. By improving the evidence on which prescription decisions are based, service provision and orthotic outcomes are likely to improve for this group of children.

CHAPTER 2: REVIEW OF THE LITERATURE

2.1 Gait Impairments in CP

CP is a group of disorders of movement and postural control that is caused by a disturbance to the developing fetal or infant brain before, during or after birth (Rosenbaum et al., 2007). This condition is the most common cause of childhood disability in western countries, affecting 2-3 of every 1000 live births (Oskoui, Coutinho, Dykeman, Jetté, & Pringsheim, 2013; Smith, Kelly, Prkachin, & Voaklander, 2008). It is associated with a wide range of possible motor and cognitive impairments, activity limitations, and clinical presentations.

Because of this heterogeneity, categorization and classification are necessary mechanisms for describing and comparing the nature and severity of the condition, predicting an individual's needs and outcomes, and evaluating change over time (Rosenbaum et al., 2007). Rosenbaum and colleagues (2007) recommend classifying children with CP according to four main components: 1) motor abnormalities, including the nature and typology of the motor disorder (e.g., tonal and movement abnormalities such as hypertonia, hypotonia, spasticity, athetosis, ataxia, or dystonia) and functional motor abilities (e.g., using the Gross Motor Function Classification System (GMFCS); Palisano et al., 2007); 2) accompanying impairments (e.g., secondary musculoskeletal problems and/or non-motor difficulties like seizures or sensory impairments); 3) causation and timing when there is a clearly identified cause, such in post-natal CP (e.g., meningitis); and 4) anatomical distribution and neuro-imaging findings, if present. Traditionally, terms such as hemiplegia, diplegia, and quadriplegia have been used to describe anatomical distribution; however, these terms are imprecise and not reliably used; therefore, a more reliable approach is to use the term unilateral CP when one side of the body is impaired (instead of monoplegia and hemiplegia), and bilateral CP when both sides are involved (instead of diplegia and quadriplegia) (Palisano, Rosenbaum, Bartlett, & Livingston, 2008; Rosenbaum et al., 2007).

A systematic review by Dobson and colleagues (2007) summarized the range of classification systems to describe the gait patterns observed in this population; however, none of these classification systems adequately describes the range of gait patterns that exist. These systems either lack adequate psychometric properties or were developed using arbitrary definitions/categories. Few described the relationship between clinical impairments and the categories.

More than 65% of children with CP are able to walk to some extent, using a wide range of gait patterns and strategies (Kirby et al., 2011; Pharoah, Cooke, Johnson, King, & Mutch, 1998). For ambulatory children with CP, the neurological injury may result in primary physical impairments such as abnormal muscle activation, force production, and motor control (Gage & Schwartz, 2009). As a result, gait quality impairments may include altered lower extremity joint motions, and decreased walking speed, cadence, and step length (Baker et al., 2009; Ries et al., 2015; Schwartz & Rozumalski, 2008). Joint motions may be excessive or restricted, and/or timed differently in comparison to normal gait (Gage & Schwartz, 2009; Gage & Stout, 2009).

Potential consequences of poor gait quality include increased energy costs, impaired function (e.g., difficulty keeping up with peers), poor balance, and long-term musculoskeletal stresses and pain (Gage & Schwartz, 2009; Gage & Stout, 2009). Over time, abnormal tissue loading and strain associated with altered gait patterns may contribute to musculoskeletal pain and subsequent deterioration or cessation of walking (Bleck, 1987; Bottos, Feliciangeli, Sciuto, Gericke, & Vianello, 2001; R Jahnsen, Villien, Egeland, Stanghelle, & Holm, 2004; Reidun Jahnsen, Villien, Aamodt, Stanghelle, & Holm, 2004; Murphy, Molnar, & Lankasky, 1995; Opheim, Jahnsen, Olsson, & Stanghelle, 2009; Steele, DeMers, Schwartz, & Delp, 2012).

For example, the foot is one of the most common sites of pain in adults with CP (Bleck, 1987). In a survey of 406 adults with CP in Norway, 44% of respondents reported foot pain (Jahnsen et al., 2004), and in another survey of 149 participants, 50% reported foot pain (Opheim et al., 2009). The foot may be a common site of pain in individuals with CP owing to the prevalence of distal lower extremity spasticity and gastrocnemius contracture, as well as gait patterns and foot deformities that impose abnormal biomechanical stresses at the foot during gait (Kadhim & Miller, 2014; Sees & Miller, 2013). For example, equinus gait affects approximately 60% of ambulatory children with CP (Wren, Rethlefsen, & Kay, 2005), and planovalgus foot deformity, which is often associated with equinus gait and gastrocnemius contracture, is the most common foot deformity in this population (Sees & Miller, 2013). When gastrocnemius contracture limits ankle dorsiflexion range of motion (ROM), compensatory motion is required for gait, and this is often achieved by midtarsal dorsiflexion accompanied by subtalar pronation (Karas, 2002), as seen in pes planovalgus. Excessive midfoot dorsiflexion can disrupt the foot’s ability to function as a rigid lever in late stance and pre-swing, thereby reducing ankle power, and can contribute to the development of pain associated with excessive pronation or midfoot break (Gage & Schwartz, 2009; Karas, 2002; Maurer et al., 2013).

Gait quality varies widely between children, depending on the location and extent of the neurological injury, and the effects of that injury (e.g., abnormal muscle tone, impaired balance and motor control, deformity; Gage & Schwartz, 2009; Novachek et al., 2009). Although the brain injury associated with CP is static, the appearance and quality of a child's gait changes over time– with growth or with interventions like surgery or orthoses (Gage & Schwartz, 2009; Johnson, Damiano, & Abel, 1997; Wren, Rethlefsen, & Kay, 2005).

2.2 Types of AFOs for Children with CP

A variety of orthoses can be useful for children with neurological impairments. Custom-made AFOs are frequently prescribed in clinical practice to address an individual's biomechanical and neurological impairments and improve walking performance. For example, a Swedish study reported that at least half of children with CP wear AFOs, with the most common purposes being to improve function and/or increase or maintain range of motion (Wingstrand et al., 2014). Several styles of AFO (e.g., solid, hinged) and design options (e.g., trim-lines, strapping configurations, AA-AFO) are used, each with different biomechanical effects, intended to be selected to match the individual child's needs.

Solid AFOs are fabricated as a single piece with plastic spanning the ankle joint, intended to prevent sagittal and frontal plane motion of the ankle, as well as subtalar joint and foot motion (Figure 1.1A-C). They are designed to prevent motion by applying forces at three points – directly at the level of the joint to be stabilized, and proximal and distal to it (Meadows, Bowers, & Owen, 2008). Carbon ribs or folds can also be added to reinforce the ankle joint. The AA-AFO is typically set at 90˚ (Figure 1.1A) but can also be set in some degree of plantarflexion (Figure 1.1B). Depending on whether the plastic is trimmed distal or proximal to the MTP (metatarsophalangeal) joints, the AFO can restrict or allow MTP extension in terminal stance and preswing. To help harness the ground reaction force (GRF) in stance, directing it to the anterior tibia to assist knee extension, a Saltiel design GRF AFO (with a pretibial shell and strapping

Figure 1.1. Common types of AFOs: A. Solid AFO with 90˚ AA-AFO; B. Solid AFO with AA-AFO in 10˚ plantarflexion; C. Ground reaction force AFO; D. Hinged AFO; E. Energy storage and return AFO; F. Semi-flexible plastic commercial AFO (Flexisport, Cascade DAFO, Ferndale, WA); G. Carbon fiber AFO ToeOFF carbon composite dynamic floor reaction orthosis, Allard USA, Rockaway, NJ).

behind the calf; Figure 1.1C) may be used (Harrington, Lin, & Gage, 1984), or a solid AFO may be fabricated with an anterior tibial shell that is attached using Velcro straps.

Another type of AFO is a hinged or articulated AFO (Figure 1.1D). These are composed of two sections – one for the shank segment and one for the foot, with medial and lateral joint components connecting the two sections. The joints are intended to be aligned with the axis of the talocrural joint, to allow sagittal plane motion while limiting motion in the frontal plane. They can be designed to limit plantarflexion, by using a plantarflexion stop, often limiting plantarflexion beyond 90º while allowing dorsiflexion. Joint components that assist dorsiflexion motion can be employed to compensate for weakness of the ankle dorsiflexor muscles.

Solid and hinged AFOs are often custom-fabricated from polypropelene. The plastic is heated to around 200º Celsius, then drape-formed and vacuum molded over a 3-dimensional positive plaster model that has been created by casting or electronically scanning the child’s lower leg and foot (Supan, 2008). The plastic is usually 3/16” (4.8mm) thick, but other thicknesses may be used depending on the amount of stiffness required to resist the forces applied by the child during gait. Semi-flexible AFO styles allow the AFO to bend at the ankle or other areas, either through the material properties or by trimming the orthosis posterior to the malleoli. Some are designed to store energy during stance and release it to aid propulsion or allow a more normal gait pattern. Examples include posterior leaf spring AFOs, energy storage and return AFOs, and commercially available orthoses made from plastics (e.g., Flexisport, Cascade DAFO, Ferndale, WA) and carbon fiber (e.g., ToeOFF carbon composite dynamic floor reaction orthosis, Allard USA, Rockaway, NJ; Figure 1.1E., F., G).

Although numerous laboratory studies have shown that AFOs can improve aspects of gait quality such as step length and velocity, these research findings cannot be generalized to clinical situations (Bowers & Ross, 2009); most samples are quite small, heterogenous and poorly described, and the analyses focus on mean results. This is problematic because the mean is unlikely to be meaningful in the presence of the high intra-individual variability observed in individuals with CP; when some children improved, and some got worse, reporting only the mean can obscure important differences in how individuals responded to an intervention (Damiano, 2014). Most studies of AFOs have not been designed to examine the effects of elements of the prescription such as AFO type on individual children and they provide little information about the characteristics of the orthoses or the individual participants. Therefore, results attained in research and clinical settings may not be analogous or applicable across settings. While *clinically prescribed* AFOs may improve some aspects of walking such as dorsiflexion kinematics and stride length (Hayek et al., 2007), authors of a large cohort study reported that 63% of the clinical AFO prescriptions failed to optimize gait quality, and predicted that a change in prescription (e.g., AFO type) would have significantly improved the child's gait quality (Ries et al., 2014). Results of a smaller study showed that children may walk less in the community when they wear their AFOs, compared to when they wear shoes alone (Bjornson et al., 2016). These are important findings, given the numbers of children who wear AFOs and the resources invested in this intervention. Therefore, further study is needed in order to understand how to optimize a child's prescription to improve the match between the child and the orthosis.

2.3 Biomechanical Effects of AFOs for Children with CP

AFO use can benefit walking in multiple ways, including increased step length and velocity, better balance, and improved joint and segment motion (Bowers & Ross, 2009; Figueiredo et al., 2008; Morris, 2002; Ries et al., 2015). With respect to joint kinematics, AFOs are thought to primarily affect the foot and ankle, although proximal effects (e.g., increased hip and knee extension) have been described during stance phase (Butler & Nene, 1991; Eddison & Chockalingam, 2013; Jagadamma et al., 2010, 2015; Owen, 2010). These effects are primarily reported in the sagittal plane (ankle dorsi-/plantarflexion, hip and knee flexion) (Bowers & Ross, 2009), likely because this is the plane in which most gait cycle motion occurs, and the plane in which its design gives it the greatest leverage.

The ankle plantarflexor muscles play a key role in both the stance (weightbearing) and swing (non-weightbearing) phases of the gait cycle. During stance phase, controlled gait is dependent on the alignment of the ground reaction force vector (GRFv) relative to the lower extremity joints (Butler, Thompson, & Major, 1992; Eddison & Chockalingam, 2013; Meadows, 2014). As the plantarflexors control the forward progression of the body over the foot, they also prevent collapse of the weightbearing leg by controlling the location of the GRFv (Arnold, Anderson, Pandy, & Delp, 2005; Perry & Burnfield, 2010). The actions of these muscles in terminal stance and preswing are not fully understood, but it appears that tension developed in these muscles during eccentric contraction is key to forward progression and transition into swing phase (Fukunaga et al., 2001; Neptune, Kautz, & Zajac, 2001; Perry & Burnfield, 2010). Assuming adequate ankle dorsiflexion range of motion, timely relaxation of the plantarflexors also allows the swinging foot to clear the floor in preparation for the subsequent step (Novachek et al., 2009). Therefore, neurological conditions that impair plantarflexor muscle function (such as CP) can hinder mobility by impairing postural control, resulting in undesirable lower limb movements, which may be amenable to AFO intervention.

By encompassing the foot and lower leg, a solid AFO aims to stabilize the ankle joint, compensating for abnormal plantarflexor muscle function and controlling some of these gait deviations. For example, it may prevent excessive plantarflexion in the case of plantarflexor spasticity or inadequate flexibility; it may also maintain a position of adequate plantarflexion (i.e., prevent dorsiflexion or crouching) and generate a plantarflexing moment when the plantarflexor muscles are weak (Davids et al., 2007). Excessive dorsiflexion or plantarflexion motion during stance phase moves the GRFv farther anterior or posterior to the lower extremity joints, contributing to abnormal joint moments, strain, and inefficiency. By redirecting the GRFv closer to the lower extremity joints vertically, a well-designed AFO can promote stability and improve gait (Butler & Nene, 1991).

The greatest benefits of orthotic intervention are thought to be conferred when brace design is optimally tailored to address the individual child's physical impairments (e.g., lower extremity joint flexibility, abnormal muscle tone, bony deformity) and walking pattern (Davids et al., 2007; Harlaar et al., 2010; Owen, 2010, Owen, 2015). Ideally, the mechanical properties of the brace will control the abnormal forces (resulting from the child's neurological impairments), optimizing the resultant joint motions and producing a more normal gait pattern (Butler & Nene, 1991; Novacheck, 2008; Owen, 2010). Therefore, the effectiveness of an AFO prescription on gait quality may be evaluated by objectively describing the child's gait pattern, and quantifying the extent to which it differs from normal, with and without the AFO (Galli, Cimolin, Rigoldi, & Albertini, 2016).

2.4 AFO-Footwear Combination Tuning

AFO-Footwear Combination (AFO-FC) tuning involves the biomechanical optimization of the AFO-FC for a specific activity, such as walking (Bowers & Ross, 2009; Eddison & Chockalingam, 2013; Meadows, 2014; Owen, 2018). The shank to vertical angle (SVA) of the AFO-FC may be tuned or adjusted to optimize the alignment of the GRFv relative to the lower extremity joints (Jagadamma, 2010; Novachek et al., 2009; Owen, 2004a, 2010). This may involve adapting the heel or sole (e.g., using heel flares, heel wedges, or toe rockers) (Owen, 2004b, 2010). If the AFO is sufficiently rigid, tuning may improve stance phase stability by altering external joint moments (Bowers & Ross, 2009; Butler et al., 1992; Eddison & Chockalingam, 2013; Meadows, 2014; Morris et al., 2011; Owen, 2010; Pratt, Durham, & Ewins, 2007).

While tuning has been recommended to improve lower extremity kinematics in children with CP (Bowers & Ross, 2009; Eddison & Chockalingam, 2013; Jagadamma et al., 2015), the process is not well-utilized in practice, nor are its effects fully understood (Eddison, Chockalingam, & Osborne, 2015; Meadows, 2014). In typical gait, the shank is reclined relative to vertical at initial contact (IC), and then inclines progressively throughout midstance as the ankle dorsiflexes. This gradual increase in shank incline facilitates forward progression, allowing the body's centre of mass to continue to move forward, and the centre of pressure to progress distally along the foot; however, a solid AFO is designed to prevent this ankle motion, so it likely impairs this aspect of gait. Compounding this problem, AFO-FCs are typically aligned to produce a vertical tibia at temporal midstance (TMSt), even though the tibia normally inclines to approximately 10˚ at that point in the gait cycle for adequate stability in stance (E Owen, 2010; Tilley & Associates, 1993). Therefore, the typical alignment of an AFO-FC with a solid AFO (with a 90˚ AA-AFO and 0˚ to 5˚ forward pitch in the shoe) may induce compensatory gait strategies to progress forward while walking. Thus, gait impairments may be created or exacerbated by the biomechanical restrictions imposed by the AFO-FC.

Shank kinematics and the SVA provide another – perhaps more direct way – to view the effects of AFOs on gait kinematics. Many studies focus on ankle, knee and hip joint kinematics as an indication of AFO efficacy (Bowers & Ross, 2009); but the effect of an orthosis on knee and hip joint motion is indirect. Because of the direct effect of the AFO-FC on the SVA, and the direct influence of the SVA on lower extremity joint moments, the SVA at TMSt may be another meaningful outcome (Eddison, Healy, Needham, & Chockalingam, 2017; Jagadamma et al., 2010, 2015; Kerkum, Houdijk, et al., 2015; Meadows et al., 2008; Owen, 2010; Pratt et al., 2007). Normative SVA values have been studied in a small number of typically developing children (Pratt, 2007), and a few authors have reported optimal SVAs in populations with neurological impairments (Eddison et al., 2017; Eddison & Chockalingam, 2013; Jagadamma et al., 2009; Nuzzo, 1986; Owen, 2004a). Owen has also published guidelines for AFO intervention based on SVA (Owen, 2010), although these have not been tested empirically.

A small but growing body of evidence supports the use of tuning for children with neurological conditions like CP; however, these studies are typically of low methodological quality – tending to be small and lack key details about the orthoses, participants, and methodology (Eddison, Mulholland, & Chockalingam, 2017; Eddison & Chockalingam, 2013; Ridgewell, Dobson, Bach, & Baker, 2010). Tuning is not yet standard practice, possibly due to barriers relating to inadequate research evidence and clinician knowledge (Eddison et al., 2015). Yet, tuning has been recommended for individuals wearing AFOs following stroke (National Health Service Quality Improvement Scotland, 2009) and children with CP who wear solid AFOs (Bowers & Ross, 2009; Meadows, 2014). For children with CP, some of the effects of tuning include reduction of knee hyperextension for children with extended knee or jump knee gait patterns (Jagadamma et al., 2015). Two studies (Butler, Farmer, Stewart, Jones, & Forward, 2007; Jagadamma et al., 2015) reported that the effects of tuning depended on the child's gait pattern at the knee. Butler and colleagues (2007) found that children whose AFOs could be successfully tuned showed 20˚ of knee flexion or less in the first third of stance followed by extension to 10° or less in the second third of stance. However, neither paper included details about the AFOs, such as the AA-AFO.

2.5 Methodology – Measuring the Effects of an AFO

2.5.1 Laboratory methods of orthotic evaluation

Published research studies have provided a variety of information about the effects of AFOs for children with CP. This data has primarily been collected in laboratory studies using three-dimensional gait analysis (3DGA) to examine variables including kinematics (e.g., ankle, knee, hip, and shank) and kinetics (e.g., GRF, ankle, knee and hip), spatiotemporal variables (velocity, step length, cadence), muscle excursion (using muscle length modelling) (Choi, Wren, & Steele, 2017; Choi, Wren, & Steele, 2014), or EMG (Lam, Leong, Li, Hu, & Lu, 2005; Radtka, Skinner, & Johanson, 2005; Rethlefsen, Kay, Dennis, Forstein, & Tolo, 1999; Romkes, Hell, & Brunner, 2006; Romkes & Brunner, 2002; Wren, Rethlefsen, & Kay, 2005). Wearable sensors and instrumented walkways have also been used to obtain spatiotemporal gait data. The effect of AFOs on function has been assessed using tools like the Timed Up and Down Stairs (Sienko Thomas, Buckon, Jakobson-Huston, Sussman, & Aiona, 2002), and the Pediatric Balance Scale (Kott & Held, 2002).

The gold-standard for quantifying gait impairments, and evaluating spatio-temporal variables, kinematics, and kinetics is instrumented 3DGA. Kinematic and kinetic data can be plotted for one or more gait cycles, and curves can be visually compared between conditions (e.g., barefoot, shoes, AFO) or with normative data; or meaningful discrete values can be calculated and compared (e.g., peak knee flexion in stance; velocity). Gait quality summary measures (e.g., Gillette Gait Index (Schutte, Stout, Gage, & Selber, 1997; Wren et al., 2007), Gait Deviation Index (Schwartz & Rozumalski, 2008), and Gait Profile Score (Baker et al., 2009; Beynon, McGinley, Dobson, & Baker, 2010)) can also be calculated by comparing data from 3DGA to normative reference values. Such indices seek to provide a concise measure of gait quality that objectively quantifies the overall severity of the gait problem (Cimolin & Galli, 2014), or to monitor changes over time or in response to treatment (Baker et al., 2009). Although gait observation is a daily function for mobility experts such as physical therapists, doctors, and orthotists, 3DGA requires significant resources, equipment, and expertise, and is rarely accessible to clinicians (Toro, Nester, & Farren, 2003a). Furthermore, these global indices may not be specific enough to identify the effects of focussed orthotic intervention on isolated, yet targeted, gait parameters such as ankle kinematics (Danino et al., 2012; Galli et al., 2016).

2.5.2 Clinical methods of orthotic evaluation

Clinicians lack a simple means to describe walking patterns, identify deviations, and monitor change in order to evaluate the effects of AFO intervention with accuracy and specificity (Rathinam, Bateman, Peirson, & Skinner, 2014). Currently, observational gait assessment – performed using either the unaided eye or video recording – is the most common means of identifying and describing gait deviations and impairments in clinical environments (Toro et al., 2003b). Gait observation is readily applied in clinical practice, as it is quick, requires little space, and does not use specialized equipment (Krebs, Edelstein, & Fishman, 1985; Toro et al., 2003a). It is typically approached in an unsystematic fashion, without standardized protocols or checklists (Toro et al., 2003a). Despite its wide popularity, gait observation is subject to observer bias and error, and therefore its reliability and its validity with respect to 3DGA have been questioned (Coutts, 1999; Kawamura et al., 2007; Krebs et al., 1985; Maathuis, van der Schans, van Iperen, Rietman, & Geertzen, 2005; Toro et al., 2003a; Toro et al., 2003b).

The challenges of accurately observing the complex motions of live, pathological gait in a clinical setting are likely associated with physiological error, incurred as the visual system infers

2-dimensional information from a 3-dimensional context (Lappin & Fuqua, 1983). This error is likely compounded by the speed of human visual tracking with respect to the complexity and constant multiaxial motion of abnormal gait (Bahill & McDonald, 1983; Krebs et al., 1985). Parallax error, or the discrepancy between the observer's line of sight and the plane of motion may also contribute (Deluca, Davis, Ounpuu, Rose, & Sirkin, 1997; Kawamura et al., 2007). For instance, an observer may underestimate the amount of flexion at the knee (sagittal plane) when there is excessive concurrent hip internal rotation (transverse plane) (Deluca et al., 1997).

Standardized checklists (e.g., the Physicians Rating Scale (Koman, Mooney, Smith, Goodman, & Mulvaney, 1993) and its subsequent iterations (Boyd & Graham, 1999; Mackey, Lobb, Walt, & Stott, 2003), the Salford Gait Tool (Toro, Nester, & Farren, 2007a), and the Edinburgh Visual Gait Score (EVGS; Read, Hazlewood, Hillman, Prescott, & Robb, 2003) are thought to improve the accuracy and consistency of gait observation (Bella, Rodrigues, Valenciano, Silva, & Souza, 2012; Brown, Hillman, Richardson, Herman, & Robb, 2008; Dickens & Smith, 2006; Ferrarello et al., 2013; Gupta & Raja, 2012; Hillman et al., 2010; Hillman, Hazlewood, Schwartz, van der Linden, & Robb, 2007; Mackey et al., 2003; Ong, Hillman, & Robb, 2008; Read et al., 2003; Toro et al., 2003a; Toro, et al., 2007a; Toro et al., 2007b). Yet, within the literature examining the psychometric properties of these scales, estimates of reliability and validity vary widely − even between similar items on different scales. For example, while Read and colleagues (2003) reported 83% agreement between 3DGA and ratings of maximum ankle dorsiflexion in swing, Kawamura and colleagues (2007) found very low kappa scores (0.01-0.10) for the nearly-identical item, dorsiflexion at IC. Similarly, this first study (Read et al., 2003) reported near-perfect agreement between 3DGA and 64% of numerical items on the EVGS; while the latter (Kawamura et al., 2007) concluded that ratings of only two gait variables (pelvic obliquity and knee flexion at IC) were valid. Yet, gait observation is a fundamental clinical tool, and gait scales provide a means to modestly improve the objectivity and standardization of gait analysis compared to unstructured observation alone.

Despite inconsistencies across different scales, there is evidence that certain elements of gait can be reliably and accurately observed, given the right conditions. McGinley (2003) concluded that when attention is focussed on a single gait variable (i.e., ankle power in adults following stroke), and the task is clearly defined, therapists can make accurate and reliable judgements from a gait video. Other authors have reported that numeric items (e.g., using degree or degree-based categories to rate joint position; Grunt et al., 2010; Hillman et al., 2010), and gait events in the sagittal plane (Coutts, 1999; Krebs et al., 1985; Mackey et al., 2003; Read et al., 2003) may be most reliably rated. Other factors that may improve the reliability and validity of gait observations include: high quality video (Dickens & Smith, 2006; Fatone & Stine, 2015; Harvey & Gorter, 2011; Wren, Rethlefsen, Healy, et al., 2005), video analysis software (Borel, Schneider, & Newman, 2011; Grunt et al., 2010), clear definitions of scale items (Mackey et al., 2003), standard rater education about normal gait kinematics (Krebs et al., 1985), standardized camera views (e.g., orthogonal views in line with the camera's optical axis; Fatone & Stine, 2015), and subject preparation methods such as tight-fitting clothes and markings on the skin over anatomical landmarks (Fatone & Stine, 2015; Hillman, Hazlewood, Loudon, & Robb, 1998; Viehweger et al., 2010).

2.6 Overview of Current AFO Prescription Processes in Canada

AFO prescription (including evaluation and determination of the prescription, and follow-up) ideally involves the child and family, physician, certified orthotist, and physical or occupational therapist (Uustal, 2008). In Canada, where health is a provincial responsibility, provincial governments determine the types of orthoses that will be funded or partially funded, the criteria for each type of orthotic device, and the conditions (including the frequency) under which they can be prescribed and dispensed (e.g., Government of Saskatchewan, 2018). In Saskatchewan, AFOs must be requisitioned by a physician and most are fabricated and dispensed by orthotists at two publicly-funded facilities (Government of Saskatchewan, 2016). These centres provide tertiary service to the province. There are also a small number (<5) of private orthotists, though only one or two provide (infrequent) services to children with CP. Follow-up is typically provided by the primary care provider/community therapist, in conjunction with the team at the tertiary facility (Government of Saskatchewan, n.d.). Although many aspects of the AFO prescription process could affect the success of the intervention, this process (including aspects such as which disciplines are involved, the timing of involvement, and the role of each provider) has not been described in the literature. Furthermore, if best practice guidelines are to be developed for AFO prescription, they would need to be implemented within this context.

