The effects of biomechanically optimised ankle-foot orthoses-footwear combinations on the gait of children with cerebral palsy

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Abstract

The purpose of this study was to investigate the effects of the biomechanical optimisation of ankle-foot orthoses and footwear combinations (AFO-FCs) on the gait and energy expenditure of children with cerebral palsy (CP). The child's perception and compliance of wearing AFO-FCs were also investigated. Additional aims were to examine common clinical practice regarding AFO-FC tuning in the UK and to study the validity of using the static shank to vertical angle (SVA) to measure the dynamic SVA during gait.

The study included five children with CP. Outcome measurements included sagittal plane kinematics and kinetics derived using 3D motion analysis, physical examination, heart rate (HR), energy expenditure, speed, distance, energy expenditure index (EEI), static SVA and dynamic SVA and an after study questionnaire.

When studying children with CP, beneficial effects of biomechanically optimised AFO-FCs on gait parameters were evident; the results identified improvements to knee, hip and pelvic kinematics, particularly in cases where the principal gait deviation was hyperextension of the knee in stance.

There were also beneficial effects on energy expenditure with the study highlighting a reduction in energy expenditure, and an increase in self-selected speed and distance covered, when walking in a biomechanically optimised AFO-FC compared to a non-tuned AFO-FC.

The study demonstrated validity in using the static measurement of the SVA to estimate the dynamic SVA during temporal mid-stance (TMST).

The importance of cosmesis and social inclusion was also highlighted as being important for disabled children who are asked to wear adapted footwear and AFOs. However, the results of this study indicated that when there is an improvement in physical function and activities of daily living, children will choose to comply with what they perceive to be uncosmetic orthoses.

It was concluded that biomechanically optimised AFO-FCs have the potential to improve the kinematics and kinetics of gait, energy expenditure, speed and distance covered for children with CP, and that tuning the AFO-FC should be mandatory.

Publications arising from this thesis

Eddison N and Chockalingam N. The effect of tuning ankle foot orthoses-footwear combination on the gait parameters of children with cerebral palsy Prosthet Orthot Int published online 24 July 2012. DOI: 10.1177/0309364612450706.

Eddison N, Chockalingam N and Osborne S. Ankle foot orthosis-footwear combination tuning: An investigation into common clinical practice in the United Kingdom. Prosthet Orthot Int published online 24 February 2014. DOI: 10.1177/0309364613516486.

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Eddison N, Healy A, Needham R, Chockalingam, N and Unnithan V. Exploratory investigation into energy expenditure using tuned versus non-tuned ankle foot orthoses-footwear combinations in children with cerebral palsy. (Under review).

List of abbreviations

AAAFO	Angle of the ankle in the ankle-foot orthosis
A-AFO	Articulated ankle-foot orthosis
AFO	Ankle-foot orthosis
AFO-FC	Ankle-foot orthosis – footwear combination
COM	Centre of mass
CP	Cerebral palsy
COP	Centre of pressure
DAFO	Dynamic ankle-foot orthosis
EEI	Energy expenditure index
EVA	Ethyl Vinyl Acetate
FAFO	Fixed ankle-foot orthosis
FPI	Foot posture index
FRAFO	Floor reaction ankle-foot orthosis
G.C	Gait cycle
GCSH	Gillette Children's Specialty Healthcare
GMFCS	Gross motor function classification system
GRAFO	Ground reaction ankle-foot orthosis
GRF	Ground reaction force
HAFO	Hinged Ankle-foot orthosis
HR	Heart rate
HSD	Heel sole differential
I.C	Initial contact
ISO	International organisation for standardisation
kcal	Kilo calorie
L.R	Loading response
MAS	Modified Ashworth Scale
M-L	Medio-lateral
MSt	Mid stance
MSw	Mid swing
MTPJ	Metatarsal phalangeal joints
PCI	Physiological cost index
PLS	Posterior leaf spring ankle-foot orthosis
SACH	Solid Ankle Cushion Heel
SAFO	Solid ankle-foot orthosis
SAV	Shank and vertical angle
SMO	Supramallear ankle-foot orthosis
SVA	Shank to vertical angle
TMST	Temporal mid-stance
TSt	Terminal stance
TSw	Terminal swing
P.I.G	Plug-in-gait
PLR	Point loading rocker
PROM	Passive range of motion
ROM	Range of motion

RQ	Respiratory quotient
SAB	Shank angle to bench
SD	Standard deviation
TSA	Toe spring angle
PSw	Pre swing
VO_2	Volume of oxygen

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Chapter 1: Introduction

1. Introduction

This introductory chapter provides the background to the thesis and explores the aims and of objectives of the research.

Cerebral palsy (CP) has often been considered the prototype childhood ‘neurodisability’(1) and has been identified as the most common physically disabling condition(2). Overall global rates of CP are between 2 and 3 per 1000 live births(3) and longitudinal epidemiological studies from several countries have reported increased prevalence over time(4–7).

The definition of CP has changed considerably over time due to the complexity of the term. A historical perspective of CP is provided elsewhere(8), the most recent definition of CP was suggested by Rosenbaum(1), which reads:

“Cerebral palsy describes a group of permanent disorders of the development of movement and posture, causing activity limitation that is attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication, and behaviour, by epilepsy, and by secondary musculoskeletal problems”.

CP is a heterogeneous population with no two people being affected in the same way. Thus, it is, in reality, a group of disorders with widely varying type, timing, location and extent of brain injuries(1). Hence, the term CP can be used to describe a range of motor problems from the child who has a mild impairment to the motor difficulties of a child in a wheelchair who has no voluntary movement including speech(9).

Classification of such a heterogeneous condition is fundamental in research and clinical practice, for communicating the type and severity of the disorder and advancing research and clinical practice(10). The first known classification of CP was by Little(11) since then various classifications, and approaches to classifications have been used(12–18). Three standard methods to classification address the nature of the motor problem, topography, and aetiology. Descriptions of the predominant motor disorder refer to spastic, dystonic, athetotic, and ataxic features(12,19). Functional status can be categorised (concerning gross motor activity) by using the five levels of the gross motor function classification system for CP(20).