With respect to gait quality, the efficacy of AFO intervention may fall short of its potential (Ries et al., 2014, 2015). The reasons behind this are not understood; however, it is likely that developing a valid and reliable means of clinical gait evaluation specific to AFO intervention is an important step toward more efficacious prescription. Recent evidence (Ries et al., 2014), highlights a lack of evidence-based guidelines and outcome measures for AFO prescription and evaluation. Instead, the process appears to be guided by clinical opinion, preference, and trial and error (Morris, Newdick, & Johnson, 2002). While objective and accurate documentation of treatment goals and progress has been recommended for effective AFO provision (Davids et al., 2007), it is not clear whether goal-setting occurs consistently (Ries et al., 2015), or how – or even if – outcomes are assessed.

2.7 AA-AFO

Although plantarflexor muscle flexibility greatly affects gait, determination of the optimal angle at which to position the ankle within an AFO (i.e., the AA-AFO) has not been explored (Eddison & Chockalingam, 2013; Jagadamma et al., 2015; Owen, 2010). AFOs are traditionally fabricated with the child's ankle at a 90˚ angle in the sagittal plane. This is typically done with the intention of stretching the spastic plantarflexor muscles and preventing deformity; however, there is insufficient evidence to support this practice (Eddison & Chockalingam, 2013; Morris et al., 2011). Furthermore, for children with equinus, these muscles (which span the knee, ankle and hind-foot joints) may lack the length or flexibility to allow the ankle and foot to achieve this position without compromise. Even if the child's ankle can be forced to a 90˚ angle while at rest during an examination, spastic muscles are stiffer than typical muscles, and muscular activity increases excessively with the physical effort of walking (Van Der Krogt, Doorenbosch, Becher, & Harlaar, 2010).

When an AFO's form requires greater flexibility of the plantarflexor muscles than the child has, as in the case of a 90˚ AA-AFO for a child with equinus, the ankle motion required to wear the brace often occurs at the expense of other tissues and walking is uncomfortable. Activation of the fully lengthened muscles is impaired (Lieber, 2002), and gait compensations may include an inability to straighten the knee, altered foot contact with the floor, and compromised foot posture (Owen, 2010; Ridgewell et al., 2010). Children may also be less likely to wear their AFOs if they are uncomfortable or hinder mobility. Given that mobility optimization and deformity prevention are two key reasons for AFO prescription for children with CP (Novachek et al., 2009), the consequences of orthotic non-compliance or AFO-induced deformation may be significant.

As an alternative to the conventional 90˚ AA-AFO, Owen (2005, 2010). describes a method for determining an individualized AA-AFO that reflects calf muscle function during the dynamic task of walking and is based on clinical measures of the child's plantarflexor muscle length and stiffness. This approach has not been examined in an experimental setting.

2.8 Gaps in the Literature

As with many areas in rehabilitation, there are challenges with conducting high-quality research on AFO prescription for children with CP, and numerous gaps exist. Populations are heterogenous, and problems are multifactorial. Studies often report the means of select variables for the group of children with CP; however, for diverse populations such as children with CP, the mean is likely to represent a variety of responses to the intervention, and therefore is not meaningful (Damiano, 2014). As a clinician's role is to tailor the intervention to an individual child, research evidence may be more meaningful if studies described the observed variation or strove to understand individual responses to intervention. Gait impairments in CP are not well understood, and the factors impacting a child's response to an AFO are unknown. Furthermore, the characteristics of the orthoses and participants are often not fully described in the literature, making it difficult to generalize and interpret the results for clinical purposes (Bowers & Ross, 2009; Ridgewell et al., 2010). Most studies have not incorporated tuning and biomechanical optimization, possibly affecting study outcomes, and making comparisons difficult. These factors (among others) suggest a lack of evidence to guide clinical AFO prescription practice.

Clinical AFO prescription appears to face several challenges - perhaps in part because of the state of the evidence - although these have not been described in detail. Variable practices have been described, reliant on subjective judgements and local experience rather than objective evaluation and biomechanical rationale (Morris et al., 2002; National Health Service Quality Improvement Scotland, 2009). Research evidence seems inadequate to allow prescriptions to be based on biomechanical principles. In the absence of evidence, some conventional practises – such as the ubiquitous 90˚ AA-AFO – appear to contravene biomechanical reasoning.

As such, the outcomes of AFO prescription have the potential to be aided by evidence-based guidelines. Key steps toward improving clinical outcomes and furthering orthotic research are: 1) to describe the present state of AFO prescription for children with CP, and 2) to begin to understand the biomechanical effects of key aspects of the AFO prescription, such as the AA-AFO.

CHAPTER 3: CLINICIAN PERSPECTIVES AND EXPERIENCES IN THE PRESCRIPTION OF ANKLE-FOOT ORTHOSES FOR CHILDREN WITH CEREBRAL PALSY

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3.1 Abstract

Purpose: Physiotherapists, orthotists, and physicians are involved in the prescription of ankle-foot orthoses (AFOs) for children with cerebral palsy (CP); however, little is known about how prescription decisions are made in practice. Therefore, the study objective was to identify current AFO prescription and clinical decision-making practises for children with CP in Canada. ***Methods:*** Focus groups were conducted in five pediatric rehabilitation facilities, with 32 clinicians. Semi-structured interviews focused on the goals and types of AFOs used, referral and follow-up processes, and clinical evaluation measures. Interpretive Description was used as a framework for analysis. Transcribed dialogue was imported into NVivo 11 for data coding and analysis. Three researchers participated in coding to establish categories and themes. ***Results:*** Categories included: what is made, how it is used, and factors that either support or challenge outcomes. Strengths and challenges of the current prescription process were discussed, including funding, communication, and technology to enhance clinical evaluation. Throughout the interviews, the theme of prescription as a collaborative, iterative, and individualized process emerged. ***Conclusions:*** Processes, strengths, and challenges associated with AFO prescription in Canada were identified. This is a first step toward the development of guidelines to help clinicians improve AFO prescription for children with CP.

KEYWORDS: clinician decision-making; interpretive description; cerebral palsy; ankle-foot orthoses; orthotic prescription

3.2 Introduction

Cerebral palsy (CP) is a neurodevelopmental disorder of movement and postural control that is caused by a disturbance to the developing infant or fetal brain (Rosenbaum et al, 2007). While approximately 2/3 of children with CP attain some independent walking ability (Pharoah et al, 1998), gait impairments vary depending on the location and extent of the neurological injury, and the resultant impairments (e.g., abnormal muscle tone, impaired balance and motor control, deformity) (Gage & Schwartz, 2009). Children with CP may experience limitations across all domains of the International Classification of Functioning, Disability and Health (ICF) framework (World Health Organization, 2016a), including body structures and functions, (e.g. spasticity), activity (e.g., mobility), and participation (e.g., attending school) (Schiariti & Masse, 2015; World Health Organization, 2016b).

Custom-made walking braces called ankle-foot orthoses (AFOs) are frequently prescribed for children with CP, to address biomechanical and neurological impairments, and improve walking performance. AFO intervention is known to improve several aspects of gait, such as mechanics, step length, and velocity (Bowers & Ross, 2009); however, the greatest benefits appear to be conferred when brace design is optimally tailored to the individual child's physical impairments and gait pattern (Davids, Rowan, & Davis, 2007; Harlaar et al, 2010; Owen, 2010, 2015). Ideally, the mechanical properties of the brace will control the abnormal forces (which result from the child's neurological impairments), optimizing the resultant joint motions and producing a more normal gait pattern (Butler & Nene, 1991; Novacheck, 2008; Owen, 2010).

Although numerous studies and reviews have reported the benefits of AFOs in research-based laboratory settings (Bowers & Ross, 2009; Morris et al, 2011), AFOs may not achieve the same standard of effectiveness in clinical practice. As an example, Ries, Novacheck and Schwartz (2014) reported that only 37% of AFO prescriptions in a clinical sample maximized the child's gait quality, and 28% of the prescriptions negatively impacted gait pattern. The same group (Ries, Novacheck, & Schwartz, 2015) reported that increased step length was the only consistent, clinically-significant benefit of AFO use, and suggested that clinicians require a more effective approach to AFO prescription. However, to date, the perceived challenges and opportunities associated with clinical AFO prescription have not been examined, and little is known about the way prescription decisions are made in clinical settings.

When prescribing and designing an AFO, clinicians choose from numerous types of orthoses (e.g., solid ankle, hinged) and design options (e.g., strapping, trim-lines), in order to deliver the optimal orthosis for each child (Davids, Rowan, & Davis, 2007). Current research focuses broadly on CP subtype (e.g., hemiplegia, diplegia) and gait pattern (e.g., patterns of knee involvement, and hemiplegic gait patterns; Sutherland & Davids, 1993; Winters, Gage, & Hicks, 1987), as the factors determining AFO selection (Bowers & Ross, 2009; Radtka, Skinner, & Johanson, 2005). While a few authors advocate that individual factors (e.g., each child's range of motion) should influence the prescription (Davids, Rowan, & Davis, 2007; Owen, 2010; Ridgewell, Dobson, Bach, & Baker, 2010), specific evidence-based guidelines are lacking (Harlaar et al., 2010; Ries, Novacheck, & Schwartz, 2014). Instead, the process appears to be guided by subjective clinical opinion and prescriber preference (Morris, Newdick, & Johnson, 2002). While objective and accurate documentation of treatment goals and progress has been recommended for effective AFO provision (Davids, Rowan, & Davis, 2007), goals and goal attainment are generally not reported in the literature (Ries, Novacheck, & Schwartz, 2015). The extent to which objective measures are used to evaluate the effectiveness of the AFOs that are prescribed is also unclear.

Therefore, the purpose of this qualitative study was to learn about the experiences of clinicians, in order to identify current AFO prescription and clinical decision-making practices. As this topic has not been examined previously, qualitative methodology was considered the most effective way to explore and gain a first-hand understanding of current practices, as well as the perceived challenges associated with AFO prescription.

3.3 Methods

3.3.1 Design

Interpretive Description (Thorne, Reimer Kirkham, & MacDonald-Emes, 1997) provided a framework for this study. As a grounded approach to conducting qualitative health research, Interpretive Description extends beyond simple description to examine meanings and explanations underlying participants' experiences (Thorne, Reimer Kirkham, & O'Flynn-Magee, 2004). It aims to produce a new interpretation of a complex clinical experience and can help to inform practice (Thorne, et al., 2004). The study was approved on ethical grounds by the Research Ethics Boards of the University of Saskatchewan and Regina Qu'Appelle Health Region.

3.3.2 Participants

Purposive, convenience sampling was used to select rehabilitation centres that provide primary (within health region) and tertiary (outside of region) orthotic care to children under a publicly-funded, single payer health system (including physician, orthotic, and physical therapy services). This strategy was anticipated to facilitate access to potential participants who could provide rich, meaningful data that would be relevant to the study purpose (Milne and Oberle, 2005; Morse, 2015). Five rehabilitation centres in four Canadian provinces participated. A physical therapist (PT) at each facility invited all physical therapists, orthotists, and physicians involved in AFO prescription for children with CP at the centre to take part in the focus group.

Participants were 4 physiatrists, 17 physical therapists, 10 orthotists, and 1 kinesiologist. Within the group, clinical experience in pediatrics ranged from 1 year to 39 years.

3.3.3 Data collection

One or two of the researchers (KJK and/or KEM) conducted an in-person focus group at each participating centre. Both researchers were present at two interviews, and due to the need to travel, the remaining interviews were conducted by one researcher (KJK or KEM). A semi-structured interview guide was used (table 3.1) and the discussions were audio-recorded. Focus group meetings lasted 35-56 minutes and group size ranged from 3-9 participants. Researchers wrote field notes and impressions following each meeting, and small modifications to the semi-structured interview guide were made throughout the data collection process, consistent with an interpretative approach.

3.3.4 Analysis

Interviews were transcribed verbatim. One researcher (KJK) read the transcripts several times and listened to the audio recordings, in order to review the transcripts for accuracy and to aid in analysis. Following member checking (i.e., participant review of the transcript for accuracy), transcripts were imported into NVivo 11 for data management, coding, and analysis.

Table 3.1. *Examples of open-ended questions from the interview guide that were used in the focus group meetings*

Sample questions used in semi-structured interviews
1. What do you see as the purpose of an AFO? What are some typical goals for AFO intervention?
2. What are the most common AFO types and design features your program uses? When is each one used?
3. When determining the prescription for the new AFO, what are the important factors or clinical measurements that you consider?
4. After the child is fitted with the AFO, how is it evaluated or assessed?
5. What do you think works well in your facility's current AFO prescription process? What factors do you think are important in providing children with AFOs that are beneficial to them?
*Note that additional questions and probes were asked as appropriate to the discussion at each facility.

Three researchers (KJK, PJM, KEM) then independently coded one transcript deemed to contain the richest data. Codes were then discussed as a group. This was done in order to inductively derive preliminary categories and themes based on the units of information that made up the transcripts (Morse, 2008). Using the preliminary categories, two researchers (KJK and KEM) coded the remaining transcripts independently and resolved discrepancies through discussion.

Transcripts were reread several times after initial coding to review interpretations, and similarly coded segments were compared to ensure coding definitions were applied consistently (Corbin & Strauss, 1990; Hewitt-Taylor, 2001). New codes were added as necessary, and the preliminary analytic structure was adjusted several times as data were re-contextualized through constant comparative and iterative analysis (Corbin & Strauss,1990; Hewitt-Taylor, 2001; Thorne, et al., 2004). Notes were made about how decisions were reached, in order to increase credibility (Emden & Sandelowski, 1999; Thorne, et al., 2004) and transparency (Tracy, 2010). Once the transcripts had been coded, and preliminary codes and a theme identified, three researchers (KJK, PJM, KEM) discussed the developing analytic structure and the need for further adjustments.

3.4 Results

Participants described AFO prescription as an iterative, collaborative, individualized process. This theme ran through the clinicians' discussions about their experiences with AFO prescription (Figure 3.1). Participants talked about "what is made", "how it is used", and topics that bridged the spaces between and within these categories. They discussed "supports/challenges" that were foundational to the "what" and "how" categories. These categories are examined below.

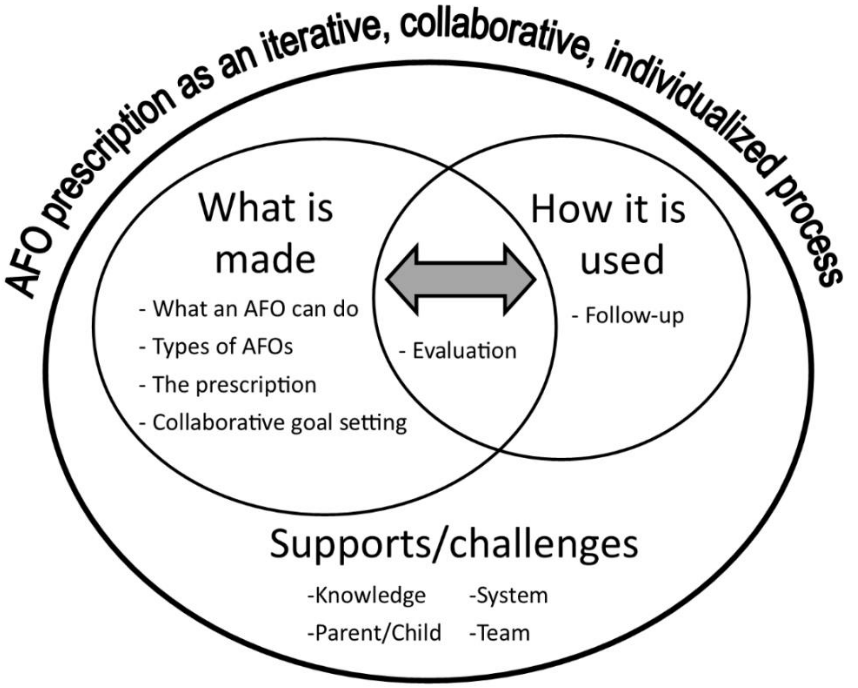

Figure 3.1. Diagram showing relationships between categories. While the orthosis that is made ("What is made") influences its effects ("How it is used"), the effects of the orthosis also impact decisions about the revisions and adjustments to the design of the orthosis. As such, the bidirectional arrow represents the capacity for the prescription to evolve, which is the essence of the theme.

3.4.1 Category 1: What is Made

Participants discussed the AFOs that are made, and the procedures that are involved in prescription. They identified types of information that clinicians consider when determining the initial prescription and as the prescription evolves. The category was comprised of four subcategories: What an AFO can do, Types of AFOs, The prescription, and Collaborative goal setting.

3.4.1.1 What an AFO can do

Participants described the purpose of an AFO as both preventative, and to effect therapeutic change. AFOs are “adjuncts to the rest of the treatment” (physician). Using the ICF framework, most reported uses were at the level of body structure and function. Here, AFOs were thought to help “manage pain”, “control tone”, and facilitate non-weightbearing alignment. Participants described using AFOs to maintain range of motion, prevent contracture, deformity, and pain over time, and to preserve gains following other interventions. One physician indicated that “maybe the AFO doesn’t achieve the goal of preventing contracture, but maybe it slowed it down.” A PT indicated that “the absence of a problem…the absence of deteriorating range of motion, contracture, and pain” may be interpreted as evidence that an AFO is preventing future problems. With respect to activity, AFOs may facilitate weightbearing, position the foot for functional activities, improve gait efficiency, and facilitate gait determinants like “clearance during swing [and] stability in stance.” The following exchange reflects the way an AFO may be used to address multiple goals and ICF levels:

> Orthotist 1: [An AFO may meet] one or all three needs: one would be to help improve their gait pattern. Two, maintain or slow progression of loss of range of motion and/or [three.] to protect foot and ankle alignment.
>
> PT: And a fourth to that would be function… Priorities will vary based on client goals, family goals, and also client’s abilities, and obviously therapy goals. So the four may change in priority, but those are probably the four that I think we look at.

3.4.1.2 Types of AFOs

Participants indicated that decisions about which type of AFO to use for a child are generally influenced by the child’s goals, and the local group’s experiences, knowledge, and preferences. One PT said: “I can’t say that we have really a whole lot of written guidelines and protocols. A lot of it depends on the clinical experience of...the practitioners involved.” Another said: “I feel like we’re limited by what we’ve always done.… Sometimes I feel like there’s a nebulous out there of things that could work, that we just don’t know about.”

Differing perceptions amongst therapists, parents, and physicians may also influence the type of AFO selected. For example, one physician described conflicting perceptions about hinged AFOs:

> Therapists like [hinged braces] because therapists are more interested in activity and participation, and hinged braces are better. But for some of us, we are interested in body function and body structure, and [a] hinged brace actually selectively over-stretches your soleus, which can cause crouch gait. And parents love hinged, they think hinged is "higher marks" than a rigid brace…

3.4.1.3 The Prescription

The prescription is influenced by the prescribing physician's habits, preferences, "personal comfort level with orthotics, and their knowledge level and interest" (PT). The amount of team collaboration varies. For example, PTs who are more comfortable with AFO prescription may be "very assertive and say, 'oh this is what I think they need'" (PT). At one facility, a PT commented that "certain [prescribers]… will just provide a prescription [that says only] 'orthotic'... And then the orthotist will assess the client and determine [which orthosis] would [provide] the best function." At another centre, the prescription includes "the [AFO type], the goal, and usually the range of motion" (orthotist).

When the orthotist assesses the child, they typically "fill[s] in the gaps" in the prescription. The orthotist determines the need to communicate with the team in order to resolve discrepancies between their assessment and the prescription, or to make decisions necessary to complete the brace design (e.g., the casting position for the foot and ankle, trim-lines, strapping configuration, joints, AFO-footwear combination tuning.) Although orthotists "don't look that hard at prescriptions" (orthotist), they are responsible to either fabricate the orthosis according to the prescription, or contact the PT or physician "to discuss what [they] think might be better". This judgement is pivotal, as collaboration may trigger improvements to the prescription or alter the child's management plan.

3.4.1.4 Collaborative goal setting

Goals are central to the discussion about what will be made. Participants described how "a team approach [facilitates] consensus [about] goals" (PT). Although collaboration amongst team members occurs, it was generally described as fragmented and unsystematic. Multi-disciplinary goal-setting and evaluation were identified as ideals:

> PT: To be able to...have those family team meetings with…everybody involved so that physios, physicians, orthotists, family, are all in the meeting discussing…big picture goals,…minor goals, and then be able to review them regularly…It would be nice if funding would let that happen and we all had time to do it.

To bolster collaboration, clinicians may make additional efforts to communicate about the prescription and goals. For example, PTs sometimes attend the orthotics appointments, "to have that communication with the orthotist directly to make sure that the splint is meeting those goals, or that we're having common goals."

3.4.2 Category 2: How it is Used

In this category, participants described what typically happens after the child gets the AFO, how the child uses it, and outcomes. There was one subcategory: Follow-up.

3.4.2.1 Follow-up

Prescription involves "trial and error" (PT). Therefore, the PT or orthotist may re-assess the AFO after the child receives it.

> PT: [There are] times where you actually have to see the child with the orthosis, to see how they're functioning, to see if the goals are being met .... And if not, are there minor adjustments that can be made? And that's again a collaborative conversation with the clinicians.

Children (and their AFOs) are often reviewed annually by the physician, or sooner if a concern is identified by a therapist or family. Reasons to review or revise a prescription include growth, discomfort, adverse effects on gait, loss of flexibility, and/or surgery or botulinum toxin injection.

For children who reside long distances from the prescribing centre, efforts to coordinate collaborative assessment and intervention are enhanced. "Because they're coming such a distance and we want to…make the best use of their time, our time,…we often ask an orthotist to…see the child with us so we can really come up with a firm decision [about the orthotic issue or prescription]" (PT).

The interdependence of “what is made” and “how it is used” is evident in the flexibility of the prescription, as it evolves through clinical re-evaluation. Although the specifics of each orthosis will impact how the child uses it, participants indicated that the reverse may also occur. That is, the outcome may influence changes in the initial prescription and subsequent prescription decisions A subcategory of both category 1 and 2, Evaluation, reflects this process (Figure 3.1).

3.4.2.2 Evaluation

Clinical findings influence the initial AFO prescription (“what is made”), as well as any subsequent changes once the orthosis has been made. Changes to the AFO during or following the fitting are informed by evaluating “how it is used”.

Participants reported seeking out subjective feedback, including information about the comfort of the AFO, the child’s reliance on it, and satisfaction. As one physician described: “We rely on the families to give us a lot of feedback. …What’s working, what’s not working, challenges they are facing…”

Participants described the information that they collect from the physical examination, and the assessment tools (primarily visual and informal) that inform prescription and adjustment decisions. Most information was collected at the ICF body structure and function level, including skin integrity, alignment, midfoot stability, lower extremity range of motion, muscle tone, strength, and selective motor control. At the activity level, balance, and walking distance and speed may be evaluated. Most participants visually observe the child’s gait pattern.

However, once a child receives the new AFO, assessment may focus more on subjective feedback than on objective evaluation of the orthosis:

> PT: Ideally because we’ve usually done a lot [of pre-assessment], we should be doing all of that again…But often it doesn’t [happen] for whatever circumstances. [The reassessment] ends up being – from the family’s…and the child’s point of view – is it working? …Are they happy with it, is it better than before?

More frequent use of video for gait observation and “problem solving” (PT) was identified as an ideal to strive for. Video can facilitate more objective monitoring: “…Kids grow and change and I can’t remember what this child looked like a year ago.…If we could see that difference [using video] that would be ideal” (physician). Video can also provide a more concrete “platform [for parent education],…to help [families] see what you are seeing and break down their concerns.” Challenges associated with privacy, storage and transfer of digital files were identified as limitations to the use of video gait analysis. Other limitations related to evaluation included: lack of orthoses available for trial, insufficient space for gait assessment, and inadequate time and infrastructure to allow collaboration.

3.4.3 Category 3: Supports/Challenges

Participants discussed four main factors that either support or challenge the outcomes of AFO management. These factors are foundational to the AFO prescription (“what is made”) and its outcomes (“how it is used”). This category included four subcategories: Knowledge, Parent/child perceptions, System, and Team.

3.4.3.1 Knowledge

Participants discussed limitations regarding knowledge about AFOs. In general, PTs described few opportunities to learn about orthotics during professional post-secondary programs, and discussed the challenges of accessing relevant continuing education events. Continuing education opportunities described by orthotists seemed to focus on opportunities to learn about new products (often industry-sponsored). Participants discussed the need for more research evidence to help prioritize goals, and inform treatment decisions.

3.4.3.2 Parent/child perceptions

The parent and child’s perceptions about AFOs, were considered to impact acceptance of the AFO, compliance, and outcomes. As one PT described, "every family comes in with a certain coloured lens…in terms of how they view…disability, …their child, ….assistive devices. …It’s important for us as clinicians to be able to meet the needs of [all] families.”

3.4.3.3 System

Participants described factors related to the health care system that can affect service delivery. Considerations included funding for orthotic devices, and staffing levels and funding. Long wait times to see a physician in clinic (e.g., 3-6 months in one facility) as well as for orthotist services can be problematic for children. “For kids, not having a big wait time is really important, because if you cast and then you wait three months to get the splint, then it doesn’t necessarily fit the same way” (PT). Provincial funding also dictates the types of orthoses available, how often a child can receive a new AFO, and whether families must pay for a portion of the device.

3.4.3.4 Team

Factors related to the health care providers and team may also strengthen or challenge outcomes. These included: proximity of team members, and communication with community professionals. Having the team in one building was considered beneficial for care providers, children, and families; one physician described it as “instrumental to…communication.” Collaboration and communication between the team and school/community practitioners also impact outcomes. One physician described a “major problem” that may occur when the child outgrows their current AFO and “the wrong AFO is…made without interim detailed assessment.”

3.5 Discussion

This qualitative study illustrates the experiences of Canadian clinicians with the process of prescribing and implementing AFO intervention for children with CP. Participants in these focus groups told us about how the prescription is determined (“what is made”), clinical follow-up (“how it is used”), and factors that either challenge or support prescription decisions and orthotic outcomes for this population. The theme of the prescription as a collaborative, iterative process was woven throughout the interviews. In contrast to the traditional definition of a prescription as a static medical directive, participants described the orthotic prescription as dynamic, and shaped by multiple inputs. They talked about how it often evolves iteratively, from the physician’s initial requisition to a design that is judged by the team and family to best meet the child’s goals.