50% -80% of individuals with CP will achieve the ability to walk in some manner(21,22) and as such gait in CP has been classified and documented(23–32). Typical kinematic and kinetic features present during normal gait are also well documented(28,33–35). Patients with pathological gait have abnormal lower limb kinematics, particularly at the shank segment. Attempting to normalise the shank kinematics offers a higher chance of optimum thigh and trunk kinematics and knee and hip kinetics(36–38).

The ground reaction force (GRF) has been identified as contributing to a more energy efficient gait when it is directed through or as close to the joints as possible, requiring minimum turning effect resulting in minimum muscular activity, producing a very efficient gait(36). In pathological gait the GRF does not pass through the centre of the joints, resulting in an increased turning effect which requires increased energy expenditure and thus a less efficient gait. Therefore, it is widely accepted that pathological gait requires more energy expenditure than normal gait(39–46). Researchers found changes in walking kinematics and kinetics could be caused by alterations of the origin(47) and orientation(48) of the GRF which was supported in studies measuring healthy adults walking in high heeled shoes(49–52).

Ankle-foot orthoses (AFOs) are commonly prescribed in an attempt to manipulate the GRF and normalise kinetics and kinematics. An orthosis is defined by the International Standards Organisation (ISO) as '*an externally applied device used to modify the structural and functional characteristics of the neuromuscular and skeletal system*'(53). AFOs are commonly prescribed to children with CP in an attempt to improve their gait; they are defined as "*orthoses that encompass the ankle joint and the whole or part of the foot*"(54). AFOs are intended to control motion, correct deformity and compensate for weakness(55).

There are a wide variety of AFOs used in clinical practice, which are characterised by their design, the material used and the stiffness of that material. Changing any of these three components will alter the control the AFO has on the patient's gait(56).

Previous research has demonstrated the effect AFOs have on the GRF during the stance phase of gait(48,57–67), with Butler et al(62) emphasising the importance of monitoring the moment arm during gait. Further studies have demonstrated a positive effect on the following gait parameters when using AFOs; cadence, stride length, single side support time, decrease in double support and velocity(66–73). Whilst these studies indicate improvements in specific gait parameters they are not all in agreement as to which gait parameters are improved with the use of an AFO.

Furthermore, current literature is equivocal on whether the intervention of an AFO can reduce the metabolic cost of walking(47,73–82). Children with CP commonly expend two to three times as much energy to walk as typically developing children(74). There is a debate as to how pathological changes in gait effect energy expenditure, Saunders, Inman and Eberhart(35) propose that a set of kinematic features help to reduce the displacement of the body's centre of mass (COM). This theory assumes that the vertical and horizontal displacements of the COM require increased energy. However, recent studies indicate that three of the determinants listed by Saunders, Inman and Eberhart(35) may contribute very little to reducing the vertical displacement of the COM(83–85)Thus the "six determinants" are perhaps better described as "six kinematic features of gait". Conversely, the inverted pendulum theory(86,87) proposes that it requires less energy for the stance limb to act like a pendulum with the COM following an arc profile. The pendulum theory also presents a dilemma in that if pendulums can swing freely, why is there an energy cost to walking? (88) the mechanical explanation of these features remains unresolved(88).

Biomechanical optimisation

Ankle-foot orthosis footwear combination (AFO-FC) tuning can be defined as the process whereby fine adjustments are made to the design of the AFO-FC to optimise its performance during a particular activity. It involves the manipulation of the shank to vertical angle (SVA) by the addition of wedges to the footwear and in some cases the addition of other modifications including rockers, flares and SACH (solid ankle cushioned heel) heels to optimise the entry and exit from mid-stance and influence the GRF in the sagittal plane(48). The measurement of the SVA is taken statically and assumed that this closely correlates with the SVA at temporal mid-stance (TMST) during gait; however, there is no evidence to support this assumption.

The term biomechanical optimisation is used to encompass the whole process of designing, aligning and tuning the AFO-FC(89).

Tuning the AFO-FC has been demonstrated to optimise the GRF during gait(36,38,48,90–94) and is recognised as an essential aspect of clinical practice(95). However, there is still a lack of evidence regarding the effects of tuned AFO-FCs on the gait of children with CP. The limited research which is available has all reported positive results(37,48,62,90,96–99). There is currently no research reporting the effects of biomechanically optimised AFO-FCs on the energy expenditure of children with CP.

To summarise there are confounding results regarding the efficacy of AFO interventions on a variety of outcome measures on children with CP. There is very little research available on the effect of tuning AFO-FCs on the gait of children with CP, and no research on the impact on energy expenditure. Furthermore, some aspects of the tuning process have not yet been validated.

1.1 Rationale for the study

AFOs are a commonly prescribed medical device given to children with CP in an attempt to improve their gait. The current literature is equivocal on the effects AFOs have on the gait of children with CP. The vast majority of AFOs issued are not subject to AFO-FC tuning. There are emerging studies investigating the effects biomechanically optimising the AFO-FC has on the gait of children with CP, however, the research is limited, and there is a lack of quantitative data and validation of the tuning process.

This thesis will explore the current literature on AFO interventions in children with CP, to determine where and how the contradictions in efficacy arise, challenging the approach to AFO intervention studies on children with CP. The thesis will also review the current literature on AFO-FC tuning and the final results of the thesis will demonstrate the effects biomechanically optimised AFO-FCs have on the kinetics and kinematics of gait and energy expenditure of children with CP, to better inform clinical practice.

1.2 The need for the study

Ensuring clinicians provide the most optimal AFO prescription is imperative to meet treatment goals. The validation of aspects the tuning process and quantitative data demonstrating the kinetic and kinematic effects and energy expenditure utilised, when wearing a tuned AFO-FC, will enable clinicians to re-evaluate their current practice of AFO prescription.

1.3 Scope and boundaries of the investigation:

The overall aim of this work is to establish the effects of biomechanically optimised AFO-FCs on the gait of children with CP. The scope of the investigation is to look at current concepts behind AFO-FC tuning and the current practice of UK clinicians. However, the research is not intended to clarify or propose prescription criteria for AFOs or produce algorithms for AFO-FC tuning.

In order to meet the aim of this investigation the following objectives were devised:

1. To analyse the quality of reporting in current literature regarding the details of the material and design of AFOs used as a primary intervention.
2. To explore current research on AFO-FC tuning in children with CP.
3. To determine the prevalence of AFO-FC tuning in clinical practice and to identify issues which are preventing the use of AFO-FC tuning.
4. To compare the SVA statically and at TMST during gait, to determine whether the static measurement correlates to the dynamic measurement as claimed by Owen(48).
5. To compare the energy expenditure during gait in non-tuned AFO-FCs and tuned AFO-FCs.
6. To analyse and compare the kinetics and kinematics during gait in children with CP, using non-tuned AFO-FCs and tuned AFO-FCs via 3D gait analysis.
7. To determine the acceptance of tuned AFO-FCs from the view point of the patient to determine compliance.

To address these objectives, a literature review(100) was conducted, and several studies were designed.

1.4 Structure of the Thesis

This Thesis is set out in 10 chapters

Chapter 1 introduces the subject matter, providing the background to the study, including an introduction to CP, AFOs and AFO-FC tuning. The rationale and need for the research to be carried out and the aims and objectives of the investigation.

Chapter two describes the principles of AFOs and reviews their efficacy concerning the gait of children with CP. This section also explores the biomechanical optimisation of AFO-FCs and describes the tuning process. These topics introduce essential background information on which the thesis will be based. The chapter is completed with a systematic review of the design of studies on AFO interventions in CP children; to determine how many of the current peer-reviewed studies of AFOs on children with CP, have included sufficient details of the design and material of the AFO, to enable the research to be reproduced and outcomes understood. This review allowed the investigator to identify potential design flaws in AFO intervention studies, which may act as a confounding factor in the varied results and conclusions offered by AFO studies. Thus, objective one was met.

To meet objective two, a systematic review of the effects of AFO-FC tuning on the gait parameters of children with CP is provided in Chapter three. The systematic review enabled the investigator to determine the level of available evidence supporting AFO-FC tuning and to identify aspects of the tuning process which lack validation and hence determine the need for further studies on AFO-FC tuning in children with CP. Consequently leading to a series of scientific studies to arrive at essential conclusions on the effects of AFO-FC tuning on the gait and energy expenditure of children with CP. Along with validation of the static measurement of the SVA to estimate the dynamic SVA during temporal mid-stance (TMST). Chapter four followed, which investigates the current clinical practice of AFO-FC tuning in the United Kingdom (UK), exploring the prevalence of AFO-FC tuning amongst UK orthotists and exploring their current level of knowledge of tuning and identifying factors which prevent clinicians from using AFO-FC tuning as routine clinical practice. This study fulfilled objective three and justified the need to inform clinicians of the more effective use of biomechanically optimised AFO-FCs. Following, Chapter five provides background technical information, instrumentation, materials, methodology and study protocol.

Chapter six describes the investigation of the static SVA as a reliable method for determining the dynamic SVA, which is a crucial aspect of AFO-FC tuning, and fulfilled objective four. The second investigation, presented in Chapter seven, looked at the effects AFO-FC tuning has on the energy expenditure of CP children during gait. This study met objective five and was the first to investigate energy expenditure in a tuned AFO-FC. It was deemed important to understand the effects the intervention was having on the child's fatigue as well as the kinetics and kinematics.

Chapter eight investigates the effect tuned AFO-FCs have on the kinetics and kinematics of gait and fulfils the main aim (objective six) of the investigation. Comparing the impact of tuned AFO-FC with non-tuned AFO-FC and barefoot, on the kinetics and kinematic of gait. The current literature showed a dearth of quantitative data on AFO-FC tuning with many of the studies being mostly empirical. Thus, it was deemed important to provide such data, from which conclusions can be drawn and recommendations based.

Although the studies outlined in chapters seven and eight provide us with the quantitative data from which we can deduce the effects of the intervention, the child's willingness to wear the device is of paramount importance. Patient perception and compliance is a crucial aspect in the success of any treatment intervention. In order to meet objective seven, Chapter nine investigates the child's thoughts on wearing the modified footwear and whether the cosmesis of the device might affect compliance and explore the participants' perception on the functional effect of the AFO-FC.

Chapter ten provides a summative discussion, conclusions and recommendations. Each study will have a discussion, where the various issues of each investigation will be critiqued and summarised tying together the findings of the whole research. This will result in a summary of evidence regarding the effects of AFO-FC tuning on the gait of children with CP.

1.5 Ethical approval

Appropriate ethical approval was sought, and granted by Staffordshire University Ethics Committee, The Royal Wolverhampton NHS Trust Research and Development Directorate (Ref: 12PAE06) and the National Research Ethics Service (NRES), Ethics Committee West Midlands South Birmingham (Ref: 12/WM/0378). Parents/guardian provided written informed consent and the child's verbal assent prior to inclusion in the study

Information regarding ethics concerning each trial will be outlined in the method section (chapter five) participant information sheets, and consent forms can be found in Appendix 12.3 – 12.6.

Chapter 2: Ankle-foot orthoses for children with CP

2.1 Introduction

Although the definition of CP by Rosenbaum(1) states that the disorder is non-progressive, the effects of growth predispose children with CP to the secondary problems of muscle contractures, bony deformities, and pathological gait(101), such pathologies requiring an AFO intervention have been identified(63). The prevalence of AFO prescription in the UK has also been investigated and indicates that the National Health Service (NHS) prescribes approximately 78,000 bespoke AFOs per year(102). However, AFOs are not commonly prescribed in isolation for children with CP, as they often require a multitude of medical and therapeutic interventions, including physiotherapy, occupational therapy, orthopaedic surgical procedures, botulinum A toxin and baclofen.