Participants described two factors as integral to the prescription’s evolution – collaboration between PT and orthotist, and ongoing evaluation of the AFO’s effects. Both collaboration and evaluation appear to support clinical problem-solving. By conducting a joint assessment, and discussing the child’s needs and response to orthotic intervention, the AFO design may be determined or further refined. Although consistent implementation of both collaborative assessment (National Health Service Quality Improvement Scotland, 2009) and outcome measurement (Jette et al, 2009) have been recommended, there is no standard for integrating either process into a child’s orthotic care. According to our interviews, clinicians’ decisions about whether or not to collaborate, and the extent and timing of that collaboration seemed to depend on factors like clinician comfort with AFOs, proximity and accessibility of team members, and the perceived complexity of the child’s clinical presentation. The tendency to collaborate sporadically was also identified in a survey of clinicians in Scotland, who reported

PT-orthotist collaboration 50% of the time in their work with adults after a stroke (National Health Service Quality Improvement Scotland, 2009).

With respect to outcomes evaluation, clinicians in this study reported limited use of standardized objective measures. Physical impairments (body structure and function) were commonly examined using non-standardized means (e.g., goniometry, inferences about muscle strength). Participants named a few measures of activity, and none of participation. However, they generally expressed an interest in using video gait observation to improve evaluation methods.

Infrequent use of outcome measures is not specific to Canadian clinicians. Although the benefits of evaluating outcomes have been widely and repeatedly recognized, recent surveys in the USA and UK showed that fewer than half of PTs regularly use standardized outcomes (Burton, Tyson, & McGovern, 2012; Jette et al., 2009). Barriers and facilitators to use may include knowledge, education level, perceived value, practical considerations, and organizational support (Duncan & Murray, 2012). Specific barriers reported by participants in this study included time, space, digital storage, difficulty scheduling children for reassessment, and lack of access to objective tools (e.g., GAITRite walkways, 3D motion analysis).

With a few exceptions, participants described an unsystematic, generalized approach to the evaluation that informs the prescription. And once the orthotic device has been fabricated, fewer evaluative measures are apparently used, with a greater reliance on subjective report to evaluate the child’s response. Visual gait observation was reportedly the most common way of evaluating the child’s walking pattern. It is used to both inform and evaluate the AFO prescription. Despite its wide popularity and clinical utility (Toro, Nester, & Farren, 2003), gait observation is subject to observer bias and error, and therefore its reliability and validity have been questioned (Kawamura et al., 2007; Toro, et al., 2003). Consistent with previous reports (Morris, Nedwick, & Johnson, 2002), participants described making prescription decisions based primarily on preference, subjective judgements, and local factors.

The quality of clinical decision-making is thought to directly impact orthotic outcomes (Davids, et al., 2007). It has been suggested that effective decision-making for AFO prescription is multidimensional, and depends on the consideration of factors such as: 1) the physical assessment, 2) clear identification of the gait impairments and deficits that the AFO is intended to address, and 3) knowledge of the biomechanics of normal gait, the mechanics of gait deviations, and the biomechanical capabilities of different types of orthoses (Davids et al., 2007). Prescription is also more likely to be successful when each team member has contributed to, and reached agreement in, the decision-making process; so collaboration and integration of the goals of the physician, therapist, orthotist, child, and family are imperative (Davids, et al., 2007; Morris et al., 2011).

In line with these recommendations, our results suggest that clinicians endeavour to base their prescriptions on assessment findings and gait impairments, and to collaborate within the constraints of the system. However, it has been suggested that clinical AFO prescription is often based on "inadequate biomechanical knowledge" (National Health Service Quality Improvement Scotland, 2009, p.18). While an examination of clinical reasoning was beyond the scope of the study, knowledge did emerge as a factor that challenged prescription practises. As such, clinical outcomes are likely to benefit from ongoing research to understand the biomechanical effects of specific AFO design features on gait. This knowledge may inform the development of clinical guidelines that enable a better match between the prescription and the orthotic goal.

It should be noted that both purposive sampling and focus group methodology carry a risk of bias. While we did invite physicians of other specialties to participate, all four who participated were physiatrists. As well, our sample did not include privately-funded PTs or orthotists, or those working in the community. It is possible that these groups may have reported different experiences. In addition, the multidisciplinary group format may have influenced what participants said. Interactions between disciplines were collegial and agreeable, however, interviewing the disciplines together may have biased what was said about collaboration or team functioning. Individual interviews may have highlighted other aspects of interdisciplinary communication or discrepant viewpoints within teams.

3.5.1 Recommendations for Clinical Practice and Future Research

Based on our analysis of this data and background literature, two main priorities for clinical practice emerged: 1) the development of evidence-informed best practice guidelines, and 2) a stronger focus on objectively evaluating each child's response to the orthosis. Both initiatives could help clinicians make better prescription decisions that address the goals of intervention.

Table 3.2. *Recommendations for clinical practice and for future research*

Practice recommendations

1. Initial prescription:
   - Clearly state team's and family's goals for AFO
   - Use standardized orthotic referral form completed by orthotist, PT, and/or doctor
   - PT and orthotist conduct assessment jointly, AFO design (prescription) finalized by orthotist
   - Individualize prescription based on standardized objective assessment
2. Measurement:
   - Use objective evaluation measures to
     - Support biomechanical basis for individualized prescription
     - Evaluate the effect of AFO once received
   - Consider implementing a standardized gait observation checklist and videotaped visual gait observation to inform prescription and evaluate effectiveness
   - Choose measures directly related to family's goals and consider all ICF levels
3. Collaboration:
   - Implement consistent inter-disciplinary communication and collaboration
   - Access continuing education opportunities in the areas of orthotics and biomechanics

Research recommendations

1. Develop valid and reliable measures of gait quality and participation specific to orthotic evaluation.

2. Examine parent and child perceptions of AFO intervention in order to understand what is meaningful to clients, and identify the most effective targets for evaluation.

3. Examine how different aspects of the AFO prescription can be altered to optimize a child's gait biomechanics.

The National Health Service Quality Improvement Scotland’s best practice guidelines (National Health Service Quality Improvement Scotland, 2009) summarize key recommendations for AFO management of individuals with stroke, borrowing from the CP literature in some cases. This document could be used as a model for developing and providing orthotic service for clinicians working with children who have CP.

Recommendations for practice and future research, based on our findings, are summarized in Table 3.2. Although many of these recommendations are highlighted in the pediatric and adult literature, we recognize the challenges of implementation in the present clinical context. Canada’s geographic size and population distribution require some facilities to serve communities located several hundred kilometers away. The proximity of orthotic and PT facilities is sometimes less than ideal, and resources are limited. Enhanced collaborative practises, for instance, require appropriate infrastructure and organizational support (e.g., adequate time and staffing levels). Some centres described the impact of orthotist understaffing in relation to the demand for services. However, with only two orthotic/prosthetic schools in Canada, the annual number of graduates may not meet the demand. And finally, as Duncan and Murray (2012) identified, barriers at the organizational, team, and individual levels must be addressed if the use of outcome measures in practice is ever going to increase. Future research has the potential to improve the meaningfulness of orthotic interventions, give clinicians tools to measure outcomes, and facilitate an understanding of the effects of AFO prescriptions so that prescription becomes more effective and individualized according to the child’s needs and goals.

We hope that a better understanding of the factors that influence AFO prescription will benefit clinicians and represent a first step towards developing guidelines to improve AFO prescription for children with CP. The information shared by clinicians in these interviews, along with the current literature, support the recommendations we have made. A greater focus on collaboration and objective outcome evaluation (from organization to individual) has the potential to improve orthotic outcomes for children with CP.

CHAPTER 4: PHYSICAL THERAPISTS' USE OF EVALUATION MEASURES TO INFORM THE PRESCRIPTION OF ANKLE-FOOT ORTHOSES FOR CHILDREN WITH CEREBRAL PALSY

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4.1 Abstract

Aims: To examine how physical therapists (PTs) use evaluation measures to guide prescription and re-assessment of ankle-foot orthoses (AFOs) for children with CP. ***Methods:*** PTs in Canada who work with children with CP were invited to complete an online survey. Survey questions examined PT evaluation and interpretation of findings at initial AFO prescription and re-assessment. The researchers analyzed closed-ended responses using descriptive statistics and conducted a conventional content analysis to examine responses to open-ended questions. ***Results:*** Sixty responses from ten provinces were analyzed. Three themes emerged from the open-ended responses, which were supported by closed-ended responses. 1) Focus on impairment-level measures. Although evaluation primarily involved observational, non-standardized measures of impairments and gait pattern, most respondents also considered participation-level constructs. 2) Lack of confidence/knowledge. Respondents reported a moderate level of confidence concerning decision-making about AFO type and characteristics. 3) Inconsistent practices between therapists, possibly reflecting the paucity of available evidence or individualization of the prescription. ***Conclusions:*** Non-standardized, observational assessment methods, and impairment-level constructs appear to guide AFO prescription decisions. Integrating current knowledge into practice, developing best practice guidelines, and developing standardized tools to assess the effects of AFOs on participation may promote confidence, consistency, and improved outcomes.

KEYWORDS: cerebral palsy, ankle-foot orthoses, evaluation, survey

4.2 Introduction

When ankle-foot orthoses (AFOs) are prescribed to improve function, gait quality, alignment, and/or prevent contractures and deformity for children with cerebral palsy (CP) (Morris et al., 2011; Novachek et al., 2009), physical therapists (PTs) work with the physician, orthotist, and family to determine the optimal prescription and provide therapeutic follow-up. (Davids et al., 2007; Kane, Manns, Lanovaz, & Musselman, 2018; Uustal, 2008). Prescription decisions to which PTs contribute include the AFO type, casting position of the foot and ankle, and other design features like trimlines.

Presently, little guidance exists to help clinicians determine the optimal AFO prescription for each child (Bowers & Ross, 2009; Kane et al., 2018; Morris, 2002). The prescription should be individualized, because each child has unique characteristics across the domains of the International Classification of Functioning, Disability and Health (ICF) framework (World Health Organization, 2016a) including body structures and functions (e.g. spasticity), activity (e.g., gait pattern), and participation (e.g., attending school) (Schiariti & Masse, 2015; World Health Organization, 2016b). In the ideal prescription process, orthotic goals are identified, and progress is objectively evaluated (Davids et al., 2007; Ries et al., 2015). A growing body of evidence supports individualized biomechanical optimization – including designing, aligning, and tuning the AFO-footwear combination (AFO-FC) – to maximize the effectiveness of intervention (Bowers & Ross, 2009; Butler et al., 2007; Eddison & Chockalingam, 2013; Jagadamma et al., 2014; National Health Service Quality Improvement Scotland, 2009; Owen, 2010). The type of AFO (e.g., solid, hinged, ground reaction) should be selected and designed to match the individual's neurological and biomechanical impairments (Meadows et al., 2008; National Health Service Quality Improvement Scotland, 2009; Owen, 2010). When a solid AFO is prescribed, it is recommended that the AFO-FC is tuned to optimize the child's gait pattern; this involves adjusting the shank to vertical angle by adding thin wedges under the heel, thereby altering the location of the ground reaction force relative to the knee and hip joints (Meadows, 2014). Although the angle of the ankle in the AFO (AA-AFO) has traditionally been set at 90˚ with the aim of maintaining ankle range of motion (ROM), a plantar flexed AA-AFO has been posited to accommodate gastrocnemius stiffness and hypertonicity, if present (Meadows et al., 2008; Owen, 2005; Ridgewell et al., 2010). However, the extent to which current practices incorporate the available literature is unclear, and present evidence suggests that clinically-prescribed AFOs may have limited, or even detrimental, effects (Bjornson et al., 2016; Ries et al., 2014).

As a first step toward improving the efficacy of AFO prescription practices, we conducted focus group interviews with PTs, orthotists, and physicians to gain a better understanding of clinicians' experiences with AFO prescription for children with CP in Canada (Kane et al., 2018). Participants identified PT evaluation as a key aspect of the prescription process. Evaluation using standardized outcomes is an accepted component of good practice, helping to enhance communication with clients, evaluate and guide intervention, and improve service provision (Jette et al., 2009; King et al., 2011). While participants in our focus groups endeavored to base prescriptions on assessment findings, they generally described a subjective and unsystematic approach to assessment, decision-making, and follow-up (Kane et al., 2018).

Although PTs evaluate body function-level impairments (e.g. ROM, strength) that are thought to affect mobility and function, the specific aspects of assessment that inform individualized prescription – and how these data influence clinical decisions – have not been explored. Therefore, we conducted a survey, based on the results of our focus group interviews, to identify: 1) what PTs evaluate when AFOs are prescribed for children with CP and after the orthosis is received; 2) what assessment measures are used; and 3) how those measures inform prescription. We hypothesized that: 1) PTs do not consistently utilize objective measures to evaluate an AFO's effects, but instead rely on non-standardized measures and observation; and 2) perspectives and practices vary regarding indications for different types of AFOs, use of plantar flexed AA-AFOs, and interpretation of findings to determine the prescription and follow-up adjustments.

4.3 Methods

4.3.1 Participants

Surveys were completed by 60 PTs who had a median of 15 years of PT experience (interquartile range=8-21 years) and a median of 10 years in paediatrics (interquartile range=4-17 years). At least one response was received from each province, and half were from Ontario (28%) or British Columbia (23%). Most worked exclusively in publicly-funded settings (89%), while 11% worked additionally or exclusively in privately-funded settings. Half (52%) worked with orthotists located on-site. Most respondents (53%) treated one to four children with CP per week, while 40% treated one to three per month, and 7% saw one per day.

Participants were recruited via snowball sampling. Study information, including the survey link, was sent by email to 35 PTs at 28 facilities that treat children, in all ten Canadian provinces. No eligible contacts were identified in the territories. The invitation included a request to forward the link to other eligible PTs, to maximize its distribution. The survey was also advertised in an email newsletter by the Canadian Physiotherapy Association's Pediatrics Division, and on social media (e.g., Facebook). Participants were included if they were licensed PTs in Canada who had been involved in AFO prescription for at least one child with CP in the past two months. In total, sixty-six completed surveys were received (online supplementary appendix 1). Of these, six did not meet inclusion criteria and were excluded. Therefore, data from 60 complete responses were analyzed. The study was approved by the University of Saskatchewan's research ethics board.

4.3.2 Survey Instrument

The researchers developed the survey based on the study objectives, and informed by the focus group interviews (Kane et al., 2018). It was translated into French by a bilingual PT and the content and intent of the questions were discussed to facilitate accurate translation. The content validity of the instrument was then evaluated by five PTs in four provinces, all of whom were experienced with AFO intervention for children with CP (Aday & Cornelius, 2006). Four examined the English version and one evaluated the French version. These content experts had 18 to 40 years of clinical experience, in addition to teaching (PT entry-to-practice or continuing education) and/or clinical research. Content experts completed the survey and were asked for feedback about whether the questions were clearly worded and addressed the stated objectives, and to identify any gaps or suggestions for improvement. The survey was subsequently adjusted based on this feedback, which was provided to one of the researchers (KJK) during a 15- to 30-minute individual telephone interview for four of the experts, and via email for the fifth expert.

The final version of the survey consisted of 28 questions (six open-ended, 22 closed-ended, which are summarized in Table 4.1). It was deployed online (SurveyMonkey) in English and French. Close-ended questions addressed: 1) demographics; 2) evaluation measures used to inform initial prescription and re-assessment; and 3) recommendations for AFO design and adjustments post-fitting. Open-ended questions asked about the clinical indications for different types of AFOs, the most important information examined initially and at re-assessment, opinions about the benefits or harms of a plantar flexed AA-AFO, and the types of adjustments recommended at re-assessment. For example, respondents were asked to base their responses about initial assessment on the following scenario: “An 8-year-old ambulatory child with CP comes to you for an assessment. AFOs have been suggested for the child. The physician wants your recommendation about the AFO type (solid, hinged, etc.) and characteristics (stiffness, trimlines, ankle angle, etc.) before writing the prescription.”

4.3.3 Data Analysis

Survey responses were exported into an Excel file for data cleaning and analysis. Incomplete responses were removed, and French responses were translated into English. Descriptive statistics were calculated to summarize closed-ended responses. The assumption of normality was tested using a Kolmogorov-Smirnov test. To examine the strength of the association between confidence in AFO prescription and years of experience in both pediatric and PT practice, Spearman’s rank correlation coefficient was calculated using SPSS (Version 24). Two researchers (KJK and KEM) independently performed a conventional content analysis (Hsieh & Shannon, 2005) on the open-ended responses. Responses were reread several times to identify important concepts and impressions about the content’s meaning. Key words and phrases were inductively grouped into categories, and preliminary themes were established through discussion. A third researcher (JL) then independently reviewed the open-ended responses and preliminary themes. The three researchers discussed and adjusted the preliminary themes to form the final themes.

4.4 Results

All 60 respondents were involved with initial prescription and re-assessment once the child received the AFO, and most also agreed about the value of re-assessment. On a 100-point scale (0=not important; 100= extremely important), respondents rated the median importance of re-assessment as 95.5 (interquartile range= 84.75-100). Seventy percent reported that they re-assessed 95-100% of children who received AFOs. Responses indicated that orthotists and PTs often assess children

Table 4.1. *Summary of survey questions. Open ended questions are denoted by (*). All other questions were closed-ended, and used a variety of response formats (e.g., 5-point Likert scales, slider scales, free text boxes, multiple choice).*

Section of survey	Summary of questions
1. Demographics	1. In the past 2 months, how often have you been involved in AFO prescription for a child with CP, or made decisions about the AFOs of a child with CP? (This may include checking or re-assessing a child's AFOs as part of a treatment session or contributing to decisions about new AFOs.)
	2. In which province do you work?
	3. How many years have you worked as a physiotherapist?
	4. How many years have you worked in paediatrics?
	5. Please describe your main work setting
	6. Where are the orthotists that you work with located?
	7. How confident are you in your ability to recommend the correct AFO type (solid, hinged, etc.) and characteristics (stiffness, trimlines, ankle angle, etc.) for children with CP?
2. Recommendations about AFO prescription	*The next questions relate to the following scenario:* *An 8-year-old ambulatory child with CP comes to you for an assessment. AFOs have been suggested for the child. The physician wants your recommendation about the AFO type (solid, hinged, etc.) and characteristics (stiffness, trimlines, ankle angle, etc.) before writing the prescription.*
	8. Please select the items that you think would likely be most helpful in making this decision.
	9. How do you measure each item? If you use any specific tools, please list them (e.g., videorecording, goniometer, names of standardized outcome measures or clinical tests).
	10. Of the information that you consider when recommending an AFO for a child, which ones usually influence your decision the most? Please list the three most important things that you assess, in order of their importance.
	11. How do you evaluate the child's gait, to make a decision about the type of AFO you are recommending?
	12. Please describe the most important examination findings that would lead you to suggest each of the following AFO types: Solid AFO, Hinged AFO, Posterior leaf spring/other semi-flexible AFO, Ground Reaction AFO, Energy Storage and Return AFO, Carbon Fiber AFO.*
	13. How do you decide whether a hinged AFO or a solid AFO is more appropriate for a child? If there are certain assessment findings that help you to decide between these 2 types of AFO, please describe them as specifically as you can.*

3. Casting positions for the foot and ankle	*A doctor prescribes a new AFO for a child on your caseload, and a casting appointment is scheduled with an orthotist. The following questions relate to the recommendations you make about the position of the child's foot and ankle in a new AFO.* 14. For the children you see, how often do you provide recommendations to the orthotist about the position of the foot and ankle in the cast? 15. For the children you see, how often are AFOs fabricated with the ankle positioned at a plantarflexed angle? 16. What examination findings would cause you to recommend positioning the ankle at a plantar flexed angle in an AFO?* 17. How harmful or beneficial do you believe it is to position an ankle in plantarflexion in an AFO? 18. Why do you think it may be harmful or beneficial to position an ankle in plantar flexion?*
4. Follow-up evaluation for a new AFO	*The next questions are about PT follow-up evaluation for an ambulatory child who has received a new AFO.* 19. Please select the items you would likely assess, to evaluate the effects of the new AFO. 20. How would you measure each item during your re-assessment? If you use any specific tools, please list them (e.g., videorecording, goniometer, names of standardized outcome measures or clinical tests). 21. Please list the three most important things that you assess to evaluate the effect of an AFO, in order of their importance. 22. Of the children you see with AFOs, approximately how many do you re-evaluate once they have a new AFO, to check how well the AFO is working for the child? 23. How important do you think it is to complete a PT evaluation after a child gets a new AFO?
5. AFO-footwear combination tuning and adjustments	*The following questions are about adjustments to the AFO and footwear that you might make after a child receives a new AFO.* 24. When a child gets a new AFO, have you ever made or recommended adjustments (e.g., to the orthotist) to optimize how the child walks in it? 25. Please describe some examples of adjustments that you usually make or recommend for the AFO and/or footwear, in order to improve the way the child walks.* 26. How often do you make or recommend adjustments or modifications to the AFO or footwear? 27. How do you evaluate the AFO and footwear to make this decision? 28. Is there anything you would like to suggest, in order to improve assessment and prescription/recommendation of AFOs?*

together; more than half of the time, 60% reported doing joint initial assessments, and 53% did joint re-assessments. In comparison, 28% and 26% of PTs performed initial assessments and re-assessments, respectively, together with another PT more than half the time. Physicians were less often involved, with 35% and 18% of PTs performing initial assessments and re-assessments, respectively, with a physician more than half the time.

Only 32% of respondents reported making recommendations about the casting position of the foot and ankle for more than half of children. Even if they did not make recommendations, most believed that positioning the ankle in some plantar flexion was beneficial when indicated; on a 100-point scale (0=extremely harmful; 100=extremely beneficial under the right circumstances), the median rating was 72 (interquartile range=52-91.25). Approximately 77% of respondents recommended a plantar flexed AA-AFO at times, typically for fewer than half of children. Twenty-two percent never used a plantarflexed AA-AFO.

Most respondents described making several types of recommendations once a child receives an orthosis. More than 2/3 of these involved facilitating adjustments by the orthotist to relieve pressure areas and improve the fit and comfort of the AFO via padding, trimming, and flaring the plastic. Adjustments to straps and footwear recommendations (type, size, optimizing the fit of the footwear) were mentioned less often (50%). Fewer recommendations pertained to the goal of optimizing gait mechanics. For example, less than 30% mentioned wedges (without specifying the purpose), and only 10% specifically mentioned tuning. The least prevalent recommendations (about 5%-20%) aimed to improve gait by various other means. These included adding joints to solid AFOs, adjusting the AA-AFO or the amount of motion the AFO allowed, adding shoe raises to equalize leg lengths, posting the AFO to alter alignment, and adjusting the AFO's stiffness by altering its trimlines.

4.4.1 Themes

Three themes for evaluation practices in AFO prescription were identified based on responses to the open-ended questions: 1) focus on impairment-level measures; 2) lack of confidence/knowledge about types of AFOs and casting position of the ankle; and 3) inconsistent practices between therapists.

4.4.1.1 Focus on impairment-level measures

Individualized recommendations for AFO type and AA-AFO were primarily guided by impairment-level assessment measures and findings. Respondents described how the AFO type was frequently determined by ankle dorsiflexion ROM and plantar flexor tone (including R1/“first catch”, R2/“muscle length at rest”, and the difference between the two as an indication of dynamic tone or contracture; Boyd & Graham, 1999), strength, and alignment. Activity-level considerations were function and gait pattern. One respondent said a hinge is “require[d]… for function (stairs, sit-to-stand, floor-to-stand, squatting).” Crouch gait was described as an indication for solid AFOs, and being ambulatory was generally an indication for hinged AFOs. Similarly, two impairment-level factors—dorsiflexion ROM, including the presence of contracture, and plantar flexor tone (specifically, R1 and the difference between R1 and R2)—were described as primary influences on the choice of AA-AFO. Many PTs thought a plantar flexed AA-AFO could allow a child with limited dorsiflexion ROM to tolerate an AFO or gain ankle ROM; however, they also expressed concern that a plantar flexed AA-AFO could cause contracture if the child had more dorsiflexion ROM available. Therefore, many recommended changing the AA-AFO as ROM improved. At the activity level, a plantarflexed AA-AFO “may be necessary to get best gait pattern [if there is a contracture].”

The predominant influence of impairment-level constructs on the initial prescription was corroborated by the closed-ended responses. Figure 4.1 illustrates the breadth of variables evaluated (e.g., ROM, gait pattern), and the frequency with which each is examined at initial assessment and re-assessment. At initial assessment, gait pattern, ROM, and muscle tone were most frequently evaluated (impairment- and activity-level constructs); however, participation-level constructs were evaluated by 68% of respondents. On re-assessment, it was most common to examine gait pattern, parent/child satisfaction, and participation in school, social, and recreational activities (activity- and participation-level constructs). Participants ranked ROM as the most important construct to evaluate at initial assessment, followed by gait pattern, and muscle tone (Figure 4.2). At re-assessment, gait pattern, pain/comfort/fit, and gross motor function were reported as the most important variables to evaluate.