The efficacy of many of these interventions have been assessed in Cochrane reviews(103). Conversely, although the provision of an AFO is a commonly prescribed intervention for this patient group(104–106) reviews of their efficacy are limited(92,103,105,107). This is despite the ISO emphasising that an orthosis has the potential to change the musculoskeletal and neuromuscular system(53).

2.2 Principles and characteristics of AFOs

There are a wide variety of AFOs used in clinical practice, which are characterised by their design, the material used and the stiffness of that material. The inherent rigidity of an AFO has been demonstrated to play an essential role in determining its biomechanical function and needs to be optimal to positively influence pathological gait(63,108,109). The rigidity of an AFO may be determined by a number of factors, such as the mechanical properties of the material, the trim-lines, the material thickness and the shape of the superstructure(109–112).

Lunsford(113) reported that the variation in the material properties used in the manufacturer of an AFO may influence the flexibility at the ankle and metatarsophalangeal joints (MTPJs) of these “rigid” devices. The current literature also indicates that differences in mechanical properties of the AFO occur as a consequence of relatively minor variations in AFO design(114–117). There are numerous types of AFOs which due to their design differ in how they aim to control the lower limb and thus their potential effects on gait. Whilst relatively small adjustments of only a few millimetres can alter the performance of the AFO(37,38,48,91–93,96,100,118). Although there is an agreed definition of what an AFO is(54) there is currently no standardised accepted terminology for the description of different types of AFOs(119). Therefore, descriptions and acronyms differ between researchers.

An AFO which blocks movement in all three planes is often termed a solid AFO (SAFO) or a rigid AFO. However, the term solid AFO can be used to describe an AFO which has trim-lines anterior to the malleoli but allows deformation of the material during stance phase; others will use the term to describe an AFO which has no deformation during stance phase. To confuse matters further, the acronym SAFO is also used to describe a very soft silicone ankle-foot orthosis.

AFOs can also have hinges (HAFO), also called articulated AFOs (A-AFO) which permit dorsi-flexion, others terminate just above the malleoli and are commonly termed supra-malleolar orthoses (SMO) and offer control in the coronal and transverse planes only. AFOs can be designed to incorporate the knee joint thus applying an extension moment about the knee; these are often termed ground reaction force AFOs (GRAFOS) but could also be called floor reaction AFOs (FRAFO). AFOs which incorporate a neurological footplate and terminate above the malleolar aim to reduce tone and are commonly termed dynamic AFOs (DAFO). Similarly, AFOs with trim-lines posterior to the malleolar and are said to offer some energy return can also be termed DAFOs, more commonly they are termed posterior leaf spring AFOs (PLS).

It is clear to see from the number of available designs of AFOs, that research in to how AFOs can affect gait, can be hazardous. Researchers must be clear on the exact design of the AFO being studied and that the design is appropriate for the presenting gait pathology.

2.3 The efficacy of AFOs on the gait parameters of children with CP

Previous research has demonstrated the effect AFOs have on the GRF during the stance phase of gait(38,48,57,58,60–67,120), these studies identify three stance phase gait abnormalities associated with CP, which are effectively treated with AFOs; hyperextension of the knee joint, excessive knee flexion and a lack of hip extension.

Velocity

The majority of research measuring velocity, using a variety of AFOs, reported an increase(66,68,76,121–127), with the majority of research into the effect of AFOs on velocity in hemiplegic gait reporting significant increases(76,121,123,124,126,128). In contrast other studies reported no significant difference in velocity(47,73,79,82,129–133). The evidence for AFOs increasing velocity in mixed and diplegic subjects is contrasting, with some studies showing little or no effect on velocity.

Cadence

Several studies have reported a decrease in cadence when using a variety of AFOs(47,68,79,120,121,123–127), whilst others have shown no significant effect on cadence(66,76,132–134). The majority which studied hemiplegic subjects indicated a decrease in cadence(79,121,124,126), whilst studies involving mixed groups and diplegic patients had differing results.

Stride length

Current literature indicates that stride length often increased when walking with AFOs in CP gait(47,66–68,76,79,82,120,123,126–128,132–136)

Step Length

Step length was reported to increase in the following studies, involving several designs of AFOs, used by children with CP(47,68,79,121,123–128).

Single Support

Research has demonstrated an increase in single support when children with CP use AFOs(66,68,76). In contrast, Romkes(126) reported no significant change in single support time.

Double Support

A contrast in findings is also reported when studying the effect of AFOs on double support. Research by Hayek(127) and Abel(66) described a decrease in double support time; Brunner(123) noted an increase in double support time whilst Romkes(126) found no significant difference.

Hip kinetics and kinematics

The effect AFOs have on the hip joint has been investigated(47,66,121,123,125–128,133,134,137–139). Once again the conclusions are equivocal with researchers reporting significant effects on hip extension(74,121,123,126,139,140) and others reporting minimal or no effect(47,127,137,138). Effects on hip flexion(123,126,133,137) have been reported along with research indicating no effect on hip flexion(47,127). Other effects reported are a reduction in hip adduction, increase in hip abduction(123) and an increase in hip excursion(66).

Van Gestel 2008(121) reported significant improvements in hip moments and power when using an AFO, similarly, Crenshaw(139) reported an increase in hip extension moment and power.

Pelvic kinetics and kinematics

Brunner(123) reported an increase in hip flexion, extension and abduction when using a SAFO and a flexible AFO. Hassani(137) noted significant differences in peak hip flexion in stance but reported no significant difference in peak hip extension in HAFOs and DAFOs compared to barefoot gait. Lam(133) and Romkes (126) noted an increase in hip flexion at initial contact. However, Lucareli(138) and Buckon(47) reported no significant changes to maximum hip extension and no changes at the hip respectively. Similarly, Hayek(127) found that SAFOs and HAFOs had minimal effect on hip kinematics when compared to barefoot gait, whilst Van Gestel(121) reported significant improvements in hip moments and power.

Knee kinetics and kinematics

Buckon et al.(47) Desloovere et al.(140) (using HAFOs) and Van Gestal et al.(121) (using a dual carbon fibre AFO) all reported an increase in knee extension during stance, with the use of an AFO. Contrastingly, other studies have reported a decrease in knee extension in CP gait when studying a variety of AFOs(37,79,121,123,141,142). Whilst several studies have reported no improvement in knee extension during stance (76,135,137,143).

Lam et al.(133), Balaban et al.(76), Hayek et al.(127) and Lucareli and Lima(138) all report a reduction in knee flexion at initial contact, using a variety of AFOs. Desloovere et al.(140) found that AFOs increased knee flexion during loading response. Lam et al.(133) also reported an increase in knee flexion at initial contact when using DAFOs, whilst Radtka et al.(82) stated that the use of HAFOs and SAFOs had no significant effect on excessive knee flexion during stance phase.

Buckon(47) also reported that the knee extensor moment in early stance, increased with a hinged AFO whilst Radtka(82) reported that knee moments during stance were not affected by the AFO intervention.

Ankle kinetics and kinematics

An improvement in dorsi-flexion during swing and stance phase when using a variety of AFOs has been reported(47,73,79,82,121,123,127,130,133,135,140,144). Similarly, researchers have reported a reduction in plantar flexion with the use of AFOs in CP gait(82,120,126,132,133,139,140).

Several studies have reported a decrease in ankle power generation using a variety of AFOs(47,66,76,79,82,130,139,144), whist other studies reported an increase in ankle power generation(125,128,133), or no significant difference in ankle power generation when using HAFOs, although a decrease in ankle power generation when using SAFOs(82). Similarly, Chambers(142) reported a decrease in power when using “standard” AFOs and no significant difference in power generation when using SAFOs. Carlson(132), Romkes(135) and Hassani(137) all reported no significant difference in ankle power generation when using a variety of AFOs.

Energy efficiency

It is widely accepted that energy expenditure is increased in pathological gait compared to normal gait(39). It has also been indicated that the metabolic cost of walking may be reduced in CP gait when walking speed is controlled and the subject wears an AFO(75,76,78). Other studies have reported no change in oxygen consumption but self-selected walking speed was reportedly increased(47,73,123).

A review of the literature on the effect of AFOs on the gait of children with CP indicates there is a lack of agreement in the potential effect of AFOs. The potential cause of the discrepancies in results from the studies reviewed is summarised below.

2.4 Summary

- There is a lack of standardisation in study design; thus, some studies compare AFOs to shod and un-shod gait, others compare different designs of AFOs against each other. The vast majority of the current literatures on AFO interventions for children with CP don't appear to use biomechanically optimised AFO-FCs.

- Research on CP children is difficult because CP is not a homogenous disorder and therefore comparing the gait of children with differing degrees of disability will inevitably produce variable results. Considering mean group results is insufficient for evaluating whether an individual patient may or may not benefit from a given treatment(10).

- The current evidence for the efficacy of AFO intervention in children with CP is low, the quality of the studies are poor, there is a lack of standardisation and terminology and there is a lack of detail regarding the AFO intervention(92,103,107,145).

- The lack of information may be partially due to differences in the AFO prescription process, which is largely dependent on clinical experience(103,146) due to a lack of prescription guidelines.

2.5 Conclusion

A systematic review of the details of the AFO intervention used in research, on children with CP, is required to further investigate the cause of the equivocal findings in the current literature.

2.6 Biomechanical optimisation of ankle-foot orthoses and footwear combinations.

2.7 Introduction

People with pathological gait have abnormal lower limb kinematics, particularly at the shank segment. Attempting to normalise the shank kinematics offers a greater chance of optimum thigh and trunk kinematics and knee and hip kinetics(36), this is often achieved by the use of a solid AFO. However, the footwear that is worn with an AFO is integral in determining the overall biomechanical control provided, so the AFO and footwear have been termed ankle-foot orthosis footwear combination (AFO-FC)(48).

The effects of footwear on gait when wearing AFOs has been documented. Cook and Cozzens(147) recognised the importance of heel height on footwear in affecting the biomechanics of AFOs in normal subjects. They investigated the effect of different heel heights and AFO configurations on the ground reaction force. They used one healthy adult and compared three different heel heights combined with an AFO in plantar flexion, plantigrade (a neutral position) and dorsi-flexion and without an AFO. The study indicated that the while the ground reaction force was unaffected without an AFO for different heel heights, it was affected when the participant wore AFOs. The researchers concluded that the heel height and AFO configuration should be matched to produce the best results.

Churchill et al.(148) investigated the contribution of footwear to the effectiveness of AFOs. They studied five patients, with hemiplegia and reduced mobility following stroke, in three conditions; walking without footwear, with footwear alone, and with footwear and an AFO. They reported stride length was increased by an average of 5cm when wearing footwear and an additional 5cm increase was also observed when wearing an AFO.

More recently AFO-FC tuning has been recognised as an essential aspect of clinical practice when prescribing AFOs(36,92,95,149). Issuing a sub-optimal AFO-FC may have an immediate detrimental effect on function and in the longer term it may contribute to deterioration(149).

2.8 Definition of AFO-FC tuning

AFO-FC tuning can be defined as the process whereby fine adjustments are made to the design of the AFO-FC to optimise its performance during a particular activity. The term biomechanical optimisation is used to encompass the whole process of designing, aligning and tuning the AFO-FC(89).

2.9 The angle of the ankle in the AFO (AAAFO)

It is imperative to ensure the angle of the ankle in the AFO (AAAFO) is correct and fully accommodates the length of the gastrocnemius. The AAAFO can be described as the angle of the foot relative to the shank in the sagittal plane in the AFO. It is measured as the angle between the line of the lateral border of the foot (base of 5th metatarsal head to the base of the heel) and the line of the shank. It is described in degrees of dorsi-flexion, plantar flexion, with plantigrade describing a neutral position(36).