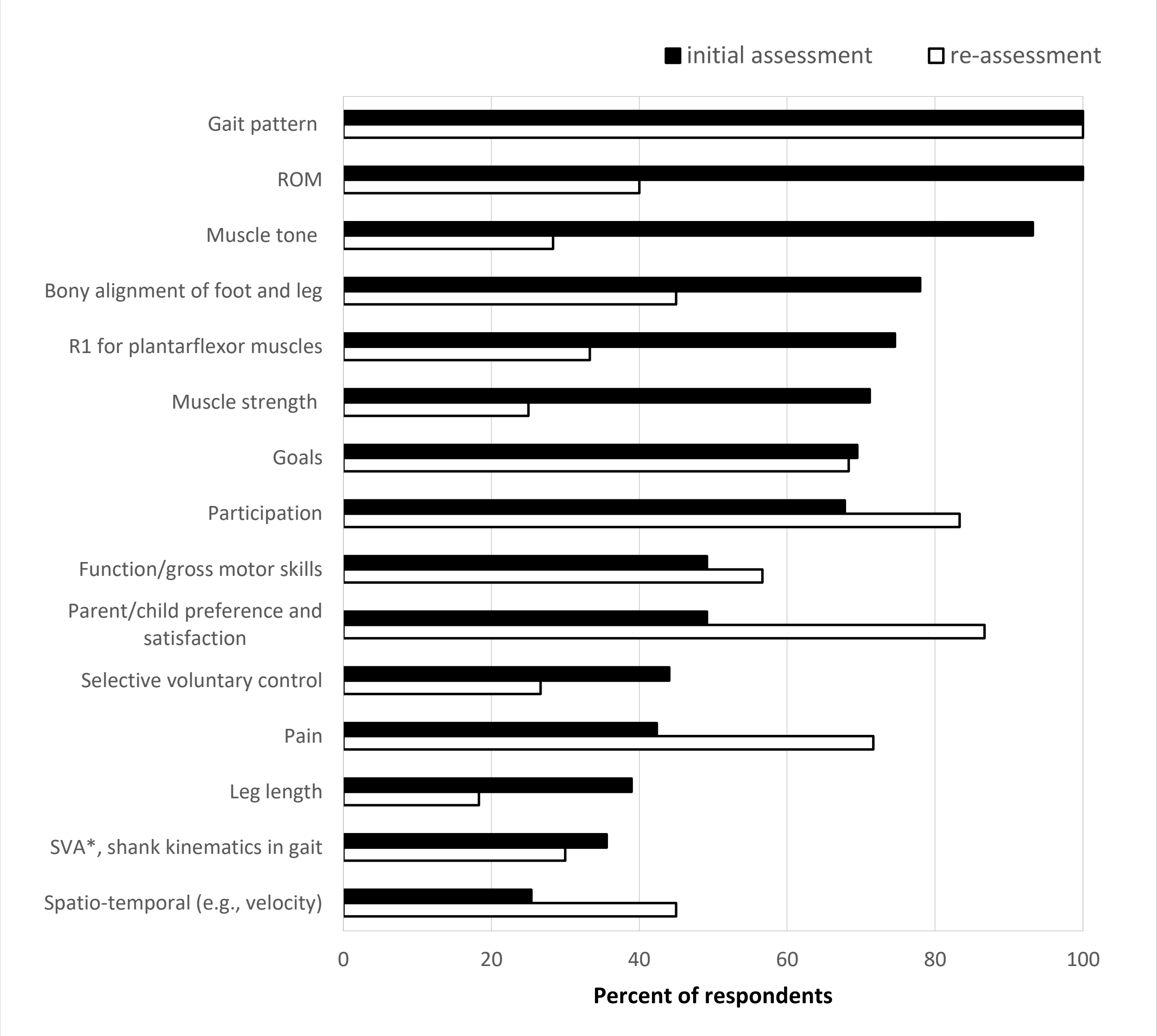


Figure 4.1. Information that PTs evaluate at initial assessment (when making recommendations about the AFO prescription) and re-assessment (after the child has the AFO).

*Shank to vertical angle

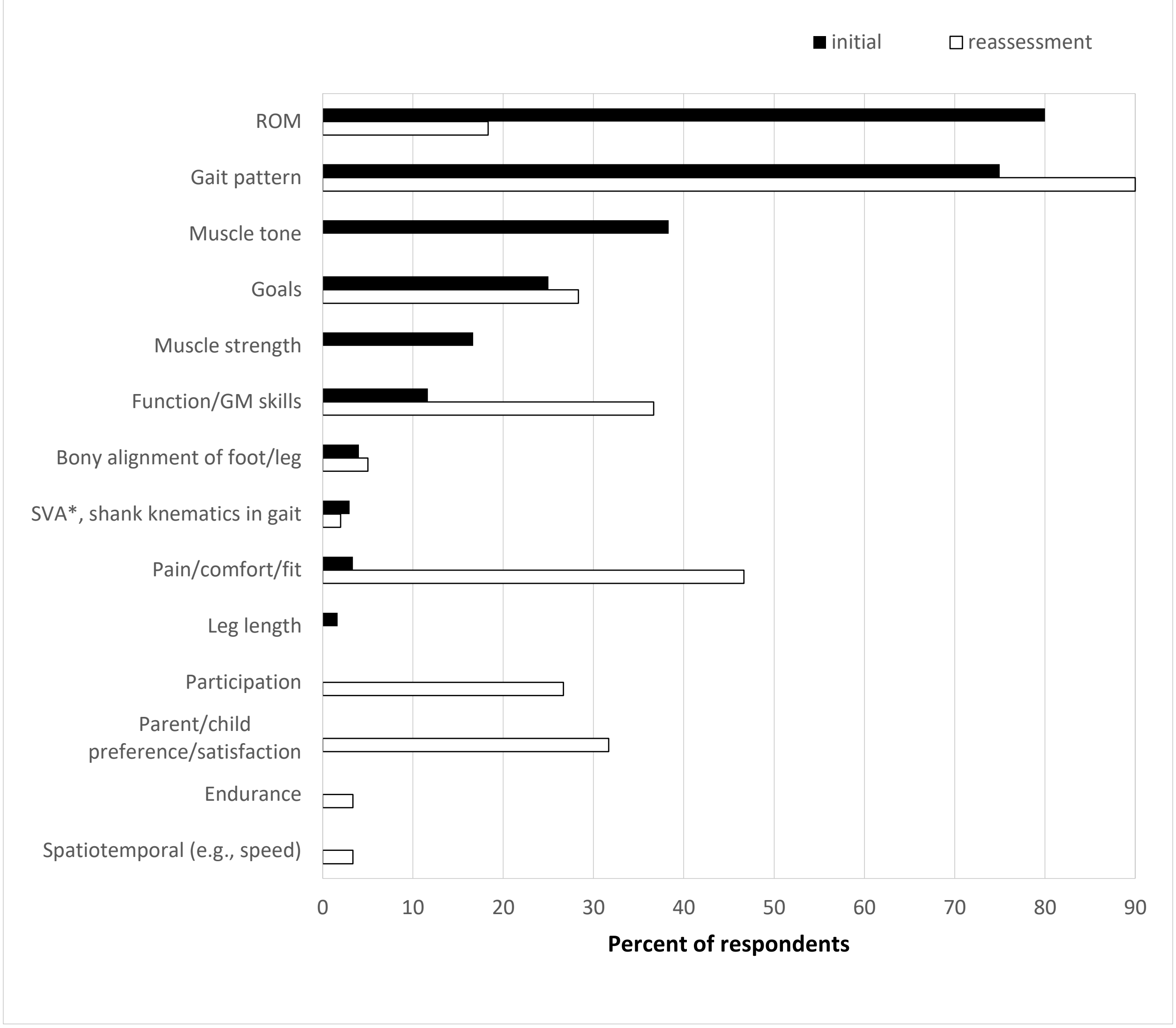


Figure 4.2. Most important information to consider at initial assessment and re-assessment (by % of respondents).

*Shank to vertical angle

4.4.1.2 Lack of confidence/knowledge about types of AFOs, and casting position of the ankle

Participants reported a wide range of confidence levels for making decisions about AFO type and characteristics. On a scale of 0-100 (0=not confident at all; 100=extremely confident), the median rating was 57.5 (interquartile range=37-69). Some also described a lack of knowledge/confidence in their open-ended responses (e.g., “I am still guessing, defer to orthotist.”) Confidence rating was moderately correlated with years of pediatric PT experience ($\rho=0.52$; $p<0.001$) but only weakly correlated with overall PT experience ($\rho=0.38$; $p=0.003$). When asked to describe clinical indications for six different types of AFOs– solid, hinged, ground reaction, posterior leaf spring, energy storage and return, and carbon fiber– most were unfamiliar with the latter four types. Those who used ground reaction AFOs consistently cited crouch gait as the primary indication. Those who used posterior leaf spring AFOs typically reported using them for children who had drop foot without excessive gastrocnemius hypertonicity. The few who used carbon fiber AFOs suggested that they were useful for active children with minimal impairment (e.g., foot drop, plantar flexor weakness, “lighter weight support in adolescent population”, or at least neutral dorsiflexion ROM).

Respondents appeared most confident about indications for solid and hinged AFOs, although responses were inconsistent (as described in theme 3, below). Many participants appeared to view solid and hinged AFOs as having opposite indications. Overall, solid AFOs were reportedly used for less ambulatory children with poor ROM, significant spasticity, and poor mid-foot integrity. In contrast, hinged AFOs were recommended for more ambulatory children with higher functional abilities, “adequate ROM”, less spasticity, and good mid-foot integrity. Some respondents also described uncertainty about why a plantar flexed AA-AFO may be harmful or beneficial. One PT stated: “Based on my experience and training of 30 years ago, this practice would not be recommended. However, you asking this question leads me to believe there may be more recent thinking [regarding the] use of [a plantar flexed AA-AFO].”

4.4.1.3 Inconsistent practices between therapists

Responses reflected inconsistency across PTs regarding the rationale for determining AFO type and AA-AFO. Some only used hinged AFOs for children with “normal shank kinematics” and minimal impairments: “I usually default to solid unless there is optimal range, strength, and no concern regarding bony alignment.” Others “preferred hinged AFOs for all ambulatory children. One PT wrote: “First choice is hinged as it provides a more natural gait pattern, but sometimes this cannot be used if the client falls into crouch or lacks ROM.” These respondents tended to perceive that solid AFOs are “most appropriate as a resting…splint” and “negatively impact gait pattern in an ambulatory client”, while hinged AFOs promote ankle motion and function.

Some respondents indicated that a plantar flexed AA-AFO may “decrease stability in standing/walking,” and impair function or gait pattern (e.g., “not functional”; “could promote…hyperextension of knee in gait and/or toe walking.”), while others described benefits (e.g., “can allow for heel strike”; “allow ‘normal’ shank/thigh kinematic and knee/hip range throughout gait.”) One respondent indicated: “It would be harmful to not have the ankle in plantar flexion if the client has insufficient range with knee extended in the standing position. This could lead to pain and…worsening of range due to…compensations.”

Most responses illustrated a lack of detail surrounding decision-making. When asked how they determined the AFO type, many respondents merely named the constructs that they measured (e.g., “[the choice of AFO] depends on knee control, amount of tone and functional skills”). The few responses that explicitly described how they interpreted their measurements lacked consistency. For example, ROM was the most common factor guiding both AFO type and AA-AFO; yet there was little agreement about how much ROM is needed to warrant either decision. Opinions about ROM indications for a hinged AFO included: “adequate range”, “enough range past neutral to tolerate hinged AFO”, “neutral,” “>5 degrees,” or “>10 degrees”, and “some active dorsiflexion”. Some stated that a contracture and “R2 <90 degrees” warranted a plantar flexed AA-AFO, while others focused on dynamic limitations (e.g., “I prefer to have the child cast close to their R1 angle. If the R1 is in a plantar flexed position I will request the AFO be in plantar flexion.”) Others were less specific about rationale (e.g., “not tolerating neutral dorsiflexion”) or described the individualized nature of decisions: “Depending on the tightness and tone of the plantar flexors it is either harmful or beneficial to position the ankle in plantar flexion. It’s a big grey area and each child is different.”

There was considerable variety in the evaluation methods that PTs selected to inform AFO prescription and re-assessment (Table 4.2). More than one evaluation method was reported for most variables, with a combination of non-standardized/observational methods and standardized/objective measures reported. For example, gait was evaluated more often by observation than by more structured tools (e.g., video, standardized checklists, instrumented measures; Figure 4.3); however, ROM, was primarily evaluated with objective tools, such as a goniometer. More objective gait measures were used more frequently at initial prescription than at re-assessment.

4.5 Discussion

This survey study examined the way PTs in Canada use evaluation measures to inform AFO prescription for children with CP. Responses suggest that, in AFO prescription: 1) PTs base decisions primarily on impairment-level findings; however, the majority of PTs also consider activity- and participation-level constructs and use a combination of standardized and non-standardized evaluation measures; 2) there is a lack of confidence/knowledge about decision-making; and 3) there is inconsistency across PTs in evaluation practices and interpretation of findings. These results partially support our hypotheses and provide new insights about PT evaluation practices for AFO prescription. In Table 4.3 we detail recommendations for clinical practice and future research and discuss them in the following paragraphs.

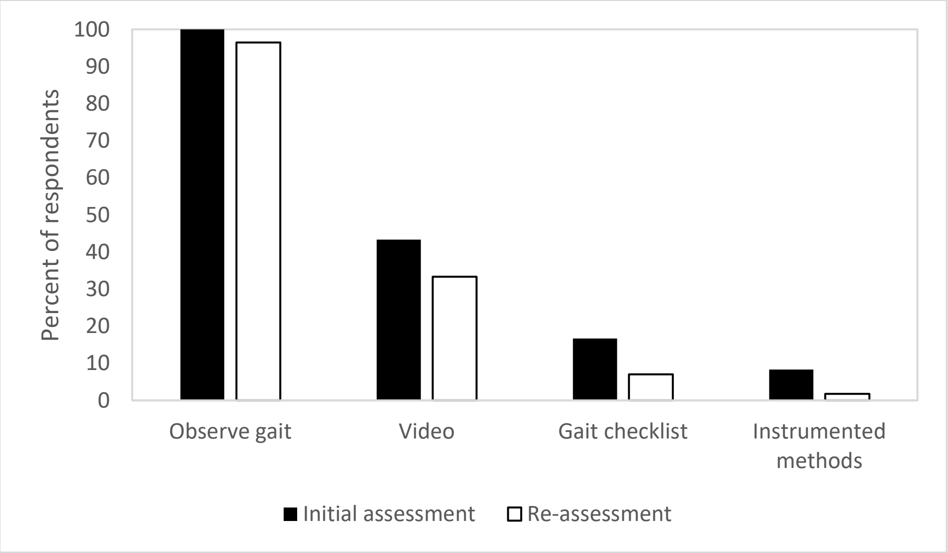


Figure 4.3. Percentage of PTs using each of four different gait evaluation methods more than 50% of the time

Table 4.2. *Assessment tools and methods used by PTs to make AFO decisions at initial assessment and re-assessment, in order of frequency of use*

Constructs being assessed*	Initial assessment (Most common to least common)	Re- assessment (Most common to least common)
Range of motion	1. Goniometer; 2. Special tests (e.g., Thomas test; Duncan Ely test)	1. Goniometer
Muscle tone	1. MAS[a], MTS[b] (specifically R1/R2), informal assessment	1. MAS, MTS, or informal assessment
R1 (plantarflexors)	1. Goniometer	1. Goniometer
Bony alignment	1. Observation, palpation, goniometer 2. Thigh-foot angle, foot progression angle, x-ray, caliper, angle finder, bi-malleolar axis, foot axis, Ryder's test	1. Observation 2. Goniometer/ clinical measurements 3. Photos or video
Muscle strength	1. Manual muscle testing 2. Observe functional skills, squat, calf raises	1. Manual muscle testing
Leg length	1. Tape measure 2. Visual estimate, Galeazzi test, standing (block test), X-ray	1. Tape measure 2. Standing (block test)
Pain	1. Pain scale (e.g., VAS[c], NPRS[d], faces scale), subjective report	1. Pain scale (VAS, NPRS) or subjective report
Selective voluntary control	1. Observation of functional skills 2. SCALE[e], confusion test, isolation of movement	1. Observation
Shank to vertical angle and shank kinematics during gait	1. Observation or video 2. Goniometer; gait lab	1. Observation or video 2. Goniometer; gait lab
Gait pattern (general appearance, e.g., crouch, scissoring)	1. Observation 2. Video recording 3. OGS[f]; EVGS[g] (with video); 3D motion analysis	1. Observation 2. Video recording 3. OGS; EVGS (with video); 3D motion analysis
Spatio-temporal variables (e.g., step length, velocity)	1. Observation, video 2. Gait lab, GAITRite, video (measured background), tape measure	1. Observation, video 2. Gait lab, GAITRite, 6-minute or timed walk test
Gross motor skill	1. Observation, standardized test (GMFM[h], BOT-2[i], MABC-2[j], PDMS-2[k], TGMD-2[l]), or non-standardized developmental checklist	1. Observation, standardized test (e.g., GMFM, PDMS-2), or non-standardized checklist
Goals	1. Informal discussion with parent/child 2. SMART[m] goals, GAS[n], COPM[o]	1. Informal discussion with parent/child 2. Repeat GAS or COPM
Parent/child preference (initial) or satisfaction (re-assessment)	1. Informal discussion child/parents	1. Informal discussion with child/parents
Participation in school/ social/recreational activities	1. Informal discussion with child/parents	1. Informal discussion with child/parents, +/-teacher 2. COPM, observation, review goals 3. Pediatric Community Participation Questionnaire
Other	1. Consult with or defer to other professionals	1. Skin integrity (redness/pressure), observation

*Identified during focus group interviews; [a]Modified Ashworth Scale; [b]Modified Tardieu Scale; [c]Visual Analog Scale; [d]Numerical Pain Rating Scale; [e]Selective Control Assessment of the Lower Extremities; [f]Observational Gait Scale; [g]Edinburgh Visual Gait Score; [h]Gross Motor Function Measure; [i]Bruininks-Oseretsky Test of Motor Proficiency, 2nd ed; [j]Movement Assessment Battery for Children; PDMS-2: [k]Peabody Developmental Motor Scales; TGMD-2: [l]Test of Gross Motor Development; [m]Specific, Measurable, Agreed upon, Realistic, Time-based; [n]Goal Attainment Scaling; [o]Canadian Occupational Performance Measure

4.5.1 Measure Participation-Level Outcomes

Although impairment-level measures seemed to influence decisions (especially at initial prescription), current rehabilitation paradigms for children with CP consider outcomes at all ICF levels (Anaby et al., 2017; Law & Darrah, 2014; Novak, 2012). In particular, activity- and participation-level goals are among the most valuable to the child and family (Naslund et al., 2003; Schiariti et al., 2014). Moreover, pediatric rehabilitation is shifting toward activity- and participation-oriented paradigms because impairment-based approaches (e.g., “fixing the child”) have not been demonstrated to be effective (Law & Darrah, 2014). Participants reported assessing two activity-level constructs – gait pattern and gross motor function; however, this was typically done via informal observation, which is likely to be less objective (see section 2.5.2).

Most PTs considered participation when making decisions (i.e., 68% at initial assessment and 83% at re-assessment); yet, fewer than 30% ranked it as one of the three most important constructs to measure. One possible explanation for this finding is that the choice of evaluation measures should be consistent with the purpose and the expected outcome of the AFO; and clinicians primarily prescribe AFOs to impact impairments and gait pattern, without expecting participation-level effects (Kane et al., 2018). Further, while only two respondents named standardized participation-level measures, six used goal setting tools, which may also reflect activity- and participation-level goals. Goal setting tools may be preferable to participation-specific tools in some circumstances, such as where AFOs are prescribed to address alignment or deformity, rather than participation-level effects.

It is also worth noting that the information provided by assessment of certain constructs may be more relevant at either the initial prescription or at re-assessment; this may explain why some constructs were evaluated more often at one time-point compared to the other. For example, ROM, strength, tone, R1, alignment, leg length, and selective voluntary control were more often considered at initial prescription. This information may be more relevant to decisions about the type of AFO and prescription details. Conversely, re-assessment may be a more relevant time to assess participation, satisfaction, pain, and spatiotemporal variables, as this dispensing visit serves as a baseline for evaluating the effect of the new AFO on these important constructs.

4.5.2 Increase use of standardized measures

Overall, our results indicate that PTs use few objective, standardized measures for initial AFO prescription; and at re-assessment, they may be more reliant on subjective report. Despite challenges associated with outcome measurement in rehabilitation (Jette et al., 2009; King, Wright, & Russell, 2011), more consistent measurement at baseline and follow-up may present an effective strategy to improve orthotic outcomes in this population, as well as clinician confidence for prescription decision-making. Without quantification, clinicians are unlikely to obtain the objective information necessary to specifically identify and communicate about the child's gait impairments, quantify progress, or optimize the orthosis. They may also miss opportunities to improve care by engaging families and promoting shared decision-making based on the platform for discussion that measurement provides (King et al., 2011). While measures do exist for this population at all levels of the ICF (O'Neil et al., 2006), there is a need for reliable outcome measures with high clinical utility, specifically for orthotic evaluation (Table 4.3).

4.5.3 Develop evidence-based clinical guidelines

Although we did not examine the relationship, it is possible that a PT's knowledge or beliefs about AFOs (theme 2) may contribute to inconsistent practices and interpretation of assessment findings between therapists (theme 3). The qualitative data illustrate variability in both decision-making and knowledge/beliefs about AFOs. A notable example was the belief that hinged AFOs were appropriate for all ambulatory children. In contrast, several authors have asserted that the use of a hinged AFO for children with stiff or short gastrocnemius (e.g., unable to achieve 10˚ of dorsiflexion with the knee extended and arch maintained) may result in dorsiflexion at the midfoot joints, contributing to mid-foot break and potential future pain and immobility (Bowers & Ross, 2009; Karas, 2002; McGovern & Rahlin, 2016; Meadows et al., 2008; Owen, 2015).

Solid AFOs have been advocated for children with abnormal shank kinematics (i.e., atypical motion of the shank segment in the sagittal plane during gait; Meadows et al., 2008; Owen, 2010), yet few respondents based their decisions on this variable. It is also possible that some of the variability present in the responses reflects individualization of the prescription based on the child's needs. As well, clinician confidence and consistency in orthotic decision- making is likely impacted by the paucity of consistent evidence about orthotic options and

Table 4.3. *Recommendations for clinical practice and future research based on issues identified in the results*

Issue	Recommendations for clinical practice	Recommendations for future research
1. Specific and objective participation measures are not consistently used at initial prescription and re-assessment	1. Discuss participation goals with parents/child 2. Include standardized measures at the participation level, such as the [b]COPM, [c]CAPE, or [d]PCPS	1. Determine whether adequate measure of participation exists for AFO evaluation, and if not then develop one 2. Examine effects of AFOs on participation
2. Infrequent use of standardized measures to evaluate efficacy of AFO prescription	1. Clinician education regarding suitable standardized outcome measures at each ICF level (e.g., [a]EVGS, [b]COPM, [c]CAPE, [d]PCPS) 2. Document goals and a plan for objective evaluation at initial assessment; objectively document outcomes after child receives AFO 3. Wearable sensors may enhance the objectivity of gait assessment and facilitate quantification of outcomes (Sivarajah et al., 2017)	1. Identify measures that are valid, reliable, and responsive, with high clinical utility at all levels of ICF for orthotic evaluation in children with CP 2. Perform psychometric studies for measures that lack proven validity and reliability for this purpose 3. If inadequate measures exist, develop measures to enable objective evaluation of orthotic outcomes in this population 4. Evaluate the effectiveness of initiatives to implement these measurement practices and change clinician behavior
3. Variability in PT practices for AFO prescription	1. Educate clinicians about current orthotic/tuning literature (may promote integration of current literature and use of common terminology in practice)	1. Develop best practice statement to support evidence-informed decision-making, similar to Best Practice Statement Following Stroke (National Health Service Quality Improvement Scotland, 2009) 2. Evaluate efficacy of different types of AFOs to support future development of clinical guidelines
4. Most follow-up adjustments do not appear to address impairments, activity, or participation goals	1. Increase clinician knowledge of tuning (may help PTs to address biomechanical goals of the AFO) 2. Support collaboration between PT and orthotist 3. Consider how follow-up adjustments may address orthotic goals	1. Evaluate efficacy of AFO-FC tuning 2. Simplify and clarify tuning processes to improve accessibility (Nicola Eddison et al., 2015) 3. Examine the relationship between tuning and activity/participation

[a]Edinburgh Visual Gait Score, [b]Canadian Occupational Performance Measure, [c]Children's Assessment of Participation and Enjoyment; [d]Pediatric Community Participation Questionnaire; AFO-FC: AFO-footwear combination

assessment measures. Clinical outcomes and confidence for decision-making would likely benefit from examining topics such as how much passive ankle dorsiflexion ROM is required to use a hinged AFO without compensatory foot motion, and the validity and reliability of observing shank kinematics to inform prescription decisions.

4.5.4 Increase study and knowledge about tuning

AFO-FC tuning provides another example of the potential link between knowledge and practice. Several respondents described thinking that solid AFOs can impair gait or hinder function– an observation that may be associated with failing to tune the AFO-FC (Bjornson et al., 2016; Bowers & Ross, 2009; Owen, 2010). Although tuning has been recommended to optimize biomechanics and function (e.g., sit to stand), only 10% of our respondents described this practice. Most AFO adjustments seemed to involve comfort and fit, rather than objective evaluation for the purposes of biomechanical optimization. This implies the lack of a clear relationship between what PTs evaluate on follow-up and the adjustments they make, beyond simply enabling the child to tolerate wearing the AFO. It is possible that PTs did not report tuning because the orthotist performs this function; however, a survey of orthotists in the United Kingdom (Eddison et al., 2015) concluded that only about half of them tuned AFO-FCs, and that knowledge of the topic was poor. Therefore, outcomes may improve as PTs and orthotists increase their knowledge of tuning and incorporate tuning into routine practice (Table 4.3). More broadly, increasing PTs' knowledge about AFO prescription may also contribute to improved confidence for making orthotic decisions.

A limitation of survey methodology is the inability to draw causal inferences from the responses or ask clarifying questions. For example, our questions did not specifically query the types of ROM (active, passive, dynamic) respondents evaluated, yet this information may have provided further insights. Some comments suggested confusion about altering the AA-AFO versus AFO-FC tuning, possibly implying a need for common language to facilitate communication; however, our methodology does not afford examination of respondents' knowledge levels. Finally, it is not possible to know the percentage of the population that participated in the survey, although all provinces were represented. In 2012, 849 PTs in Canada reported pediatrics as their primary employment setting (Canadian Institute for Health Information, 2013); however, our exclusion criteria further constrained the size of this population.

4.6 Conclusions

The results of this survey suggest that PT evaluation for AFO prescription primarily focuses on non-standardized, impairment-level measures, but most PTs also consider participation-level information. Evaluation may include standardized or objective measures of gross motor function, strength, and tone; however, gait evaluation appears to be primarily non-standardized. While PTs may evaluate similar constructs to inform prescription recommendations, our results suggest a lack of confidence and discrepant interpretations of assessment findings. Inconsistent orthotic practices amongst PTs may reflect differences in skills or knowledge, as well as attempts to individualize prescriptions. Confidence, consistency, and orthotic outcomes may be enhanced by integrating current knowledge into practice, developing best practice guidelines, and developing standardized tools to assess the effects of AFOs on participation. In addition to identifying these recommendations for clinical practice, the findings provide a basis for future research aimed at helping clinicians use evaluation measures more effectively to optimize AFO prescriptions for children with CP.