A non-tuned AFO is commonly set at 90° regardless of the passive length of gastrocnemius, this stems from the fallacious belief that the AAAFO must always be 90° or that dorsi-flexion and plantigrade positions are acceptable, but not plantar flexion. This argument ad populum of the ankle/foot complex having to be in a 90° position may have come from the belief that the shank must be vertical to obtain straight knees during gait(118). However, gastrocnemius is a biarticular muscle and as such, if it does not have the required length to reach 90°, with the knee extended, and is placed in a solid AFO with an AAAFO of 90° the result will be insufficient length at the knee which will prevent knee extension when required at mid-stance (MSt) terminal stance (TSt) and terminal swing (TSw) (27). In addition, the muscles will not be able to produce power when the sarcomeres are stretched to their maximal length(150).

Thus, the AAAFO must be correct to allow the musculotendinous unit to be at the optimum length for force production and prevent the development of bony foot deformities caused by enforced supination or pronation within the AFO(118). Thus, failing to accommodate the length of gastrocnemius in the AFO will prevent successful AFO-FC tuning.

2.10 The shank to vertical angle (SVA)

It is essential to have the most appropriate AFO design and material stiffness to control the foot in all three planes as the gait pathology necessitates(110,116,151,152). Once the design of the AFO and AAAFO has been decided, the heel sole differential (HSD) can be adjusted in an attempt to produce optimum kinematics and kinetics during gait. This is done by manipulating the SVA via the HSD. The SVA can be defined as the angle of the shank relative to the vertical, measured in the sagittal plane. The SVA is described as inclined if the shank is inclined forward from the vertical and reclined if it is reclined backwards from the vertical. It is described in degrees, with vertical being 0°(36). The AAAFO and the pitch of the HSD will determine the SVA. Note other authors have used different terms to describe the angle between the shank of the tibia and the floor, Bowers, Owen and Meadows(149) used shank vertical angle (SVA), Pratt et al.(153) used shank and the vertical angle (SAV) whilst Hullin et al.(57) used the term foot-shank angle. All of which are synonymous with SVA.

Owen(48,118) indicates that anthropometric measures dictate that a SVA of 10-12° inclined from the vertical brings the knee joint centre over the middle of the foot during mid-stance in normal subjects. This inclination allows the forward translation of the vertical head, arms, trunk, and pelvis(154). In contrast, with a vertical SVA this is not possible, unless the knee hyperextends, which is not desirable. The optimum inclination of the SVA also allows the centre of pressure (COP) to remain within the base of support, which allows switching between external flexing moments and extending moments during gait. This creates stability through the positioning of the centre of mass (COM) and the COP, which dictates the position of the GRF(154)

Kerkum et al.'(96) study investigated whether the SVA, during walking, responds to variations in heel height and footplate stiffness and if this reflects changes in joint angles and moments in healthy adults. Ten subjects walked on an instrumented treadmill and performed six trials while walking with bilateral rigid AFOs. The AFO-FC heel height was increased to manipulate the SVA. They reported that the SVA significantly increased with increasing heel height, increasing the knee flexion angle and internal knee extensor moment, concluding that the results support the potential to use the SVA as a parameter to evaluate AFO-FC tuning, as it is responsive to changes in heel height and reflects concomitant changes in the lower limb angles and moments.

Choi et al.(155) reported a single case study of an adult post-stroke where the subject walked with an AFO-FC with two SVA alignments, a posterior leaf spring AFO and shoes alone. They concluded that adjusting the SVA of the AFO-FC has the potential to improve gait kinematics by controlling the length of the pathologic gastrocnemius.

Pratt et al.(153) investigated the shank and vertical angle (SAV) and the moment arm at the knee joint on 11 healthy subjects in attempt to establish a baseline for AFO-FC tuning. The research reported a mean SAV of 11.4°± 3.4 in the barefoot condition and 10.5° ± 3.6 in the shod condition. However, this research was lacking in the fact that the difference between shod and unshod was not investigated for statistical significance, the reason for the difference was not discussed, and the difference between the thickness of the heels and soles on the footwear used was not referenced either. Albeit these shortcomings, the research still provided support for Owen's(48) indication of the position of the SAV during mid-stance.

Further research has also demonstrated that the shank is not vertical at mid-stance and there is no place in the gait cycle when both the shank and thigh are vertical(26,28,34,156–158). An SVA between 10-12° inclined allows the thigh to become inclined and thus the pelvis and the trunk to move forward in a vertical position(118).

Thus, from these studies we can deduce that during mid-stance an element of tibial inclination is required during normal gait. Therefore, having an ankle complex and SVA fixed at 90° (when heel/ground contact is maintained) cannot achieve an optimal gait pattern as it prevents the shank from the necessary inclination at mid-stance.

An SVA of 10°-12° at mid-stance is important for the following reasons(118)

1. It contributes to stability in stance by placing the knee joint centre over the centre of the foot, which creates a stable distal support mechanism in the form of a triangle.
2. It facilitates ballistic movement of the thigh, pelvis and trunk. Soleus is restraining the forward movement of the shank and, momentum carries the thigh, pelvis and trunk forward to extend the knee.
3. It dictates thigh, pelvis, trunk and head kinematics.
4. It facilitates appropriate ground reaction force alignment to the knee and hip and switching of moments, from flexion to extension moments, at the knee and hip.
5. It may contribute to the conservation of energy.