CHAPTER 5: EFFECT OF THE ANKLE ANGLE IN AN ANKLE-FOOT ORTHOSIS ON GAIT BIOMECHANICS FOR CHILDREN WITH CEREBRAL PALSY

5.1 Abstract

Introduction: For children with cerebral palsy (CP) and equinus, the conventional practice of setting the ankle angle in an ankle-foot orthosis (AA-AFO) at 90˚ may not fully accommodate the length and stiffness of the gastrocnemius muscle. Instead, determining the AA-AFO based on clinical gastrocnemius measures may better reflect the dynamic demands of gait. Therefore, this study examined the effects of individualizing the AA-AFO on gait and functional mobility for children with CP and equinus, compared to their usual AFOs. ***Methods:*** Ten children with CP and equinus (6-18y; GMFCS I-III; 15 limbs with AFOs), and a reference group of 15 typically-developing (TD) children (6-18y) participated. For the children with CP, solid AFOs with individualized AA-AFOs (iAA-AFOs) were fabricated, accommodating gastrocnemius length and stiffness (range=5˚-25˚ plantarflexion). These study AFO-footwear combinations were statically aligned to standardize the location of the ground reaction force at temporal midstance and compared with the children's usual AFOs using three-dimensional gait analysis. TD children grouped into three age-bands (6-8y; 9-13y; 15-18y), walked in shoes only. Peak values and Gait Variable Scores (GVS) for joint and segment kinematic and kinetic variables were calculated for stance phase. Confidence intervals (90% CI) were used to categorize responses to the iAA-AFO compared to the Usual AFO for each variable as positive, negative, or equivocal relative to TD data, for each affected leg. ***Results:*** Net responses to the iAA-AFOs were positive for 60% of limbs, and negative for 40%. The greatest benefits were observed at the knee. The variables that were most often affected negatively were: foot-floor angle and vertical ground reaction force. ***Discussion:*** Individualized AA-AFOs may improve knee kinematics and kinetics for some children with equinus, compared to conventionally-prescribed AFOs. The range of responses highlights the need for objective gait evaluation after fitting of the iAA-AFO, and AFO-footwear combination tuning to optimize individual outcomes. Future research may identify factors that predict children's responses to iAA-AFOs and inform development of evidence-based clinical practice guidelines. This information can assist clinicians in making evidence-based individualized AFO prescription decisions.

5.2 Introduction

Cerebral palsy (CP) describes a group of permanent motor disorders that result from an injury to the developing brain either before or shortly after birth (Rosenbaum et al., 2007). Children with CP demonstrate a range of motor impairments, including hypertonicity, weakness, and poor motor control. The most common musculoskeletal impairment affecting this group is equinus deformity (Cornell, 1985) which is associated with triceps surae spasticity and shortened length (i.e., static or dynamic contracture), as well as functional gait quality impairments such as excessive plantarflexion in stance phase, poor swing leg clearance, and impaired balance and stability (Davids, 2009; Perry & Burnfield, 2010; Svehlik, Zwick, Steinwender, Kraus, & Linhart, 2010; Wren, Do, & Kay, 2004; Wren, Rethlefsen, & Kay, 2005). Altered talocrural motion and hindfoot malalignment associated with equinus may influence the development of excessive midfoot motion, resulting in lever arm dysfunction and pain (Karas, 2002; Maurer et al., 2013). This muscle shortening may alter the plantarflexors' length-tension curves and reduce their ability to produce force (Davids, 2009; Foran, Steinman, Barash, Chambers, & Lieber, 2005; Lieber, 2002). Foot deformity and altered biomechanics may lead to chronic overuse and pain, and affect long-term ambulation outcomes in individuals with CP (Bleck, 1987; Bottos & Gericke, 2003; Davids, 2009; Jahnsen et al., 2004; Murphy et al., 1995; Opheim et al., 2009).

Ankle-foot orthoses (AFOs) are one of the most common non-operative interventions prescribed to address these concerns (Novacheck, 2008; Wingstrand et al., 2014). Mechanically, AFOs can help restore normal joint motion and walking patterns for children with equinus by compensating for weakness and hypertonicity (especially ankle plantarflexor and dorsiflexor muscle weakness and gastrocnemius hypertonicity), and redirecting the ground reaction force vector to optimize knee and hip kinematics and kinetics (Butler et al., 2007; Butler & Nene, 1991; Meadows et al., 2008; Novachek et al., 2009; Uustal, 2008).

In order for AFOs to achieve the optimum effect for each child, the child's individual characteristics (gait pattern, clinical examination) should be matched to the mechanical properties and design of the orthosis (Davids et al., 2007; Singerman, Hoy, & Mansour, 1999). Ideally, the design is determined collaboratively by the team and outlined in the prescription (Kane et al., 2018; Uustal, 2008). An important and often overlooked aspect of individualized AFO prescription is the angle of the ankle joint within the AFO (AA-AFO) (Jagadamma et al., 2015; Ridgewell, Dobson, Bach, & Baker, 2010). The AA-AFO is conventionally set at 90˚, in an attempt to maintain ankle flexibility or prevent ankle plantarflexion contracture, while allowing gait with a plantigrade foot (i.e., foot flat on the ground). However, this convention is not substantiated by evidence, and is likely based on an erroneous assumption that a 90˚ ankle with vertical shank will help the knee to extend in stance phase (Eddison & Chockalingam, 2013; Owen, 2010). This may present a problem for children with equinus, as the orthosis requires ankle dorsiflexion to 90˚ during gait (or further if a hinged or flexible design is prescribed), regardless of the severity of gastrocnemius hypertonicity or contracture.

If the AA-AFO does not fully accommodate the length and tone of the gastrocnemius muscle – which spans the knee, talocrural, and subtalar joints – several compensations are possible. Knee extension may be limited at initial contact (IC) (thus preventing IC with the heel) or during stance (Karas, 2002; Meadows et al., 2008; Nuzzo, 1983; Owen, 2010). As well, subtalar pronation may compensate for restricted talocrural dorsiflexion. When the subtalar joint pronates, the alignment of the axes of the talonavicular and calcaneocuboid joints become more parallel to allow more dorsiflexion at the forefoot and midfoot (transverse tarsal or mid-tarsal joint) compared to when the subtalar joint is in neutral or supination (Elftman, 1960; Johanson et al., 2014; Sammarco & Hockenbury, 2001). If the ankle lacks dorsiflexion ROM, the stretching force applied during dorsiflexion motion is more likely to stretch the small, extensible ligaments of the midfoot than the Achilles tendon (Karas, 2002). This makes it difficult to selectively target stretching forces to the talocrural joint and suggests that casting the ankle in a position of excessive dorsiflexion (judged relative to the anatomy of the individual's foot and ankle) may promote hyperpronation and/or midfoot break, potentially contributing to lever arm dysfunction and long-term pain. Recently, this rationale has led some authors to raise concerns about the practice of positioning the ankle in angles of dorsiflexion that exceed the measured gastrocnemius length (Eddison & Chockalingam, 2013; Meadows et al., 2008; Owen, 2010; Ridgewell et al., 2010). A few authors report using plantarflexed AA-AFOs (Harrington et al., 1984; Nuzzo, 1983, 1986; Owen, 2004b), although they do not clearly describe the rationale for determining the AA-AFO. Most studies do not report the AA-AAO, or use a 90˚ ankle angle for all children regardless of clinical findings, suggesting that the rationale for determining the AA-AFO varies and does not consistently consider the length of gastrocnemius (Eddison & Chockalingam, 2013; Ridgewell et al., 2010).

Thus, for children with CP, orthotic intervention may be more effective when the AA-AFO is individualized based on the length and stiffness of the child’s plantarflexor muscles (Eddison & Chockalingam, 2013; Jagadamma et al., 2015; Owen, 2010); however evidence-based consensus or guidelines regarding the AA-AFO do not exist.(Jagadamma et al., 2015; Kane et al., 2018) A clinical algorithm has been proposed to determine the AA-AFO (Owen, 2005); however to date it has not been evaluated in a controlled experiment. Therefore, this study aimed to explore the effects of individualizing the AA-AFO for children with CP using this algorithm; we compared the effects of the individualized AA-AFO to current conventional AFO prescription practices by examining lower extremity gait kinematics and kinetics, and functional mobility. We hypothesized that better control of the ankle joint using a solid AFO, in a position that accommodated the child’s gastrocnemius length and stiffness, would promote better kinematics and kinetics at the knee joint and to a lesser extent at the hip. We also expected these improvements would be reflected by more typical foot and shank segment kinematics. We did not expect that functional mobility or spatio-temporal parameters would be adversely affected.

5.3 Method

5.3.1 Participants

Children with CP were recruited from the province’s two tertiary rehabilitation facilities and the two associated orthotics departments. Children were invited to participate if they met the following criteria: 1) aged 5-18 years; 2) diagnosis of spastic CP; 3) gastrocnemius contracture of 5˚ or greater, measured with the knee fully extended (Owen, 2005, 2010); 4) Gross Motor Function Classification System (Palisano et al., 2007) level I-III; 5) had worn an AFO for >6 months; 6) able to walk 8 meters 20-30 times without AFOs; 7) able to cooperate with the testing procedure and follow simple commands in English; 8) had not undergone orthopaedic surgery or botulinum toxin injection in the past 6 months.

Typically-developing (TD) children were recruited via word of mouth and web-based advertisement to the university community. These children met the following criteria: 1) aged 5-18 years; 2) born full-term (i.e., >37 weeks of gestation) with no complications; 3) no injury or condition that affected walking or balance ability; and 4) able to cooperate with the testing procedure and follow simple instructions in English. These children were grouped into 3 age bands (6-8, 10-13, and 15-18 years), to describe the gait of TD children using the same methodology as the children with CP. The first author spoke to parents/guardians by phone to screen potential participants in both groups, to ensure they met the inclusion criteria.

The study was approved by the Research Ethics Board of the University of Saskatchewan and the Regina Qu'Appelle Health Region. All children provided informed assent and parents/guardians provided written informed consent to participate.

5.3.2 Procedures

5.3.2.1 Clinical assessment of participants with CP and determination of individualized AA-AFO

A registered physical therapist with 15 years of experience in pediatric rehabilitation (KJK) conducted a clinical assessment of each participant with CP. The clinical assessment included evaluation of each child's lower limb alignment, gait pattern, range of motion, and spasticity (Boyd & Graham, 1999; Cusick, 2006, 2009; Owen, 2016). The child's individualized AA-AFO (iAA-AFO) was determined by examining the child's gastrocnemius length and stiffness (Owen, 2005, 2010, 2018). According to this procedure, the child was positioned in supine. Dorsiflexion ROM was measured with the foot in full pronation, neutral, and supination, with the knee extended, and the most restricted measurement determined the iAA-AFO (Owen, 2005, 2018). Measurements of ankle dorsiflexion range of motion (ROM) were obtained using digital photography with an iPad (Apple Computers, Inc., Cupertino, CA) and a goniometry application (app) designed for use on a mobile phone or tablet (DrGoniometer, CDM S.r.L, Este, Italy). The orthotist took the photograph with the iPad positioned parallel with the child's lower leg and vertical (as determined by the DrGoniometer app), while the physiotherapist held the ankle at end range. The app was then used to calculate the sagittal plane angle between the shank (a line running approximately from the fibular head to lateral malleolus) and hindfoot (calcaneus). This goniometer app has been shown to improve the reliability of ROM measurements compared to traditional goniometry (Ferriero et al., 2013). The physiotherapist confirmed the app's measurements using a universal goniometer (using the same landmarks as for the measurement with the goniometry application), and they were within 5˚ of each other.

5.3.2.2 Orthoses and footwear

A certified orthotist custom-fabricated the study orthoses with iAA-AFOs for all children in the CP group. Standardized specifications were provided to the orthotists (Table 5.1), to create a solid ankle AFO with an iAA-AFO (as determined above). The iAA-AFO orthoses were made with 3/16” (4.8mm) polypropylene, with trimlines distal to the metatarsophalangeal joints and anterior to the malleoli. Carbon fiber ribs were added at the orthotist’s discretion to increase the stiffness for larger children. Each orthosis was fabricated with tibial and ankle straps (anti-supination straps where the orthotist deemed it appropriate), and an ethylene-vinyl acetate (EVA) wedge under the heel to create a shank to bench angle of 0˚ (i.e., the shank segment of the AFO is aligned vertically, when sitting on a flat surface or “workbench”). This angle allowed the researchers a consistent neutral starting point from which to add wedges and tune the AFO-FCs. All AFOs were fabricated and fit by one of three orthotists in two orthotic departments. The physical therapist (KJK) was present at all casting appointments to confirm the iAA-AFO during and after casting.

Wearing shoes has been demonstrated to affect walking speed, step length and kinematics in children (Wegener et al., 2011). Therefore, all participants (children with CP and the TD group) wore the same brand/style of shoe (Rebound mid-top skate shoe, DC Shoes, Inc.) during the test, except one participant with CP. Participant 10 wore women’s New Balance 636 extra wide shoes with 5mm pitch (New Balance, Boston, MA) because she was unable to comfortably wear the study shoes. The study shoe worn by the other children had a flat sole profile, neutral heel, and a 0mm pitch. It was selected because it was available in a range of sizes from toddler to adult, and because the depth accommodated a variety of wedge heights while allowing the shoe to be laced high enough to minimize motion of the brace in the shoe.

5.3.2.3 Static alignment of AFO-footwear combinations (AFO-FCs)

Each of the Usual (except for the hinged and flexible AFOs) and iAA-AFOs was statically aligned by the first author prior to gait testing. Participants stood with both feet on a force plate (50.8 cm x 46.3 cm, OR6-7, AMTI, Watertown, MA) while the GRF vector was visualized using direct video overlay (Nexus 2.5, VICON, Centennial, CO; A620FC Digital Camera, Basler AG, DE). High density EVA heel wedges were temporarily secured to the sole of the shoe to adjust the position of the GRF vector in the sagittal plane until it was aligned through the middle of the foot and the knee joint centre (Owen, 2004, 2014; Eddison, 2017). Once the heel wedges were added, a shoe raise was secured to the bottom of each shoe, as indicated to equalize the child’s leg lengths, accounting for any asymmetries due to measured physiological differences and/or AA-AFOs or heel wedges. Leg lengths were checked again in standing, as the children were unable to lay supine while wearing the markers and EMG equipment. Finally, bilateral point loading rockers made of ¼" (6.35mm) high density plastazote (80% of the shoe's length) were secured underneath the sole (Jagadamma et al., 2015; Owen, 2018). This was done to give the participants a simulated third (toe) rocker where the trim lines distal to the MTPs did not allow an anatomical third rocker (Owen, 2018). The final shank to vertical angle (SVA; calculated as the angle of the anterior tibia relative to vertical) was measured with the child standing still using the DrGoniometer app (Figure 5.1). The GRF location relative to the knee was confirmed using the forceplate and direct video, to complete the static alignment process. A period of acclimatization (10 – 15 minutes) was provided to ensure that the child felt comfortable walking in each AFO-FC.

Table 5.1. *Specifications provided to orthotists for fabrication of the iAA-AFOs*

1. Ankle angle determined during the casting: Right: _________ Left: ___________
[completed by PT during visit]

2. Landmarks for ankle angle measurements used by PT during physical exam:
-"line of the leg": fibular head to lateral malleolus
-"line of the foot": lateral hindfoot, along the calcaneus (up to the base of the 5th metatarsal)
To ensure consistency of the ankle angle in the AFO, please check these measurements the same way during casting, after the cast comes off, after any rectification of the cast, and to check the 'positive' once the AFO is fabricated

3. Shank to bench angle of finished AFO: 0˚ (add EVA wedge (approximately equal to the amount of ankle plantarflexion in 1) under the heel, to achieve this angle)

4. Cast with MTPs extended

5 Full toeplate length

6. Solid AFO – rigid enough that the ankle will not bend during walking

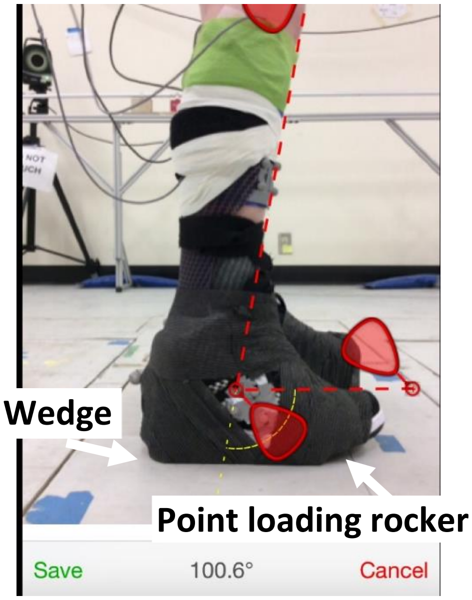


Figure 5.1. Screen shot of SVA measurement using DrGoniometer app. Photo shows a statically aligned AFO-FC, with label added to indicate location of wedge (used to adjust SVA) and point loading rocker.

5.3.2.5 Functional mobility assessments

Participants with CP completed three functional mobility measures – the Pediatric Balance Scale (PBS; Franjoine, Gunther, & Taylor, 2003), and 10-meter walk test at self-selected (10mSSWT) and fastest (10mFWT) speeds (Kane, Lanovaz, Bisaro, Oates, & Musselman, 2016; Thompson et al., 2008) – in each of the two AFOs. The order of both the tests and the AFO conditions were randomized to mitigate the effects of fatigue and practice. The PBS is a standardized measure of functional balance, used to evaluate changes in function for children with CP. The PBS assessment was video-recorded and scored off-line by the first author (KJK). The PBS (Chen et al., 2013; Verbecque, Lobo Da Costa, Vereeck, & Hallemans, 2014) and the 10mSSWT and 10mFWT (Kane et al., 2016) have been shown to be reliable for children with CP.

5.3.2.4 Gait analysis

Three-dimensional motion analysis was conducted using an 8-camera motion capture system (Vicon Nexus, Centennial, CO) with a custom, full-body marker set, and two force plates (AMTI, Watertown, MA). Participants walked at a comfortable self-selected speed along a walkway that was 10 meters long and 3 meters wide. Children with CP walked in three conditions, in randomized order: 1) shoes only; 2) usual AFO(s); and 3) iAA-AFO(s). TD children walked with shoes only. For each condition, trials were conducted until at least six force plate contacts were obtained with each foot. Children were not informed about the force plates, in order to reduce the likelihood that they would change their gait pattern to step on them. Rest periods were provided as needed to mitigate fatigue effects. None of the markers were replaced in between conditions. Kinematic data were sampled at 100 HZ and force plate data were sampled at 2000Hz.

A total of 47 reflective markers (a combination of 9 mm and 14 mm diameter markers) were used, nine of which tracked upper body points that were used for visualization only. Of the remaining 38 lower body markers, 10 were used only in the calibration process and removed for data collection. The 28 tracking markers for the lower limb consisted of clusters of four markers fixed to rigid thermoplastic molded plates that were attached to the lateral aspect of each thigh and shank using two-sided tape and medical wrap. For some of the smaller children (n=2), the four shank markers were fixed directly on the skin rather than using the rigid cluster. A rigid four-marker cluster was fixed to the sacrum using a belt and two-sided tape in order to track pelvic motion. Three markers in a triangular configuration were fixed to the lateral aspect of each shoe near the rear foot and a marker was placed on the posterior heel of each shoe. The 10 calibration-only markers were placed on the medial and lateral femoral condyles, the medial and lateral malleoli and on the dorsal shoe just above the second metatarsal (i.e. a toe marker).

Segmental coordinate systems were defined for the lower limbs using a combination of static calibration data and functional joint centre calculations. Participants first stood in a static calibration pose with feet shoulder width apart in the shoe-only condition without any AFO such that the malleoli markers were visible. Ankle joint centres were defined as the midpoint between markers placed on the malleoli and expressed relative to the shank clusters. The participants then performed standing unweighted knee flexion/extension movements for each limb to estimate the flexion axis of the knee (O’Brien, Bodenheimer Jr, Brostow, & Hodgins, 2000) and the knee joint centre was estimated by projecting the midpoint of the femoral condyle markers on to the closest point on the estimated flexion axis (Hagemeister et al., 2005). Finally, participants rotated each leg through an unweighted hip range of motion (forward/backwards, side-to-side) in order to estimate the hip joint centres using data from the thigh and pelvis clusters (Ehrig, Taylor, Duda, & Heller, 2007; O'Brien et al., 2000). Hip joint centres were tracked using the thigh clusters.

The ankle, knee, and hip joint centres and the knee flexion axis were used to establish orthogonal segmental coordinate systems for the pelvis, thigh and shank, and segmental kinematics were tracked using the clusters. The medio-lateral axis (Y) of the pelvis was defined using the hip joint centres while the vertical axis (Z) was set to correspond to the global vertical direction during the starting calibration. The medio-lateral axis (Y) of the thigh was set parallel to the knee flexion axis while the anterior-posterior thigh axis (X) was defined as the cross product of the medio-lateral axis and the line between the knee and hip joint centres. The shank medio-lateral axis (Y) was also set parallel to the knee flexion axis and the shank anterior-posterior axis (X) was defined as the cross product of the medio-lateral axis and the line between the ankle and knee joint centres.

The shoe and foot were defined as two different coordinate systems that were both tracked with the same shoe-based markers. The shoe coordinate system was defined with a vertical axis (Z) parallel to the global axis and the medio-lateral axis (Y) defined as a cross product of the vertical axis and a line from the heel to the toe marker. The foot coordinate system was then established by rotating the shoe coordinate system about its medio-lateral axis based on the ankle angle within the AFO and the angle of the wedges attached to the shoe. For the TD participants, the shoe and foot coordinate systems were identical.

Three-dimensional joint kinematics were calculated as the relative movement between adjacent segments using a YXZ Cardan sequence and flexion/extension angles were reported for the hip, knee and ankle joints. Ankle joint kinematics were defined as the relative angle between the shank and foot coordinate systems. Shank-to-vertical kinematics were expressed as the angle between the Z axis of the shank and the global vertical axis. Foot-floor kinematics were expressed as the angle between the X axis of the shoe coordinate system and the global horizontal.

Kinematic and force plate data were combined using standard inverse dynamics techniques (Winter, 2009) to calculate 3D joint moments for the ankle, knee, and hip. Thigh, shank and foot body segment parameters for the inverse dynamics calculations were estimated using published data (Jensen, 1986). Flexion/extension moments for the hip, knee, and ankle were reported.

5.3.3 Analyses

Scores on the PBS, and speed (m/s) on the 10mSSWT and 10mFWT were calculated. Within-participant results of each these functional mobility assessments were compared between the two AFO conditions using a Wilcoxon signed-rank test for dependent samples.

Motion analysis data from the cameras and force plates were processed using Vicon Nexus 2.0 (Centennial, CO) and custom routines in MATLAB R2017a (MathWorks, Natick, MA). Kinematic data were filtered offline using a 4th order Butterworth filter with 10 Hz low-pass cut-off. This removed the high frequency noise while providing good-quality position, velocity, and acceleration data. Six to seven trials were processed in Vicon for each foot and condition. Following processing in MATLAB, trials were visually inspected and were excluded if there was evidence that the child was walking excessively slowly, was running, turned during the step, or stepped on the force plate with both feet. Therefore, three to six trials were included for each child for each limb and condition, except for all participants except child 2, for whom data for the shoe condition on the unaffected leg was unusable due to technical errors. Kinetic data were not collected for participant 9, because her step lengths were too short/variable to allow her to contact the force plate with only one foot. Six trials were included for each child in the TD group, and the data from this group were combined into the appropriate age band (6-8, 10-13, or 15-18 years). As there was no difference between right and left legs for the TD group, an average of both legs was included.

Kinematic and kinetic data from each participant were ensemble averaged for each condition for the stance phase of the gait cycle. The following peak kinematic variables were calculated: knee extension angle (KneeIC), SVA (SVA_IC) and foot-floor angle (FFA_IC) at IC, peak joint angles in stance phase for ankle dorsiflexion (AnkleDF), ankle plantarflexion (AnklePF), knee flexion (KneeFlex), knee extension (KneeExt), hip flexion (HipFlex), and hip extension (HipExt), and SVA (SVA_TMSt) and FFA (FFA_TMSt) at temporal midstance. IC was defined as the first contact of the foot with the floor and TMSt was defined as 50% of the child's stance phase. The following peak kinetic variables were calculated: knee moments at 1) TMSt (KneeMom_TMSt), and 2) at the average point in the gait cycle where the two peak extensor moments occurred for the TD children (20% of stance phase or loading response (LR) and 93% of stance phase or terminal stance (TS); KneeMom_LR and KneeMom_TS), and the peak hip flexion and extension moments (HipFlex_Mom and HipExt_Mom). Moments at fixed time points were chosen because clear peaks were not consistently present in the kinetic data of the children with CP. Spatio-temporal variables were: stride velocity, step length, stride time, and stance percent. As an index of overall gait quality, individual gait variable scores (GVS) (Baker et al., 2009) were calculated for the entire stance phase for relevant variables: ankle ROM (GVS_Ankle), knee ROM (GVS_Knee), hip ROM (GVS_Hip), SVA (GVS_SVA), FFA (GVS_FFA), knee moment (GVS_KneeMom), hip moment (GVS_HipMom), and vertical force (GVS_VF). Each GVS was calculated as the mean RMS difference between each trial of the child's gait cycle data and the mean of the TD group gait cycle data. Each child's data was compared to the TD data from the appropriate age band.

Because of the wide variability within the sample, group means were not compared (Damiano, 2014). For the children with CP, gait data for each affected limb during the stance phase of the gait cycle were analyzed visually and using descriptive statistics. For each limb, the mean, SD, and confidence interval (90% CI) were calculated for the Usual and iAA-AFO conditions. A difference between conditions was defined as no overlap of the 90% CIs. When a difference was detected, if the value of the iAA-AFO condition was closer to the mean of the TD data than the Usual condition, this was considered a positive response for the iAA-AFO. iAA-AFO values farther from the TD mean than the Usual condition were considered negative responses. When the 90% CI between conditions overlapped, this indicated no difference between conditions (i.e. equivocal). Similarly, if values for both conditions were within one SD of the TD mean, the results were also considered equivocal. All comparisons with TD data were made to the most appropriate TD age band. The number of responses in each category (positive, negative, and equivocal) were summed for each limb for all 25 knee, hip, segment, and spatiotemporal variables combined. A limb was considered a net positive responder if more variables were positively affected than negatively affected. Conversely, a net negative response was recorded if the limb demonstrated more negative than positive responses. If there were equal positive and negative responses, or no differences, then the limb was considered an equivocal responder. Cohen's d was calculated using a pooled SD as an effect size measure to quantify the magnitude of each positive and negative response for each limb. An effect size of 0.8 or greater was considered to be a large effect (Landis & Koch, 1977).

As the ankle was the target of the experimental manipulation, responses of the three ankle kinematic variables were considered separately. Wilcoxon signed-rank test was used to compare

Ankle_DF, Ankle_PF and Ankle_GVS between conditions, to confirm the effectiveness of the experimental manipulation of the independent variable, induced through individualizing the AA-AFO.

Statistical significance for the Wilcoxon tests was set at p<0.05. Analyses were completed using IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY), and MATLAB R2017a (MathWorks, Natick, MA).

5.4 Results

Participants were 10 children with CP (6-18 years; median 10y 10m; 6 girls; Table 5.2), and 15 TD children (6-18 years; median 12 y 7m; 8 girls). All completed the 3D gait test. Two children with CP did not complete the functional tests – one (the youngest participant) due to an inability to pay attention by the end of testing and one (the most physically involved participant, classified as GMFCS III) due to fatigue.

5.4.1 Physical assessment

Physical examination findings for each participant are presented in Table 5.3 and Appendices D1, D2, and D3. The median passive dorsiflexion ROM was -12˚ in supination (range = -4˚ to -25˚), and 0˚ in both neutral (range = 10˚ to -18˚) and pronation (range=8˚ to -20˚).

5.4.2 Clinical Measures of Balance and Mobility

5.4.2.1 PBS

PBS scores in the Usual condition were 47-56 (median = 54.5), and 46-56 (median = 54.5) in the iAA-AFO condition. Wilcoxon signed-rank test showed no significant difference between conditions (Z = -0.828, p = 0.408). Scores for four children decreased in the iAA-AFO condition compared to their Usual AFO, three stayed the same, and one improved (median change -0.5; range -2 to 2; Figure 5.2A).

5.4.2.2 10mSSWT

Median speed was 1.04m/s (0.74-1.32m/s) in the Usual AFOs, and 1.16 m/s (0.74-2.26 m/s) in the iAA-AFO condition. Wilcoxon signed-rank test showed no significant difference between conditions (Z = -.560, p = 0.575). With the iAA-AFO compared to the Usual AFO, walking speed was faster for four children (range 0.06-1.17 m/s), slower for three children (0.01-0.26 m/s), and the same for one child (Figure 5.2B). The median change was 0.03 m/s faster.

5.4.2.3 10mFWT

Median speed was 1.73m/s (1.13-2.33m/s) in the Usual AFO, and 1.59 m/s (0.97-2m/s) in the iAA-AFO condition. Wilcoxon signed-rank test showed no significant difference between conditions (Z = -1.4, p = 0.161). With the iAA-AFO, compared to the Usual AFO, one child performed this test more quickly (0.7m/s), six were slower (0.1-0.4m/s), and one child showed no difference in speed (Figure 5.2C). The median change was 0.29 m/s slower.

5.4.3 Participant AFO Characteristics/Static Alignment of AFO-FCs

5.4.3.1 Usual orthoses

Participants habitually wore orthoses on 15 of the 20 limbs (Table 5.4). The types of Usual orthoses worn were: 7 articulated AFOs with plantarflexion stop at 0˚ and dorsiflexion assist, 3 solid AFOs, 1 carbon fiber AFO (ToeOFF®, Allard USA, Rockaway, NJ), 3 semiflexible AFOs (FlexiSport, Cascade DAFO, Ferndale, WA), and 1 supramalleolar orthosis. The AA-AFOs of the Usual AFOs were all 0˚, except for 2 semi-flexible AFOs (10˚ and 3˚ plantarflexion), and 2 solid AFOs (5˚ and 10˚ plantarflexion). The solid and articulated AFOs were custom-fabricated from 3/16” polypropylene. None of the Usual AFOs had ribs or carbons, and all had full-length toe plates and trim lines proximal to the MTP joints. All had shank to bench angles of 0˚ (created using EVA wedges where the AA-AFO was <0˚), except for one of participant 4’s AFOs, which was reclined 5˚ relative to vertical. Participants’ SVAs measured while standing in these AFOs ranged from 5˚ to 20˚ (median=10˚).

5.4.3.2 iAA-AFOs

The median ankle angle for the iAA-AFOs was 15˚ plantarflexion (range= 5˚-25˚). Table 5.4 details the iAA-AFOs and the adjustments made during static alignment of the AFO-FCs. Participants’ SVAs, measured while standing in these AFOs, ranged from 9˚ to 18˚ (median=12˚). For some children the SVA was more inclined (up to 12˚ more inclined) than with the Usual AFOs, and for other children it was less inclined (up to 8˚ less inclined; median= 2 more inclined).

Table 5.2. *Characteristics of participants with CP.*

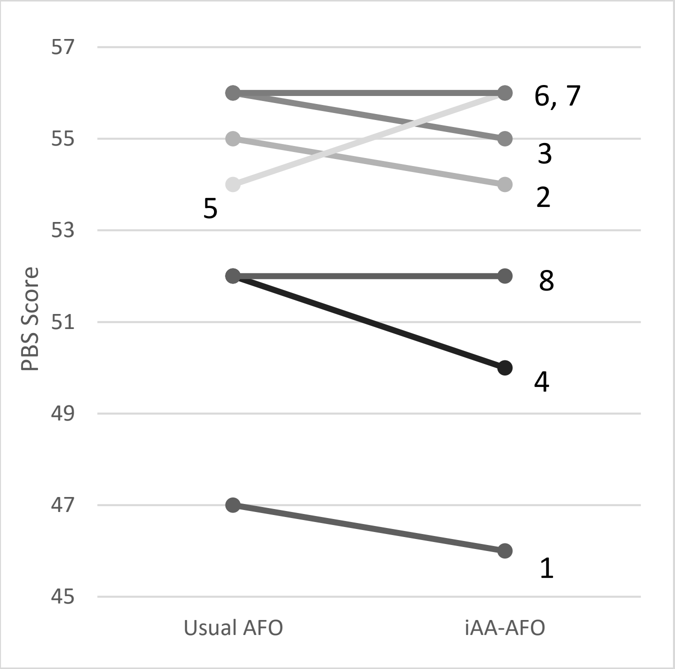
Child	Age	Sex	Diagnosis (affected limb)	GMFCS	Height (cm)	Weight (kg)
1	17y 11m	F	Bilateral	II	156.5	63.9
2	6y 8m	M	Unilateral (Right)	I	114.5	20.5
3	16y 7m	F	Bilateral	I	151.4	63.4
4	9y 10m	F	Bilateral	II	134.5	46.4
5	7y 7m	F	Unilateral (Left)	I	119.5	22
6	14y 11m	M	Unilateral (Right)	I	153	44.5
7	11y 10m	M	Unilateral (Right)	I	153	43.8
8	6y 5m	M	Unilateral (Right)	I	119.5	21.3
9	6y	F	Bilateral	II	102	14.8
10	17y	F	Bilateral	III	141	49.7

Note: Children with bilateral CP wore orthoses on both legs, and children with unilateral CP wore an AFO on the affected limb. F: Female; M; male; y: years; m: months; GMFCS: Gross Motor Function Classification System

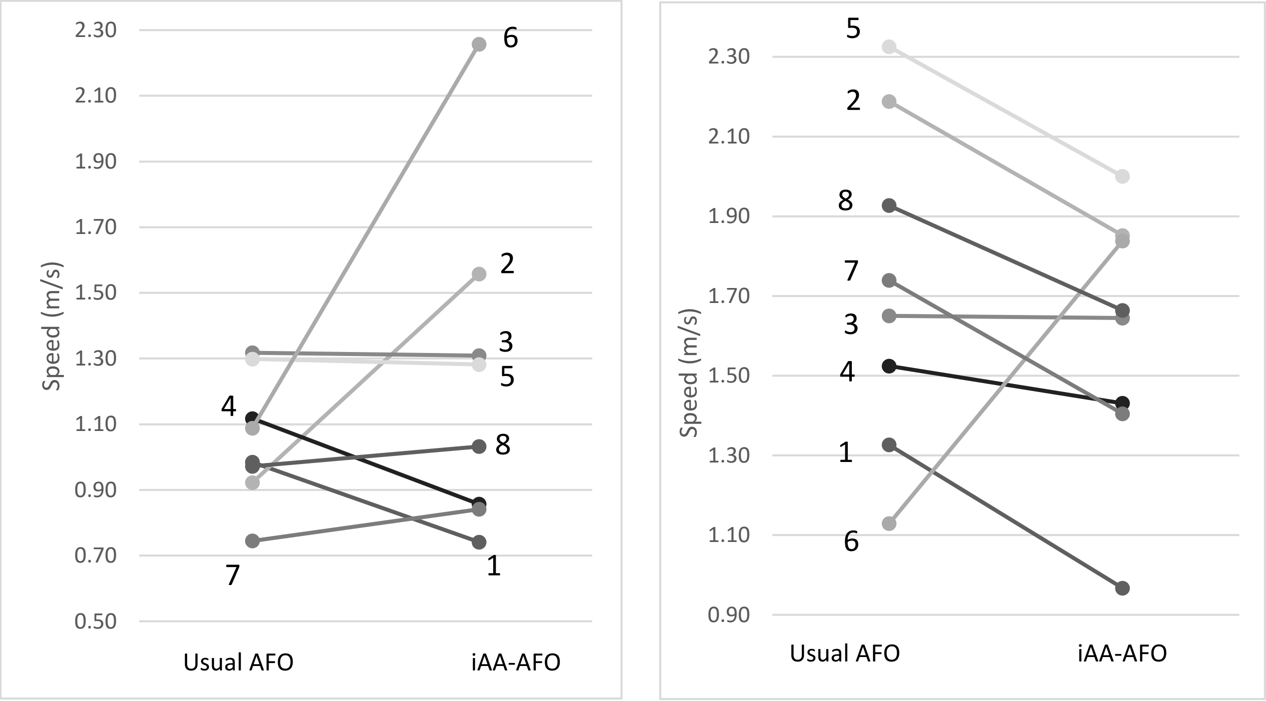
Table 5.3. *Characteristics of the participants with CP: ankle dorsiflexion (DF) range of motion measured with the foot in full supination, subtalar joint neutral, and full pronation.*

Child	**DF in supination**		**DF in neutral**		**DF in pronation**		**AA of iAA-AFO**	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
1	-15˚	-20˚	-11˚	-18˚	1˚	-20˚	-15˚	-20˚
2	n/a	-15˚	n/a	-17˚	n/a	-12 ˚	n/a	-15˚
3	-6˚	-18˚	7˚	1˚	1˚	4˚	-5˚	-20˚
4	-4˚	-12˚	-7˚	-4˚	-5˚	-15˚	-5˚	-10˚
5	-4˚	n/a	-4˚	n/a	1˚	n/a	-5˚	n/a
6	n/a	-8˚	n/a	-4˚	n/a	-4˚	n/a	-12˚
7	n/a	-25˚	n/a	4˚	n/a	-15˚	n/a	-25˚
8	n/a	-11˚	n/a	0˚	n/a	-9˚	n/a	-15˚
9	-4˚	-14˚	10˚	2˚	4˚	6˚	-5˚	-15˚
10	-18˚	-10˚	10˚	2˚	8˚	0˚	-20˚	-12˚

n/a = not applicable (i.e., child did not wear an AFO on this limb and ROM was not tested); negative numbers indicate a plantarflexed angle of the ankle; positive values indicate a dorsiflexed ankle angle



A. Pediatric Balance Scale



B. 10mSSWT

C. 10mFWT

Figure 5.2. Individual results of the: A. Pediatric Balance Scale, B. 10-meter Walk Test at Self-Selected Speed (10mSSWT), and C. 10-meter Walk Test at Fastest Speed (10mFWT) for the Usual and Individualized ankle angle in the ankle-foot orthosis (iAA-AFO) conditions for the eight participants with CP who completed these measures. Child IDs are indicated on each graph.

Table 5.4. *Characteristics of the Usual and iAA-AFOs and adjustments made during static alignment process.*

Child (Limb)	Usual AFO[a]						iAA-AFO orthosis[b]				
	AFO Type	AA-AFO[d] (height of heel wedge)	Other features	Additions		Final SVA	iAA-AFO[d] (height of heel wedge)	Other features	Additions		Final SVA
				Heel[c]	Through raise				Heel[c]	Through raise	
1(R)	Articulated[e]	0º (rest in 25º due to DF assist joints)	-	0	0	20º	-15º (4 cm)	Ribs	0	0	12º
1(L)	Articulated[e]		-	0	0	17º	-20º (4.5 cm)	Ribs	0	0	11º
2 (R)	Solid	-10º (2.4 cm)	Trim lines distal to MTPs	5º (1cm)	1cm	9º	-15º (3 cm)	-	10º	5mm	10º
3 (R)	Solid	-5º (1.5 cm)	-	2.5º (5 mm)	0	10º	-20º (4.5 cm)	-	0	7mm	12º
3 (L)	SMO	0º	-	0	0	10º	-5º (1.5 cm)	-	0	1.4cm	13º
4 (R)	Semi-flexible[f]	-3º (0.7cm)	0.5cm medial forefoot post; SMO insert, forefoot strap	0	0	17.5º	-5º (0.8cm)	12º forefoot equinus	5º	1cm	18º
4 (L)	Semi-flexible[f]	-10º (1cm)	SBA 5º recline; 0.5cm medial forefoot post; SMO insert, forefoot strap	0	0	10º	-10º (1.2cm)	15º forefoot equinus	5º	1cm	14º
5 (L)	Solid	0º	Trim lines distal to MTPs; SBA 10º	7º (1.3 cm)	1.4 cm on right leg	11º	-15º (1.7 cm)	-	5º	2 cm on right leg	9º
6 (R)	Semi-flexible[f]	0º (1cm)	SMO insert with 1cm lateral forefoot post	0	5mm	8º	-12º (3cm)	-	0	3 cm on left leg	10º

7 (R)	Carbon fiber[g]	0º	-	0	1.5 cm on left leg	10º	-25º (6.5 cm)	-	5º	5 cm on left leg	12º
8 (R)	Articulated[e]	0º	Toe strap	0	5mm on left leg	10º	15º (3 cm)	-	0	3cm on left leg	10º
9 (R)	Articulated[e]	0º	-	0	1cm	5º	15º (2.5cm)	-	0	0	10º
9 (L)	Articulated[e]	0º	-	0	0	10º	5º (1cm)	-	0	1.5cm	10º
10 (R)	Articulated[e]	0º (rest in 25º DF due to DF assist joints)	Casted in calcaneovarus with 15º lateral forefoot & hindfoot post	0	0	5º	12º (2.5 cm)	Ribs	5º (1.4cm)	0	17º
10 (L)	Articulated[e]			0	0	5º	20º (3.5 cm)	Ribs	5º (1.4 cm)	0	14º

PF: Plantarflexion; DF: Dorsiflexion; SMO: Supramalleolar orthosis; SBA: shank to bench angle; MTP: metatarsophalangeal joints; PLR: Point loading rocker

[a] All Usual AFOs had an SBA 0º, trim lines proximal to MTPs, and PLRs were added at 80% where trimlines were distal to MTPs

[b] All iAA-AFOs were solid AFOs, with trimlines distal to MTPs, PLR at 80%, toes 90º to shank.

[c] All footwear had a heel-sole differential (HSD) of 0mm, except for Child 10, whose HSD was 5mm.

[d] Articulated AFOs were custom-fabricated from 3/16” polypropylene with DF assist and PF stop, an AA-AFO of 0º, and SBA of 0º unless otherwise specified

[e] FlexiSport, Cascade DAFO, Ferndale, WA; [f] ToeOFF®, Allard USA, Rockaway, NJ

5.4.4 Kinematics and Kinetics

5.4.4.1 Ankle kinematic variables

Median peak dorsiflexion ROM (AnkleDF) in the Usual AFOs was 12˚ (range = -6˚ to 45˚). In the iAA-AFOs, AnkleDF was -12˚ (range = -20˚ to 3˚). Median peak plantarflexion ROM (AnklePF) in the Usual AFOs was -2˚ (range = -18˚ to 16˚), and in the iAA-AFO the median was -19˚ (range = -9˚ to -33˚). A Wilcoxon signed-rank test confirmed that the differences between conditions were significant for both AnkleDF (Z = -3.124, p = 0.002) and AnklePF n (Z = -2.897, p = 0.004). The median GVS_Ankle scores in the Usual AFOs (median = 9; range = 4-25) and in the iAA-AFOs (median = 24; range = 11-32) were significantly different ((Z = -3.067, p = 0.002).

5.4.4.2 Knee, hip, segment, and spatiotemporal variables

Overall, of the 15 limbs, 9 (60%) were positive net responders, and 6 (40%) were negative net responders. (Table 5.5 and 5.6). For these 25 variables, 12/15 limbs demonstrated at least 1 positive response (median=3; range=0-12), and 11/15 limbs demonstrated at least 1 negative response (median=1; range=0-9). Most variables were the same for the two AFO conditions.

The variables that were most often affected positively were: KneeExt (40%), GVS_knee (33%), KneeMom_TMSt (31%), and KneeFlex (27%) (Table 5.6 and Appendix D3). The variables that were most often affected negatively were: GVS_FFA (33%), GVS_VF (23%), HipROM (20%), KneeMom_LR (15%), and GVS_KneeMom (15%). There was little effect on spatiotemporal variables, and more knee variables were affected than hip variables. There were similar numbers of positive and negative effects at the hip. Effect sizes for the positive and negative responses ranged from 1.7 to 17.7 and -2.1 to -6.8 respectively, indicating large effects where the 90% CI analysis identified a significant response to the iAA-AFO.

Table 5.5. *Percentage of knee, hip, foot and shank segment, and spatiotemporal variables that demonstrated a positive change, negative change, or no change with the iAA-AFO, the net response for each limb, and the total (n and %) limbs in each net response category.*

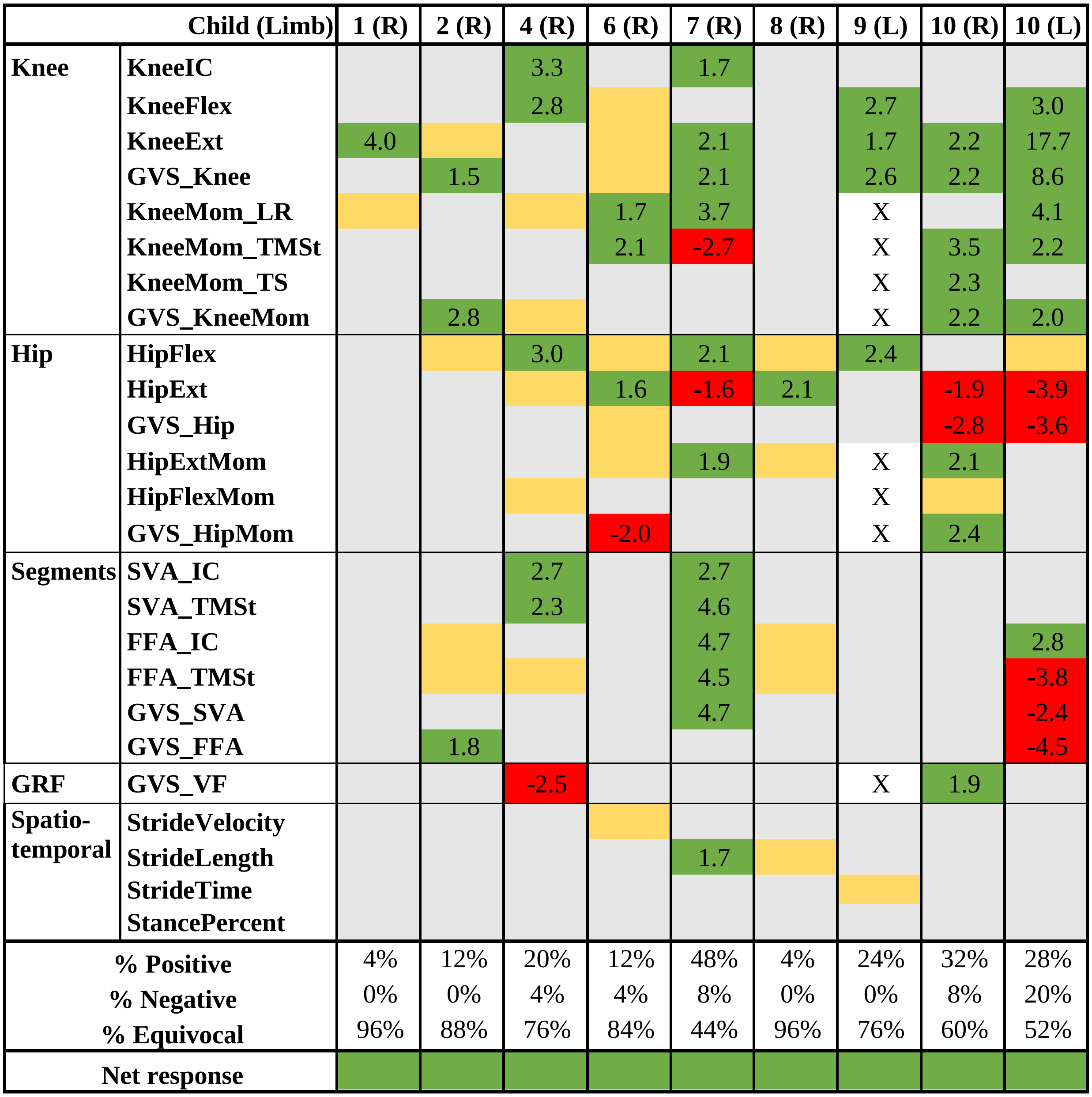
Child	Limb	Positive	Negative	No Change	Net Response
1	**R**	4%	0%	96%	Positive
	L	8%	36%	56%	Negative
2	**R**	12%	0%	88%	Positive
3	**R**	4%	28%	68%	Negative
	L	0%	4%	96%	Negative
4	**R**	20%	4%	76%	Positive
	L	12%	20%	68%	Negative
5	**L**	0%	4%	96%	Negative
6	**R**	12%	4%	84%	Positive
7	**R**	48%	8%	44%	Positive
8	**R**	4%	0%	96%	Positive
9	**R**	0%	6%	94%	Negative
	L	24%	0%	76%	Positive
10	**R**	32%	8%	60%	Positive
	L	28%	20%	52%	Positive
Net responses		**Positive responders**			**9 (60%)**
		Negative responders			**6 (40%)**

R: Right; L: Left

Table 5.6. *Individual variable response profiles by limb according to net response: A. Limbs with net positive response; B. Limbs with net negative response; C. Limbs with net equivocal response. Effect size (Cohen's d) values inside red and green boxes indicate magnitude of positive and negative responses.*

🟩 **Positive response**
🟥 **Negative response**
▨ **Equivocal response**
🟨 **Both conditions within normal range**
X **Not tested**

A.



	Child (Limb)	**1 (R)**	**2 (R)**	**4 (R)**	**6 (R)**	**7 (R)**	**8 (R)**	**9 (L)**	**10 (R)**	**10 (L)**
Knee	**KneeIC**	▨	▨	🟩 3.3	▨	🟩 1.7	▨	▨	▨	▨
	KneeFlex	▨	▨	🟩 2.8	🟨	▨	▨	🟩 2.7	▨	🟩 3.0
	KneeExt	🟩 4.0	🟨	▨	🟨	🟩 2.1	▨	🟩 1.7	🟩 2.2	🟩 17.7
	GVS_Knee	▨	🟩 1.5	▨	🟨	🟩 2.1	▨	🟩 2.6	🟩 2.2	🟩 8.6
	KneeMom_LR	🟨	▨	🟨	🟩 1.7	🟩 3.7	▨	X	▨	🟩 4.1
	KneeMom_TMSt	▨	▨	▨	🟩 2.1	🟥 -2.7	▨	X	🟩 3.5	🟩 2.2
	KneeMom_TS	▨	▨	▨	▨	▨	▨	X	🟩 2.3	▨
	GVS_KneeMom	▨	🟩 2.8	🟨	▨	▨	▨	X	🟩 2.2	🟩 2.0
Hip	**HipFlex**	▨	🟨	🟩 3.0	🟨	🟩 2.1	🟨	🟩 2.4	▨	🟨
	HipExt	▨	▨	🟨	🟩 1.6	🟥 -1.6	🟩 2.1	▨	🟥 -1.9	🟥 -3.9
	GVS_Hip	▨	▨	▨	🟨	▨	▨	▨	🟥 -2.8	🟥 -3.6
	HipExtMom	▨	▨	▨	🟨	🟩 1.9	🟨	X	🟩 2.1	▨
	HipFlexMom	▨	▨	🟨	▨	▨	▨	X	🟨	▨
	GVS_HipMom	▨	▨	▨	🟥 -2.0	▨	▨	X	🟩 2.4	▨
Segments	**SVA_IC**	▨	▨	🟩 2.7	▨	🟩 2.7	▨	▨	▨	▨
	SVA_TMSt	▨	▨	🟩 2.3	▨	🟩 4.6	▨	▨	▨	▨
	FFA_IC	▨	🟨	▨	▨	🟩 4.7	🟨	▨	▨	🟩 2.8
	FFA_TMSt	▨	🟨	🟨	▨	🟩 4.5	🟨	▨	▨	🟥 -3.8
	GVS_SVA	▨	▨	▨	▨	🟩 4.7	▨	▨	▨	🟥 -2.4
	GVS_FFA	▨	🟩 1.8	▨	▨	▨	▨	▨	▨	🟥 -4.5
GRF	**GVS_VF**	▨	▨	🟥 -2.5	▨	▨	▨	X	🟩 1.9	▨
Spatio-temporal	**StrideVelocity**	▨	▨	▨	🟨	▨	▨	▨	▨	▨
	StrideLength	▨	▨	▨	▨	🟩 1.7	🟨	▨	▨	▨
	StrideTime	▨	▨	▨	▨	▨	▨	🟨	▨	▨
	StancePercent	▨	▨	▨	▨	▨	▨	▨	▨	▨
% Positive		4%	12%	20%	12%	48%	4%	24%	32%	28%
% Negative		0%	0%	4%	4%	8%	0%	0%	8%	20%
% Equivocal		96%	88%	76%	84%	44%	96%	76%	60%	52%
Net response		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

B.

	Child (Limb)	1 (L)	3 (R)	3 (L)	4 (L)	5 (L)	9 (R)
Knee	**KneeIC**	3.9		🟨			
	KneeFlex	3.1	-3.1	🟨	-2.9		
	KneeExt	-6.8		🟨	1.8		-1.4
	GVS_Knee	-3.7		🟨	-1.6		
	KneeMom_LR	-4.7	-2.5	🟨			X
	KneeMom_TMSt		3.4				X
	KneeMom_TS						X
	GVS_KneeMom	-2.6		🟨	-2.3	🟨	X
Hip	**HipFlex**		🟨				🟨
	HipExt		🟨	🟨			
	GVS_Hip	🟨	🟨	🟨			
	HipExtMom		🟨		🟨	-2.4	X
	HipFlexMom	-1.8					X
	GVS_HipMom					🟨	X
Segments	**SVA_IC**						
	SVA_TMSt	🟨	-2.9	🟨			
	FFA_IC		-2.1		6.4	🟨	
	FFA_TMSt		-2.7		2.2	🟨	
	GVS_SVA		-2.6				
	GVS_FFA	-2.2	-3.2	-2.7	-1.6	🟨	
GRF	**GVS_VF**	-2.0		🟨	-2.2		X
Spatio-temporal	**StrideVelocity**	-2.3	🟨	🟨			
	StrideLength	-2.4				🟨	
	StrideTime						🟨
	StancePercent			🟨	🟨	🟨	
% Positive		8%	4%	0%	12%	0%	0%
% Negative		36%	28%	4%	20%	4%	6%
% Equivocal		56%	68%	96%	68%	96%	94%
Net response		🟥	🟥	🟥	🟥	🟥	🟥

5.5 Discussion

This study evaluated the immediate effects of an iAA-AFO on gait and functional mobility for children with CP and equinus, compared to conventionally-prescribed AFOs. More limbs responded positively than negatively, suggesting that this approach can improve gait mechanics, although the individual net effect may vary. As hypothesized, the greatest effects of the iAA-AFO were seen at the knee. Similar numbers of positive and negative effects occurred at the hip, foot, and shank, while spatiotemporal parameters and functional mobility were not noticeably affected. This is the first study to explicitly compare the effects of an iAA-AFO and conventionally-prescribed AFOs, and the results may assist clinicians in making more evidence-based orthotic decisions.