2.11 Adaptations to footwear

Adaptations to the footwear for optimal entry and exit at mid-stance are crucial aspects of AFO-FC tuning. The adaptations required are individual to the presenting patient. Owen's(159) algorithm outlines the footwear adaptations required, these include:

- Flexible sole units to enable MTPJ extension at the third rocker
- Stiffened sole units with modifications to stimulate third rocker but prevent extension of the MTPJs.
- Positive and negative heel flares to manipulate the GRF. (see figure 2.11.1)

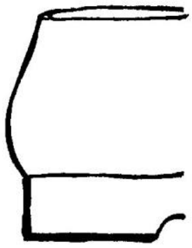
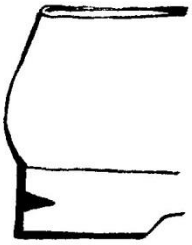
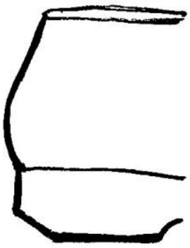
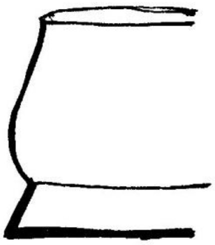
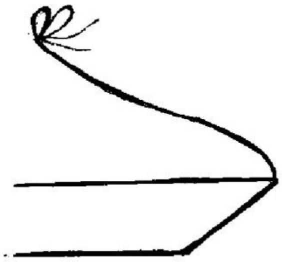
EXAMPLES OF HEELS “ENTRANCES TO MIDSTANCE”		EXAMPLES OF SOLES “EXITS FROM MIDSTANCE”	
	PLAIN HEEL		FLEXIBLE SOLE FLAT PROFILE
	CUSHION HEEL		FLEXIBLE SOLE ROUNDED PROFILE
	NEGATIVE HEEL		STIFF SOLE ROCKER SOLE ROUNDED PROFILE
	POSITIVE HEEL BACK FLOAT		STIFF SOLE ROCKER SOLE POINT-LOADING ROCKER

Figure 2.11.1: Examples of footwear adaptations, reproduced with permission (160)

The footwear is also externally adapted with tuning wedges, during the assessment process these wedges are temporary (see figure 2.11.2). Once the correct SVA has been achieved the footwear is sent for permanent modification (see figures 2.11.3 and 2.11.4).

Figure 2.11.2.: A shoe with temporary tuning adaptations

Figure 2.11.3: Permanently adapted footwear

Figure 2.11.4: Permanently adapted footwear

2.12 AFO-FC tuning is essential

The alignment of AFOs is critical if optimum effect is to be achieved at the knee and hip, with tuning of the AFOs likely to be beneficial(161).The tuning of AFO-FCs post stroke has been recommended as an essential aspect of treatment(95). Tuning AFO-FCs or children with CP is necessary because children with CP have primary and secondary heterogeneity resulting in a wide variability of gait and compensatory mechanisms, thus, their gait pattern is unique requiring a unique AFO-FC and SVA(149). The provision of a non-tuned AFO-FC may result in avoidable deterioration and the potential to miss the opportunity for functional and physiological benefits(149).

2.13 Limiting factors to successful AFO-FC tuning

The literature states that the success of tuning an AFO-FC will be limited if there is:

- Excessively increased musculotendinous stiffness
- An inability to achieve full or nearly full passive extension at the knee and hip during gait, due to insufficient musculotendinous length or joint range.
- A lack of full or almost full extension at fast angular velocity at the knee and hip
- An excessively rotated foot progression angle(149), which although may not be significant in barefoot gait can increase as a compensation mechanism when an AFO is used.

Although Owen et al.(149) still advocate that AFO-FC tuning may still provide small functional benefits in such cases, the physical presentation of the patient will have an impact on the success of AFO-FC tuning.

2.14 Methods for tuning AFO-FC

Although the visual assessment of gait is crucial in clinical decision making, accurate assessment of gait is difficult by eye alone, namely due to the complexity and the speed at which the phases of the gait cycle change, especially when assessing patients with neurological disorders. It has also been suggested that accurate estimation of the kinetics cannot be assumed from observation of the kinematics and thus kinetic information can only be obtained by using instrumented gait analysis systems(36,149). For AFO-FC tuning to be carried out regularly within a clinical setting, the ease of use of these instrumented gait analysis systems is paramount. There are various simple methods of instrumented gait analysis available to the clinician, such as the use of superimposing a force vector on a video sequence, negating the need to use an expensive gait laboratory. However, it is not known whether clinicians are aware of which methods are appropriate for AFO-FC tuning.

2.15 Conclusion

The principles of AFO-FC tuning are:

- Identifying the correct angle of the ankle complex in the AFO (AAAFO).
- Appropriate design and stiffness of the AFO.
- Building the AFO to shank angle to bench (SAB) 90 (when required).
- Controlling the inclination of the shank (SVA).
- Optimising entry and exist to and from mid-stance.

2.16 Do research papers provide enough information on design and material used in Ankle-Foot Orthoses (AFO) for children with cerebral palsy (CP)? A systematic review

2.17 Objectives:

The purpose of this review was to determine how many of the current peer reviewed studies of AFOs, on children with CP, have included adequate details of the design and material of the AFO, to enable the research to be reproduced and outcomes understood.

2.18 Introduction

Limitations relating to AFO design and inappropriate prescription to facilitate for an individual's movement pattern, can hinder the effectiveness of AFOs(144). By the same reasoning, inappropriate design and prescription of AFOs can have substantial influence on research results.

If changing the design, material and stiffness alters the control the AFO has on the subject's gait. Then it stands to reason that a detailed description of the AFO used in research studies is imperative, along with a justification of why the AFO was designed with each characteristic and what the aim of the design is. For example, if one uses a 3mm natural polypropylene AFO, with trim-lines behind the metatarsal phalangeal joints (MTPJs), with an angle of the ankle in the AFO (AAAFO) of 90°, on a subject who weighs 90kg with fixed pronation of the foot and excessive knee flexion during stance phase, and a plantar flexion contracture, one is likely to conclude that the AFO was an unsuccessful intervention in controlling this subject's gait; when the actual conclusion should be, the AFO design was inadequate.