While the AFO literature has focussed primarily on effects at the ankle, our results highlight potential proximal effects associated with bracing the ankle in a position that tries to account for the length and stiffness of the gastrocnemius muscle. The most common effects of the iAA-AFO were more typical knee kinetics and kinematics, including increased knee extension at IC and throughout stance phase. These gains may have important implications, given that many interventions for children with CP aim to improve knee ROM and gait kinematics. Increased knee extension at IC has also been observed after gastrocnemius-soleus tenotomies for children with equinus, suggesting an effect on the dynamic coupling of the ankle and knee joint (Baddar et al., 2002). It is possible that the mechanism is similar for the iAA-AFO; however, the effect in our study was not beneficial for all children, and gait mechanics appeared worse for some, in comparison to their usual AFOs.

Some of these equivocal or negative responders may have benefitted from further tuning of the AFO-FC to optimize the SVA alignment for walking. The interaction of gastrocnemius and GRF alignment relative to the knee is considered to be a primary contributor to several gait patterns affecting children with CP (e.g., genu recurvatum; Bauer et al., 2017; and crouch; Steele, Seth, Hicks, Schwartz, & Delp, 2010; Steele, van der Krogt, Schwartz, & Delp, 2012); however, effective control of sagittal plane ankle motion can allow a solid AFO to realign the GRF and normalize joint moments at the knee and hip (Butler & Nene, 1991; Carse, Bowers, Meadows, & Rowe, 2014; Meadows et al., 2008). Although we optimized the static alignment of the AFO-FC during standing, it is likely that tuning (e.g., adjustments to the AFO-FC to optimize the SVA during walking) would have conferred further biomechanical gains for these participants. Indeed, most demonstrated gait patterns that are considered amenable to tuning (e.g., knees extended during stance, less than 20˚ of knee flexion at IC) (Butler, Farmer, Stewart, Jones, & Forward, 2007b; Jagadamma et al., 2015). Eddison and colleagues (Eddison et al., 2017) reported that SVAs measured during static standing were equivalent to those seen at temporal midstance in the gait cycle; however, we did not find that our statically-aligned SVAs were dynamically optimized in temporal midstance in this study. Therefore, standard practice following the fitting of an iAA-AFO should include dynamic optimization of SVA alignment during walking, as part of the tuning process (Jagadamma et al., 2010; Meadows, 2014; National Health Service Quality Improvement Scotland, 2009; Owen, 2010, 2018).

Adequate AFO stiffness is an additional factor that influences knee and hip mechanics (Bowers & Ross, 2009; Kerkum, Buizer, et al., 2015). Visual analysis of the kinematic ankle joint data in this study suggested that most of the solid AFOs (both Usual and iAA-AFOs) may not have been stiff enough to maximize control of the shank segment and optimize effects at the knee and hip joints. For example, ankle plantarflexion at loading response (up to 10˚ of motion in some children) may have contributed to increased stance phase knee hyperextension and shank recline, as this insufficient stiffness prevented the AFO from facilitating normal shank incline as the centre of mass moved forward in midstance. In other cases, the iAA-AFOs allowed up to 15˚ of relative ankle dorsiflexion in stance phase, potentially failing to optimize the AFO's effect on knee moments. As the design of the iAA-AFOs in this study reflects accepted clinical practice (regarding trimlines, materials, and fit), these observations imply that stiffer AFO designs may be necessary to support the achievement of some biomechanical goals.

A 90˚ AA-AFO is also conventional in clinical practice. This was reflected in the large difference between the AA-AFOs of the community-prescribed Usual AFOs and the child's clinically-measured dorsiflexion ROM. As expected, there was a corresponding difference between the Usual and iAA-AFO conditions for peak dorsiflexion and plantarflexion ROM, consistent with the iAA-AFOs. Therefore, when individualizing the AA-AFO, acknowledgement of potential trade-offs may require the team to prioritize orthotic goals. For example, kinematic gains at the knee may be associated with the potential for a more plantarflexed position and less ankle motion when the AFOs are worn. This possibility may deter clinicians who have concerns that plantarflexed AA-AFOs may cause (or fail to address) plantarflexion contractures (Kane, Lanovaz, & Musselman, 2018; Kane et al., 2018), even though AFOs have not been shown to increase ankle dorsiflexion ROM or prevent contractures (Bowers & Ross, 2009), and less than 90˚ of passive ankle dorsiflexion ROM has been identified as a contraindication for a 90˚ AA-AFO (as well as hinged, dorsiflexion-free AFOs) (Eddison & Chockalingam, 2013; Owen, 2015; Ridgewell et al., 2010).

The algorithm we used in this study explicitly considers the risk of losing ankle ROM in the decision-making process (Owen, 2005). The natural history of CP involves development of secondary musculoskeletal deformities such as plantarflexion contractures throughout an individual's lifespan (Gage & Schwartz, 2009; Goldstein & Murray, 2001; Rosenbaum et al., 2007). As such, clinical management plans should be responsive to clinical re-assessment findings. Additionally, specifying the duration of wear as part of the AFO prescription provides an opportunity to discuss time out of orthoses, when the child's ankles may move through their available ROM (Owen, 2018).

Clinical algorithms have been used in medicine since the 1970s to describe and personalize intervention, and to reduce trial and error decision-making (Federer, Taylor, & Mather, 2013; Sox & Stewart, 2015). Algorithms are intended to be simplistic and systematic, and are recommended when a variety of responses, patient preferences, and needs exist, and options in the decision pathway are unambiguous (Federer et al., 2013; Keffer, 2001). While clinicians do endeavour to individualize AFO prescriptions for children with CP (Kane et al., 2018), decision-making in orthotic management is impacted by numerous factors, many of which are yet unknown. Furthermore, the standard approach to decision-making is variable, and relies on trial and error and anecdotal evidence (Kane et al., 2018; Morris et al., 2002), indicating a clear need for decision-making guidelines such as clinical practice guidelines (CPGs; Davis, Goldman, & Palda, 2007; Sox & Stewart, 2015). Algorithms have been included in evidence-based CPGs to guide complex decision-making in other aspects of rehabilitation management of children with CP (Fehlings et al., 2012; O'Neil et al., 2006). Therefore, the development and refinement of algorithms such as the one used in this study appear to be a valuable endeavour.

The algorithm we used to determine the iAA-AFO in this study is the only one of its kind for this purpose; however, as it is based on theoretical justification, clinical experience, and expert opinion, a systematic literature review and further high quality research would help link recommendations with evidence (Sox & Stewart, 2015). The results of this study suggest modifying the algorithm's present end-point to include biomechanical optimization of the AFO-

FC. The variety of responses we observed in this study highlight the need for objective evaluation and tuning post-fitting to be prioritized in clinical practice. This suggestion is consistent with previous authors who have asserted that the determination of the AA-AFO is a first step and prerequisite for biomechanical optimization for gait (Bowers & Ross, 2009; Owen, 2010, 2018). To this end, a further step may be to create an algorithm to guide visual gait analysis for tuning and biomechanical optimization following the fitting of an iAA-AFO.

5.5.1 Limitations

Given the small sample size and the variety of Usual AFO types, it is difficult to draw conclusions about the reasons underlying the variety of responses to the iAA-AFO. No clear patterns emerged that suggested effects related to participant characteristics such as GMFCS level, age, or diagnosis. The effects of the iAA-AFOs may have been in part due to differences in AFO types tested in the Usual condition. Replication with larger samples, and with solid AFOs in the Usual condition, is warranted to examine factors that may predict a child’s response to iAA-AFOs. Statistical modelling techniques may also help to identify the factors affecting individual responses to an iAA-AFO.

As this is the first study examining the effects of the AA-AFO, we examined only the immediate effects. For many participants, the iAA-AFOs were quite different from their Usual AFOs, and their performance may not have reflected their potential. As there is likely an effect of practice on gait, further longitudinal research should examine whether kinematics, kinetics, and walking speed change with gait training. While we found no significant effect of the iAA-AFO on PBS scores, spatio-temporal parameters, or the 10mSSWT or 10mFWT, the median speed on the 10mFWT decreased 0.29m/s. This change was not statistically significant, but it may be clinically meaningful. It is possible that fatigue affected the results, or that children may require more practice to become confident walking quickly in a new iAA-AFO. It may also be noted that Participant 6 walked much faster in the iAA-AFOs than in his usual AFOs at both 10mWT speeds (Figure 5.2), suggesting that the test may have questionable validity as a walking speed measure in some situation. Longitudinal research should also examine the effects of iAA-AFOs on community walking and participation in daily activities.

Finally, the extent to which either AFO controlled pronation and midfoot break is unknown. Passive dorsiflexion ROM measurements were greater with the foot pronated than supinated for 12 of 15 limbs, and pronation was observed visually during barefoot gait for most children (Appendix D3). Uncontrolled pronation and midtarsal joint dorsiflexion may explain how peak ankle dorsiflexion motion in the Usual AFOs surpassed the clinically measured ranges for many children. Dorsiflexion in gait is also likely to exceed the passively measured range due to the large lever arm and forces in terminal stance; however this motion may be achieved at joints other than the talocrural joint (e.g., via subtalar joint pronation or midtarsal joint dorsiflexion; Johanson et al., 2014; Karas, 2002). Such chronic repetitive strain may contribute to long-term pain, which is a prevalent concern for adults with CP (Bleck, 1987; Jahnsen et al., 2004). As clinicians may assume that dorsiflexion motion occurs at the talocrural joint in a hinged AFO, or with a conventional 90˚ AA-AFO, this issue warrants further exploration. Other areas for future longitudinal research include the relationship between gastrocnemius length, foot deformity and pain, along with the validity of concerns that positioning an ankle in plantarflexion increases the risk of losing ankle ROM.

5.6 Conclusion

The results of this study demonstrate immediate beneficial effects of individualizing the AA-AFO for some children with CP and equinus, in comparison to community-prescribed standard-of-care AFOs. While not all limbs demonstrated gains, almost half improved, consistent with previous statements that current AFO prescription practises may be improved (Ries et al., 2014). These results also highlight the need to individualize orthotic prescriptions, to identify and address biomechanical goals specific to the child’s individual physical characteristics. Clinical use of an iAA-AFO should be accompanied by objective post-fitting gait evaluation (using video or instrumented measures) to tune the AFO-FC and optimize dynamic alignment. Future development of evidence-based clinical practise guidelines that incorporate clinical algorithms are an important step toward consistent high quality, individualized orthotic care for children with CP.

CHAPTER 6: GENERAL DISCUSSION AND CONCLUSIONS

This thesis aimed to improve the evidence guiding AFO prescription for children with CP, and to contribute to the development of best practice guidelines for AFO prescription in this population. Two studies explored the clinical context in which AFO prescriptions are initiated and implemented in Canada; one (Chapter 3) used semi-structured interviews and focus groups to examine clinician experiences and the factors that currently influence prescription, and the second (Chapter 4) surveyed PTs to understand how outcome measures are used to inform and evaluate the prescribed AFO. A third study (Chapter 5) examined the effect of individualizing one aspect of the prescription – the AA-AFO – on gait biomechanics and functional mobility for children with CP.

In their results, each of these studies highlighted current opportunities and challenges in AFO prescription. Although numerous studies have examined the effects of AFOs in laboratories, Chapters 3 and 4 present new information about some of the factors that impact their effectiveness in practice. Chapter 3 illustrates the collaborative, iterative, and individualized process of AFO prescription, and describes supports and challenges that may impact successful orthotic care. This study identified the importance of evaluation in the process of AFO prescription, which was further explored in Chapter 4. We found that while PTs attempt to use evaluation to individualize prescriptions, the themes arising in Chapter 4 indicated a focus on impairment-level measures, inconsistency in evaluation and recommendations, and a lack of knowledge and confidence in this area. These findings may help explain reports that AFOs may not improve the child's gait pattern, or in some cases make it worse (Ries et al., 2014); however, they also suggest areas for improvement and both chapters offer recommendations for clinical practice. Chapter 5 highlights and discusses the potential to improve conventional prescriptions using an algorithm approach that is based on biomechanical principles and PT evaluation findings for the individual child. In this study, individualizing the AA-AFO based on gastrocnemius length and stiffness improved gait mechanics for half of children compared to their conventionally-prescribed AFOs.

Although the studies examined different aspects of AFO prescription, they reiterate key considerations from multiple perspectives. This thesis highlights three broad themes for exploration and growth – both through orthotic research and in clinical practice: 1) prioritizing objective evaluation at all ICF levels, especially participation, at initial prescription and follow-up; 2) collaboration and communication during goal setting, prescription decisions, and follow-up; and 3) individualizing prescriptions (based on biomechanical rationale) through the development and use of evidence-based guidelines and algorithms to optimize outcomes. These themes form an inter-connected foundation for continued progress toward evidence-based AFO prescription and better mobility outcomes for children with CP.

All three studies demonstrated the value of objective evaluation, which is essential to identify and quantify the characteristics of the child that are relevant to designing the initial prescription. Subsequently, follow-up evaluation allows clinicians to optimize the prescription. Although PTs do recognize the importance of follow-up evaluation, it may not always happen in practice (Chapter 3); furthermore, only a minority of adjustments appear to focus on biomechanical optimization of the AFO-FC (Chapter 4). Therefore, emphasizing objective follow-up assessment to tune the AFO-FC and optimize its alignment for activity may represent an opportunity to improve orthotic outcomes.

Collaboration, resources, and environmental factors must also be considered. In the absence of collaboration, it becomes challenging to implement a clinical algorithm or incorporate evaluation findings into the prescription. For example, to individualize the AA-AFO in practice, consensus must be reached amongst the team members (including family) regarding mobility goals and the orthotic plan prior to fabrication. Resources and environmental factors must also support individualized prescription. For example, if the effectiveness of a clinical algorithm is dependent on footwear, yet appropriate shoes and modifications may be difficult or costly to obtain, (as is presently the case in Canada), then optimal results are less likely to be achieved.

Although clinicians endeavor to individualize AFO prescriptions (Chapters 3 and 4), current practices rely on trial and error, habit, and inconsistent use of objective evaluation measures, primarily at the impairment level. This presents both challenges and opportunities for improvement. Chapter 5 illustrates potential benefits of individualizing the AA-AFO using a clinical algorithm. Indeed, algorithms appear to be a feasible and effective means of guiding simple orthotic decision-making in practice. However, further research is necessary to understand the factors that affect children’s responses to individual biomechanical aspects of the AFO prescription. It is likely that orthotic outcomes will improve as our understanding of these factors develops.

One challenge for clinicians is to shift the focus of prescription away from impairments and toward outcomes that children and families find meaningful. Participation-level goals have been described as being most important for children and families (Anaby et al., 2017; Schiariti & Masse, 2015); therefore, child-and family-centred care should involve goal-setting and objective evaluation at all levels of the ICF framework. Within the greater context of pediatric physiotherapy, there appears to be a growing acknowledgement that justification for the traditional focus on impairment-based interventions has not been demonstrated. It is therefore important for orthotic research to include studies of the effects of AFOs on participation and activity level outcomes (Bjornson et al., 2016; Harlaar et al., 2010).

This thesis sets the stage for future research that will advance orthotic practice and management of gait impairments for children with CP. To maximize opportunities for research evidence to inform practice, analyses should explore the responses and characteristics of individuals (as we did in Chapter 5) or attempt to identify the patterns and factors affecting individual responses within groups of heterogenous individuals. Individual analyses have the potential to explore variation in treatment responses between individuals and to identify factors predicting or affecting those responses. The limitations of analyses based on measures of central tendency for children with CP have been described (Bowers & Ross, 2009; Damiano, 2014); however, such analyses pervade orthotic research and evidence grading systems.

It is necessary for conventional clinical reasoning practices to move away from inefficient approaches that are based primarily on trial-and-error and anecdotal evidence, toward more research-based algorithms, clinical practice guidelines, and prescription decisions supported by evidence-based biomechanical rationales. A shift away from impairment-level outcome measures toward a focus on activity and participation goals is similarly needed to result in more meaningful, effective orthotic care. This thesis enhances the current understanding of how AFOs are prescribed for children with CP in Canada and provides an example of how individualizing one aspect of the AFO prescription – the AA-AFO – can improve gait mechanics for children with CP. By placing this knowledge in the context of current research evidence, future directions emerge, and new opportunities can be realized.

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Appendix A. Copyright Permissions

Title: Clinician perspectives and experiences in the prescription of ankle-foot orthoses for children with cerebral palsy

Author: Kyra Kane, Patricia Manns, Joel Lanovaz, et al

Publication: PHYSIOTHERAPY: THEORY AND PRACTICE

Publisher: Taylor & Francis

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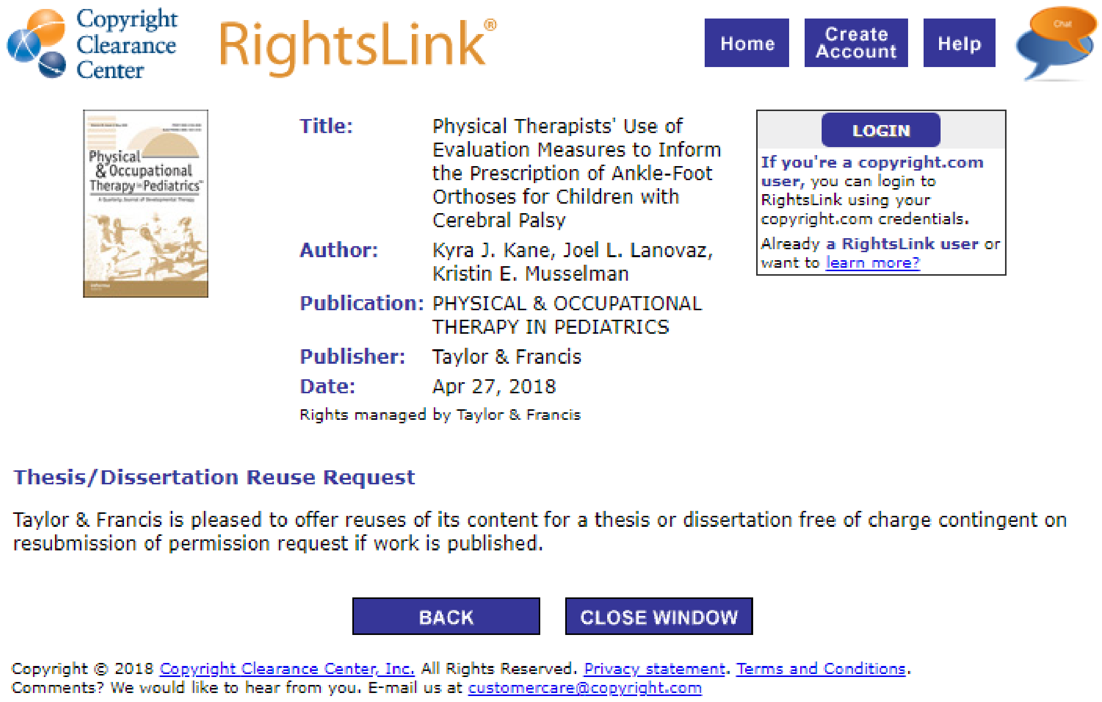

Title: Physical Therapists' Use of Evaluation Measures to Inform the Prescription of Ankle-Foot Orthoses for Children with Cerebral Palsy

Author: Kyra J. Kane, Joel L. Lanovaz, Kristin E. Musselman

Publication: PHYSICAL & OCCUPATIONAL THERAPY IN PEDIATRICS

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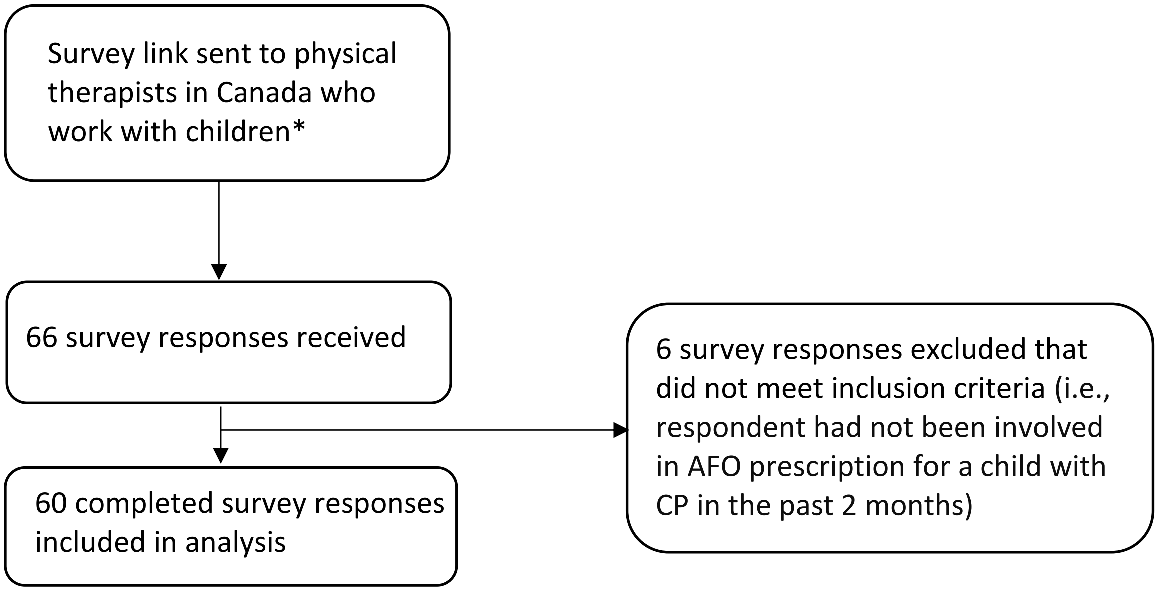
Appendix B. STROBE flow diagram summarizing collection and screening of survey responses (Chapter 4).



*Number of potentially eligible participants is unknown.

Appendix C. Survey Instrument (Chapter 4)

Project title: Understanding how physical therapists make decisions about ankle-foot orthoses (AFOs)

Researcher: Kyra Kane, BScPT, MSc, PhD candidate, Health Sciences Program, University of Saskatchewan, kyra.kane@usask.ca

Supervisors:

- Kristin Musselman, PT, PhD, University Health Network and University of Toronto, kristin.musselman@uhn.ca
- Joel Lanovaz, PhD, College of Kinesiology, University of Saskatchewan, (306) 9661073, Joel.lanovaz@usask.ca

Purpose and Objectives of the Research:

- We would like to find out how physical therapists (PTs) use evaluation measures to make decisions about AFOs for children with cerebral palsy (CP).
- The information you provide will help support the development of recommendations to improve evaluation in AFO prescription.

Procedures:

- Physical therapists who are licensed in Canada and who have been involved with AFO prescription for a child with CP at least once in the past two months are invited to complete an online survey. The survey will take about 30 minutes to complete.
- Responses from all surveys will be combined and summarized using descriptive statistics.
- Please feel free to ask any questions regarding the procedures and goals of the study or your role.

Potential Risks:

- There are no known or anticipated risks to you by participating in this research.

Potential Benefits:

- There are no direct benefits to you for participating in this research.
- The results from this research will inform rehabilitation professions about physical therapy assessment and decision-making for AFO prescription, and will provide initial clinical practice guidelines for AFO prescription.

Compensation:

- At the end of the survey, you will have the option to enter your email address into a draw for one of four $50 Amazon.ca gift cards.

Confidentiality:

- Survey responses are collected anonymously.

- If you enter your email address for the draw, your email address will be stored separately from the survey responses on a password-protected computer. The electronic file containing the email addresses will be deleted once the gift card draw has occurred.
- This survey is hosted by SurveyMonkey, a USA owned company and subject to US laws. As such the privacy of the information you provide may be subject to the laws of that jurisdiction. By participating in this survey you acknowledge and agree that your answers/information will be stored in the USA and therefore may or may not receive the same level of privacy protection afforded by Canadian law.

Right to Withdraw:

- Your participation is voluntary. You may withdraw from the research project for any reason, at anytime without explanation or penalty.
- Should you wish to withdraw, you can close the online survey in your web browser.

Follow up:

- To obtain results from the study, please contact Kyra Kane at kyra.kane@usask.ca.

Questions or Concerns:

- Contact the lead researcher (Kristin Musselman) using the information at the top of this page. This research project was reviewed and approved on ethical grounds through a harmonized review process by the University of Saskatchewan and Regina Qu'Appelle Health Region Research Ethics Boards. Any questions regarding your rights as a participant may be addressed to that committee through the U of S Research Ethics Office at ethics.office@usask.ca or (306) 966-2975.

Out of town participants may call toll-free at 1-888-966-2975.

Consent:

By completing and submitting the questionnaire, YOUR FREE AND INFORMED CONSENT IS IMPLIED and indicates that you understand the above conditions of participation in this study.

Demographics

Please tell us a bit about yourself.

1. In the past **2 months**, how often have you been involved in AFO prescription for a child with CP, **or** made decisions about the AFOs of a child with CP? (This may include checking or re-assessing a child's AFOs as part of a treatment session, or contributing to decisions about new AFOs.)

○ I have not seen a child with CP who wears AFOs in the past 2 months.

○ Monthly (I see about 1-3 children per month with AFOs and CP)

○ Weekly (I see 1-4 children per week with AFOs and CP)

○ Daily (I see one child or more per day with AFOs and CP)

Demographics

2. In which province do you work?

3. How many years have you worked as a physiotherapist?

4. How many years have you worked in paediatrics?

5. Please describe your main work setting (Check all that apply.)

☐ Publicly-funded facility (hospital, rehabilitation centre)

☐ Privately-funded clinic

☐ Rural

☐ Urban

6. Where are the orthotists that you work with located? (Check all that apply, if you frequently work with more than one orthotist.)

☐ On-site

☐ <1 km away

☐ >1 km away

☐ Other (please specify)

7. How confident are you in your ability to recommend the correct AFO type (solid, hinged, etc.) and characteristics (stiffness, trimlines, ankle angle, etc.) for children with CP?

Not confident at all ○ Extremely confident

Section 1: Recommendations about AFO prescription

The next questions relate to the following scenario:
An 8-year-old ambulatory child with CP comes to you for an assessment. AFOs have been suggested for the child. The physician wants your recommendation about the AFO type (solid, hinged, etc.) and characteristics (stiffness, trimlines, ankle angle, etc.) before writing the prescription.

8. Please select the items that you think would likely be most helpful in making this decision.

☐ Gait pattern (e.g., general gait appearance, crouch, scissoring etc.)

☐ Spatio-temporal variables (step length, velocity, etc.)

☐ Gross motor skills

☐ Bony alignment of foot and leg

☐ Range of motion - ankle, knee, hip

☐ Muscle strength

☐ Muscle tone (general resistance to passive movement or another measure of tone)

☐ R1 measurement for plantarflexor muscles

☐ Selective voluntary control of lower extremity

☐ Goals

☐ Shank to vertical angle and shank kinematics during gait

☐ Pain

☐ Leg length

☐ Parent/child preference about the type of AFO

☐ Participation in school/social/recreational activities

☐ Other (please specify or add a comment to elaborate on your answers above)

☐

9. You identified that you would normally consider the following information when deciding what type of AFO to recommend for a child with CP.

How do you measure each item? If you use any specific tools, please list them (e.g., videorecording, goniometer, names of standardized outcome measures or clinical tests).

Gait pattern (e.g., general appearance: crouch, scissoring etc.)	
Spatio-temporal variables (step length, velocity, etc.)	
Gross motor skills	
Bony alignment of foot and leg	
Range of motion - ankle, knee, hip	
Ankle range of motion - dorsiflexion with knee extended	
Knee range of motion	
Hamstring length	
Muscle strength	
Muscle tone (general resistance movement or another measure of tone)	
R1 measurement for plantarflexor muscles	
Selective voluntary control of lower extremity	
Goals	
Shank to vertical angle and shank kinematics during gait	
Pain	
Leg length to passive	
Parent/child preference about the type of AFO	
Participation in school/social/recreational activities	

Other (please specify or add a comment to elaborate on your answers above)

10. Of the information that you consider when recommending an AFO for a child, which ones usually influence your decision the most?

Please list the **three most important things that you assess,** in order of their importance.

Most important information

2nd most important

3rd most important

11. How do you evaluate the child's gait, to make a decision about the type of AFO you are recommending?

always	Never	Rarely (<25% of children with AFOs)	Sometimes (26-50% of children)	Often (51-75% of children)	Most of the time (75-95% of children)	Always or almost (95-100% of children)
Watch the child walk	○	○	○	○	○	○
Use video to record gait	○	○	○	○	○	○
Other instrumented method (e.g., 3-D gait analysis, GAITRite walkway)	○	○	○	○	○	○
Gait checklist (e.g., Edinburgh Visual Gait Score)	○	○	○	○	○	○
Evaluation with orthotist	○	○	○	○	○	○
Evaluation with another PT	○	○	○	○	○	○
Evaluation with a doctor	○	○	○	○	○	○

Other (please specify or add a comment)

12. You have finished assessing this ambulatory child for a new AFO.

Please describe the most important examination findings that would lead you to suggest each of the following AFO types. (If you do not use or are not familiar with the type of AFO, please indicate this):

Solid AFO

Hinged AFO

Ground reaction AFO

Posterior leaf spring, or other semi-rigid AFO

ESR (energy storage and return) AFO

Carbon fiber AFO

13. How do you decide whether a hinged AFO or a solid AFO is more appropriate for a child? If there are certain assessment findings that help you to decide between these 2 types of AFO, please describe them as specifically as you can.

Section 2: Casting positions for the foot and ankle

A doctor prescribes a new AFO for a child on your caseload, and a casting appointment is scheduled with an orthotist.

The following questions relate to the recommendations you make about the **position of the child's foot and ankle in a new AFO.**

14. For the children you see, how often do you provide recommendations to the orthotist about the <u>position of the foot and ankle in the cast</u>?

○ Never

○ Rarely (<25% of the children I see)

○ Sometimes (25-50% of the children I see)

○ Usually (75-95% of the children I see)

○ Always or almost always (95-100% of the children I see)

○ Other (please comment)

15. For the children you see, how often are AFOs fabricated with the ankle positioned at a plantarflexed angle?

○ Never

○ Rarely (<25% of children)

○ Sometimes (25-50% of children)

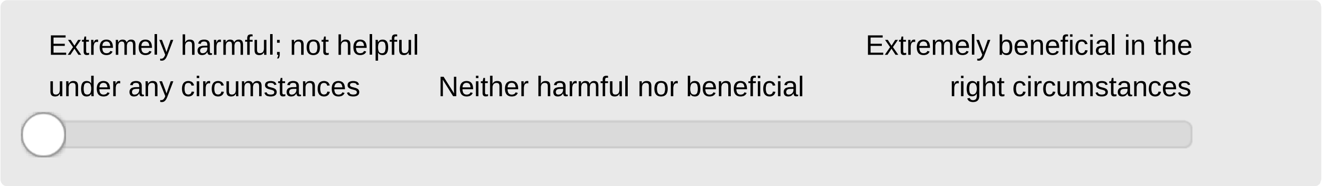
○ Usually (75-95% of children)

○ Always or almost always (95-100% of children)

○ Other (please comment)

16. What examination findings would cause you to recommend positioning the ankle at a plantarflexed angle in an AFO?

17. How harmful or beneficial do you believe it is to position an ankle in plantarflexion in an AFO?



Extremely harmful; not helpful under any circumstances

Neither harmful nor beneficial

Extremely beneficial in the right circumstances

18. Why do you think it may be harmful or beneficial to position an ankle in plantarflexion?

Section 3: Follow-up evaluation for a new AFO

The next questions are about PT **follow-up evaluation for a child who has received a new AFO.**

9. An 8-year-old ambulatory child with CP comes in to see you after getting a new AFO.

Please select the items you would likely assess, to **evaluate the effects of the new AFO.**

☐ Gait pattern (e.g., general gait appearance, crouch, scissoring etc.)

☐ Spatio-temporal variables (step length, velocity, etc.)

☐ Gross motor skills

☐ Bony alignment of foot and leg

☐ Range of motion - Ankle, knee, hip

☐ Muscle strength

☐ Muscle tone (general resistance to passive movement or other measure of tone)

☐ R1 measurement for plantarflexor muscles ("first catch")

☐ Selective voluntary control of the lower extremity

☐ Goals

☐ Shank to vertical angle and shank kinematics during gait

☐ Pain

☐ Leg length

☐ Ask parent/child if they are happy with the AFO

☐ Participation in school/social/recreational activities

☐ Other (please specify)

20. You reported that you would normally consider the following information in your decision. How would you measure each item <u>during your reassessment</u>? If you use any specific tools, please list them (e.g., videorecording, goniometer, names of standardized outcome measures or clinical tests).

Gait pattern (e.g., general appearance, crouch, scissoring etc.)	
Spatio-temporal variables (step length, velocity, etc.)	
Gross motor skills	
Bony alignment of foot and leg	
Range of motion - Ankle, knee, hip	
Muscle strength	
Muscle tone (general resistance to passive movement or other measure of tone)	
R1 measurement for plantarflexor muscles ("first catch")	
Selective voluntary control of the lower extremity	
Goals	
Shank to vertical angle and shank kinematics during gait	
Pain	
Leg length	
Ask parent/child if they are happy with the AFO	
Participation in school/social/recreational activities	
Other (please specify)	

21. Of the information that you consider when re-assessing a child's AFO, which ones are usually the most helpful or informative?
Please list the **three most important things that you assess** **in order to evaluate the effect of an AFO**, in order of their importance.

Most important information

2nd most important

3rd most important

22. Of the children you see with AFOs, approximately how many do you re-evaluate once they have a new AFO, **to check how well the AFO is working for the child?**

None	1-25% of them	26-50% of them	51-75% of them	76-100% of them
○	○	○	○	○

Other (please specify)

23. How important do you think it is to complete a PT evaluation after a child gets a new AFO?

Not at all important or beneficial	Somewhat beneficial	Extremely important and beneficial
○		

Section 4: AFO-footwear combination adjustments and tuning

The following questions are about **adjustments to the AFO and footwear** that you might make **after a child receives a new AFO**.

24. When a child gets a new AFO, have you ever made or recommended adjustments (e.g., to the orthotist) to optimize how the child walks in it?

○ Yes

○ No

25. Please describe some examples of adjustments that you usually make or recommend for the AFO and/or footwear, in order to improve the way the child walks.

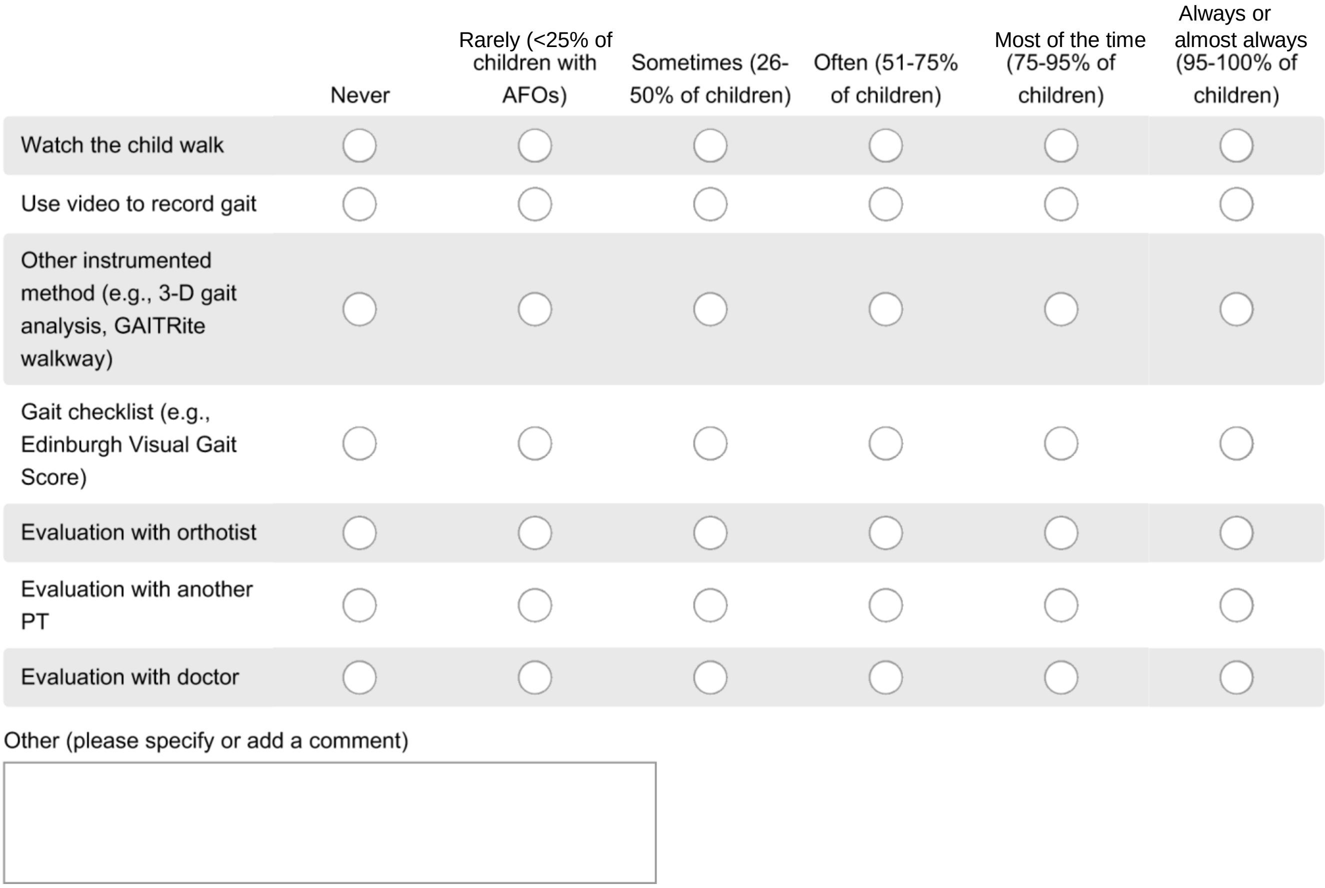
26. How often (i.e., for what percentage of children who get AFOs) do you make or recommend adjustments or modifications to the AFO or footwear?

Rarely (1-25% of children)	Sometimes (26-50% of children)	Often (51-75% of chidren)	Almost always (>75% of children)
○	○	○	○

Other (please specify or add a comment)

☐

27. How do you evaluate the AFO with the footwear to make this decision?



	Never	Rarely (<25% of children with AFOs)	Sometimes (26-50% of children)	Often (51-75% of children)	Most of the time (75-95% of children)	Always or almost always (95-100% of children)
Watch the child walk	○	○	○	○	○	○
Use video to record gait	○	○	○	○	○	○
Other instrumented method (e.g., 3-D gait analysis, GAITRite walkway)	○	○	○	○	○	○
Gait checklist (e.g., Edinburgh Visual Gait Score)	○	○	○	○	○	○
Evaluation with orthotist	○	○	○	○	○	○
Evaluation with another PT	○	○	○	○	○	○
Evaluation with doctor	○	○	○	○	○	○

Other (please specify or add a comment)

☐

Final comments

28. Is there anything you would like to suggest, in order to improve assessment and prescription/recommendation of AFOs?

☐

Thank you for completing this survey!

If you would like to enter the draw for one of four $50 Amazon gift cards, please click on the link below. Here, you will be able to enter your email address for the draw. This allows the researchers to keep your email address separate from your survey answers.

https://www.surveymonkey.com/r/6F9BW72

Appendix D. Supplementary Tables (Chapter 5)

Table D.1. *Physical assessment findings for participants with CP **

Child (Limb)	Foot posture	Forefoot posture[a]	Foot flexibility	Knee Extension PROM[b]	TFA[c]	Femoral anteversion	Duncan Ely Test	Thomas Test	LLD
1(R)	Pronation, midfoot break	WNL	Flexible to neutral	-10°	-3°	Yes	WNL	-5°	1cm short
1(L)	Neutral	Equinus	Flexible to neutral	0°	WNL	WNL	WNL	WNL	-
2(R)	Inversion/ supination, midfoot break	Moderate MTA	Flexible	0°	0°	WNL	WNL	WNL	1.5cm short
3(R)	Calcaneovalgus	Equinus	Fixed	0°	WNL	WNL	WNL	-5º	2cm short
3(L)	WNL	WNL	Flexible to neutral	0º	WNL	WNL	WNL	-5º	-
4(R)	Calcaneovarus	Severe MTA	Fixed	10°	0°	Yes	Positive	-5°	-
4(L)	Calcaneovarus	Severe MTA	Fixed	0°	5°	WNL	WNL	WNL	0.5cm short
5(L)	Equinus, inversion, hindfoot varus	WNL	Flexible	0°	0°	Yes	WNL	WNL	1cm short
6(R)	WNL	Equinus	Flexible	0°	2°	WNL	mild positive	-5°	1cm short
7(R)	Cavus with forefoot equinus	Hallux valgus; Mild MTA	Flexible	0°	15°	WNL	WNL	WNL	1.5cm short
8(R)	Supination	Severe MTA	Fixed MTA	0°	-5°	WNL	positive	WNL	0.5cm short
9(R)	Cavus	Moderate MTA	Flexible	10°	0°	WNL	WNL	-10°	1cm short
9(L)	Internal	Moderate MTA	Flexible	-5°	0°	Yes	WNL	WNL	-
10(R)	Midfoot break; hindfoot varus	Moderate MTA	Flexible to neutral	0°	5°	WNL	WNL	WNL	-
10(L)	Midfoot break; supination	Moderate MTA	Flexible to neutral	0°	5°	WNL	WNL	-15°	0.5cm short

WNL: Within normal limits; FPA: Foot progression angle; MTA: Metatarsus adductus; LLD: Leg length discrepancy; PROM: passive range of motion (measured by goniometer)

*Evaluation measures performed according to Cusick (2006, 2009)& Owen, (2016). WNL on the unaffected side for children with unilateral CP.

[a] Mild= foot axis through 3rd toe; moderate= foot axis between 3rd and 4th toes; severe= foot axis between 4th and 5th toes (Staheli, 2006)

[b] Positive values denote hyperextension and negative values denote contracture; [c] Positive values denote external torsion and negative values denote internal torsion

Table D.2. *Modified Tardieu Scale scores for participants with CP: R1 and R2 angles**

Child (Limb)	Hip Extension		Hip Abduction		Hip External Rotation		Hip Internal Rotation		Knee Extension		Knee Flexion		Ankle PF at 90°		Ankle PF at 0°	
	R1	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
1 (R)	WNL	45°	30°	30°	WNL	45°	0°	45°	WNL	WNL	-90°	-50°	0°	0°	-30°	-20°
1 (L)	WNL	45°	30°	30°	WNL	35°	0°	50°	WNL	WNL	-85°	-50°	-5°	0°	-30°	-15°
2 (R)	50°	WNL	25°	65°	WNL	65°	WNL	55°	WNL	WNL	-90°	-45°	0°	0°	-16°	-10°
2(L)	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\
3 (R)	WNL	WNL	WNL	WNL	WNL	35°	WNL	WNL	WNL	WNL	-50°	-26°	-10°	5°	-25°	0°
3 (L)	WNL	WNL	WNL	WNL	WNL	45°	WNL	WNL	WNL	WNL	WNL	-32°	5°	10°	-10°	0°
4 (R)	WNL	WNL	WNL	30°	WNL	55°	WNL	70°	WNL	WNL	-80°	-40°	WNL	5°	-20°	-4°
4 (L)	WNL	WNL	WNL	30°	10°	40°	WNL	70°	WNL	WNL	-60°	-35°	WNL	5°	-20°	-7°
5(R)	\	\	\	\	\	70°	\	70°	\	\	\	\	\	\	\	\
5(L)	WNL	WNL	WNL	WNL	WNL	75°	WNL	60°	WNL	WNL	-50°	-35°	WNL	WNL	-40°	5°
6(R)	WNL	WNL	WNL	WNL	WNL	60°	WNL	40°	WNL	WNL	-60°	-45°	WNL	7°	-15°	-4°
6(L)	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\
7(R)	WNL	WNL	WNL	WNL	WNL	70°	WNL	70°	WNL	WNL	-55°	-45°	WNL	6°	-18°	0°
7(L)	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\
8(R)	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	-80°	-40°	15°	25°	-15°	2°
8(L)	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\	\
9(R)	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	-50°	0°	0°	15°	-15°	8°
9(L)	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	WNL	-40°	0°	0°	18°	0°	10°
10(R)	WNL	WNL	WNL	WNL	WNL	60°	WNL	45°	WNL	WNL	-50°	-30°	WNL	10°	-15°	3°
10(L)	WNL	WNL	WNL	WNL	WNL	50°	WNL	50°	WNL	WNL	-60°	-40°	WNL	10°	-30°	0°

WNL: Within normal limits; R: Right; L: Left
*Measured in degrees using a universal goniometer according to Boyd & Graham (1999)

Table D.3. *Subjective comments about the iAA-AFOs, gait observations, and response to iAA-AFOs based on visual analysis of data*

Child	Subjective comments about the iAA-AFOs	Gait observations	Change with iAA-AFO based on visual analysis	Net Response
1	Felt more comfortable walking in Usual AFOs but after some practice, she said she felt like she stood taller in the iAA-AFOs. Would like to wear iAA-AFOs for graduation photos or basketball but Usual AFOs for other activities.	- IC with forefoot on L - pronates R>L - intoes R (~30º FPA) - R: crouch with ankle dorsiflexion - L: excess KF at IC - Bilateral KHE in stance phase - Weightbears more on L than R - Short step length	R: More peak KE (better)	Positive
			L: Less KF in IC/LR (Better), followed by more KHE (Worse)	Negative
2	Skin tolerance was best with iAA-AFO: reduced pressure and friction over the navicular.	- IC with flatfoot - mild equinus - Pronation - Neutral FPA	Better knee pattern (KF in LR and TSt KE)	Positive
3	Experienced pain in Usual AFOs; chose the iAA-AFOs to wear afterward because they felt more comfortable.	- IC with flatfoot on R and bilateral KF - pronates bilaterally - foot drop and foot slap on R - Minimal impairment on L - neutral FPA	R: Increase in KHE (Worse)	Negative
			L: Minimal difference (GVS_FFA worse)	Negative
4	No preference.	- IC with forefoot or flatfoot - internal FPA on R - early stance KF on R - bilateral KHE	R: Less KF at IC/LR (Better); more KHE in stance (Worse); IC with heel and better FFA & SVA	Positive
			L: increase KF in LR (Worse); slightly less KHE in stance (Better)	Negative
5	Chose to wear iAA-AFO after testing	- Winter-Gage-Hicks type IV gait - IC with forefoot - Rarely achieves heel contact in stance on L - KE thrust in late stance - FPA: ~45º internal	~10º less KHE, but difference was not significant; consistent gains in KE moment and SVA, but not significant; better FFA at IC	Negative

6	Chose to wear iAA-AFO after testing	- IC with flatfoot - Decreased stance time on R	Knee moment looks better but not significant	Equivocal
7	Did not like the iAA-AFO; prefers the carbon fiber AFO as it is easier to put on	- IC with flatfoot - Pronates - excess KF - FPA: ~25º external	More KE (Better)	Positive
8	Got a new AFO with AA-AFO in PF and tolerates it well.	- IC with forefoot, with knee and hip flexed, then KE - FPA: ~40º internal; internally rotates at hip	A bit less KHE but not significant	Equivocal
9	Participant's mother thought the shoe raise improved her gait pattern during testing, so she got one afterward; participant was nervous about walking in the iAA-AFO and would only walk with her hand held during the test	- IC with forefoot - IC with KHE on R - Excess KF on L - Runs with marked equinus and hindfoot varus and KHE - FPA: bilateral intoing (mild)	R: More KHE (Worse)	Equivocal
			L: Decreased KF (Better)	Positive
10	Chose to wear iAA-AFO after testing; feels her gait pattern and balance are much better in iAA-AFO (reports that falls have decreased 75%)	Weightbears on R>L; IC with forefoot contact and KF Sometimes supinates, sometimes pronates KHE in stance FPA ~40º internal on R and 20º internal on L	R: Less KHE (Better)	Positive
			L: Less KHE (Better)	Positive

R: Right; L: Left; IC: initial contact; LR: loading response; FPA: Foot progression angle; KE: knee extension; KF: knee flexion; KHE: knee hyperextension

Table D.4. *Responses to the iAA-AFO by limb and child for variables included in responder analysis: A. Knee variables; B. Hip variables; C. Segment, ground reaction force, and spatio-temporal variables***.**

A.

Child	Limb	KneeIC	KneeFlex	KneeExt	KneeMom_ LR	KneeMom_ TMSt	KneeMom_ TS	GVS_ Knee	GVS_ KneeMom
1	**R**	0	0	1	WNL	0	0	0	0
	L	1	1	2	2	0	0	2	2
2	**R**	0	0	WNL	0	0	0	1	1
3	**R**	0	2	0	2	1	0	0	0
	L	WNL	WNL	WNL	WNL	0	0	WNL	WNL
4	**R**	1	1	0	WNL	0	0	0	WNL
	L	0	2	1	0	0	0	2	2
5	**L**	0	0	0	0	0	0	0	WNL
6	**R**	0	WNL	WNL	1	1	0	WNL	0
7	**R**	1	0	1	1	2	0	1	0
8	**R**	0	0	0	0	0	0	0	0
9	**R**	0	0	2	NT	NT	NT	0	NT
	L	0	1	1	NT	NT	NT	1	NT
10	**R**	0	0	1	0	1	1	1	1
	L	WNL	1	1	1	1	0	1	1
Positive Response		20%	27%	40%	23%	31%	8%	33%	23%
Negative Response		0%	13%	13%	15%	8%	0%	13%	15%
No Change/ WNL		80%	60%	47%	62%	62%	92%	53%	62%

B.

Child	Limb	HipFlex	HipExt	HipExtMom	HipFlexMom	GVS_Hip	GVS_HipMom
1	**R**	0	0	0	0	0	0
	L	0	0	0	2	WNL	0
2	**R**	WNL	0	0	0	0	0
3	**R**	WNL	WNL	WNL	0	WNL	0
	L	0	WNL	0	0	WNL	0
4	**R**	1	WNL	0	WNL	0	0
	L	0	0	WNL	0	0	0
5	**L**	0	0	2	0	0	WNL
6	**R**	WNL	1	WNL	0	WNL	2
7	**R**	1	2	1	0	0	0
8	**R**	WNL	1	WNL	0	0	0
9	**R**	WNL	0	NT	NT	0	NT
	L	1	0	NT	NT	0	NT
10	**R**	0	2	1	WNL	2	1
	L	WNL	2	0	0	2	0
Positive Response		20%	13%	15%	0%	0%	8%
Negative Response		0%	20%	8%	8%	13%	8%
No Change/WNL		80%	67%	77%	92%	87%	85%

C.

Child	Limb	SVA_ IC	SVA_ TMSt	GVS_ SVA	FFA_ IC	FFA_ TMSt	GVS_ FFA	GVS_ VF	Stride Velocity	Stride Length	Stride Time	Stance Percent
1	**R**	0	0	0	0	0	0	0	0	0	0	0
	L	0	WNL	0	0	0	2	2	2	2	0	0
2	**R**	0	0	0	WNL	WNL	1	0	0	0	0	0
3	**R**	0	2	2	2	2	2	0	WNL	0	0	0
	L	0	WNL	0	0	0	2	WNL	WNL	0	0	WNL
4	**R**	1	1	0	0	WNL	0	2	0	0	0	0
	L	0	0	0	1	1	2	2	0	0	0	WNL
5	**L**	0	0	0	WNL	WNL	WNL	0	0	WNL	0	WNL
6	**R**	0	0	0	0	0	0	0	WNL	0	0	0
7	**R**	1	1	1	1	1	0	0	0	1	0	0
8	**R**	0	0	0	WNL	WNL	0	0	0	WNL	0	0
9	**R**	0	0	0	0	0	0	X	0	0	WNL	0
	L	0	0	0	0	0	0	X	0	0	WNL	0
10	**R**	0	0	0	0	0	0	1	0	0	0	0
	L	0	0	2	1	2	2	0	0	0	0	0
Positive Response		13%	13%	7%	20%	13%	7%	8%	0%	7%	0%	0%
Negative Response		0%	7%	13%	7%	13%	33%	23%	7%	7%	0%	0%
No Change/ WNL		87%	80%	80%	73%	73%	60%	69%	93%	87%	100%	100%

Response types:
0 = No difference between conditions (i.e. CI overlap)
1 = iAA-AFO closer to the TD value than Usual (i.e. positive response)
2 = iAA-AFO farther from the TD value than Usual (i.e. -negative response)
WNL= Within normal limits (Both conditions within 1 SD of TD value)
NT= Not tested
R: Right; L: Left