The AFO would be inappropriate on the basis that 3mm natural polypropylene would not be strong enough to control the gait deviations of a subject who weighed 90kg. Similarly, a lack of a lateral flange past the 5th MTPJ would allow the foot to move off the footplate and offer no control to the forefoot abduction caused by pronation. The third rocker would not be blocked, and the actual length of gastrocnemius would not be accommodated in a 90° AFO, resulting in an increase in knee flexion which reduces knee extension at terminal stance.

Previous papers have reported that the design characteristics of AFO interventions are often not reported and when they are the detail is incomplete, inexact or ambiguous(36). There are recommended reporting guidelines for AFO interventions, to enable the quality of the AFO intervention to be more accurately assessed(92,107). Recommendations include; the movements prevented, assisted and permitted by the AFO. Footplate length and flexibility, trim-line position, materials, the method of manufacture and testing of mechanical stiffness of the AFO; concluding that transparent reporting permits replication of the study, and makes it possible to understand the variables that may affect intervention outcomes(107).

2.19 Aim of the research

The aim of this research is to perform a systematic review on the current literature pertaining to studies on AFOs in children with CP, with emphasis on the detail of the design and material of the AFO offered in each paper. A secondary aim is to analyse the outcome measures used in each study. It is recognised that there are numerous other essential aspects of reporting regarding AFO research, e.g. the shank vertical angle, the footwear combination, the tuning process and the physical presentation of the subject, all of which will be analysed in the following chapters.

2.20 Methods

Data sources:

This systematic review of databases was performed in March 2015. The following 14 databases were searched: Web of Science, Medline, PubMed, CINAHL Plus, EMBASE, SCOPUS, Rehabdata, PsycInfo, ERIC, Education Research Complete, Business Source Complete, IEEE, NIHR and CEA Registry The search used the following key words; “AFO”, “ankle-foot orthoses”, “cerebral palsy”, “CP”. No language restriction was applied to the search. Searches were adapted for each database and were completed between 10th and 20th March 2015.

Study selection:

Inclusion/exclusion criteria

Two reviewers independently screened the search results.

Inclusion criteria:

•Papers which studied AFO/s on children (18 years and under) with a primary diagnosis of cerebral palsy.

•Studies which measured an outcome, excluding patient perception studies.

•Studies which were in English.

•Full studies which were located in a peer-reviewed journal.

Exclusion criteria:

•Expert opinion articles; letters to the editor; commentaries, abstracts and systematic reviews.

•Studies involving participants over 18 years old.

•Studies which involved participants who did not have a diagnosis of cerebral palsy.

Data extraction and methodological quality appraisal

One reviewer extracted data regarding the characteristics of the included studies, with the extracted data checked for accuracy and completeness by a second reviewer. For extracted data checklist see table 2.1

Table 2.1: Extracted data checklist	
AFO design:	Choose response
Is the type of AFO described?	Type of AFO/Incomplete/-
Is the AFO bespoke or stock?	Bespoke/Stock/-
Is the AAAFO described?	Yes/-
Is the manufacturer of the AFO identified?	Complete/-
Are the trim-lines of the ankle described?	Complete/Incomplete/-
Are the trim-lines of the footplate described?	Complete/Incomplete/-
Is the height of the AFO described?	Complete/Incomplete/-
Is the strapping system described?	Complete/Incomplete/-
Is there detail of the stiffness of the AFO in stance phase?	Complete/Incomplete/-
If hinges are stipulated are these described?	Complete/Incomplete/-
Is there a justification for choosing the AFO design?	Complete/Incomplete/-
AFO Material	

Is the material described?	Material/-
Is the thickness of the material described?	Thickness/-
Is there a justification for choosing the material and thickness?	Complete/incomplete/-
Has stiffness testing been carried out?	Yes/-

KEY: Complete = all information present, Incomplete = some information missing, N/A = not applicable to this paper, - = all information missing

2.21 Results

The electronic database search identified 947 articles pertaining to the study of AFOs. Following the application of the inclusion criteria, 55 papers met the criteria imposed by this review. Table 2.2 outlines the extracted data from various included studies. See table 2.3 for detailed information from each article.

Assessment of research quality:	**Data Extracted:**
Is the type of AFO described?	See figure 2.1.1
Is the AFO bespoke or stock?	25 papers reportedly used bespoke AFOs
	1 paper reportedly used bespoke and stock
	14 papers did not state
Is the AAAFO described?	13 Papers described the AAAFO
	9 papers gave incomplete details
	18 Papers did not state
Is the manufacturer of the AFOs described?	3 papers detailed the manufacturer
	1 paper gave incomplete details
	36 papers did not state
Are the trim-lines of the ankle described?	8 Papers detailed the trim-lines at the ankle
	5 papers gave incomplete details
	27 papers did not state
Is the full design of the footplate described?	16 papers gave an incomplete description of the design of the footplate
	0 gave a full description
	24 did not give any description
Is the height of the AFO described?	11 papers described the height of the AFO
	3 papers gave an incomplete description
	26 papers did not describe the height of the AFO
Is the strapping system described?	6 papers described the strapping system

	5 papers gave an incomplete description
	29 papers did not describe the strapping system
Is the stiffness of the AFO in the stance phase described?	4 papers described the stiffness of the AFO in stance phase
	2 papers gave an incomplete description
	33 papers did not state
If hinges are stipulated are these described?	10 papers described the hinges on the AFO
	2 papers gave an incomplete description
	10 papers did not state
	18 papers were N/A
Is the material described?	23 papers did not state the material used
	15 papers used polypropylene
	1 papers used carbon fibre
	1 paper gave an incomplete description
Is the thickness of the material described?	35 papers did not state the material thickness
Is there a justification for choosing the material and thickness?	2 papers gave a justification for material and or thickness choice
	1 paper gave an incomplete description
	37 papers did not state
Has stiffness testing been carried out?	1 paper carried out stiffness testing
	39 did not state

Table 2.2: Results of extracted data

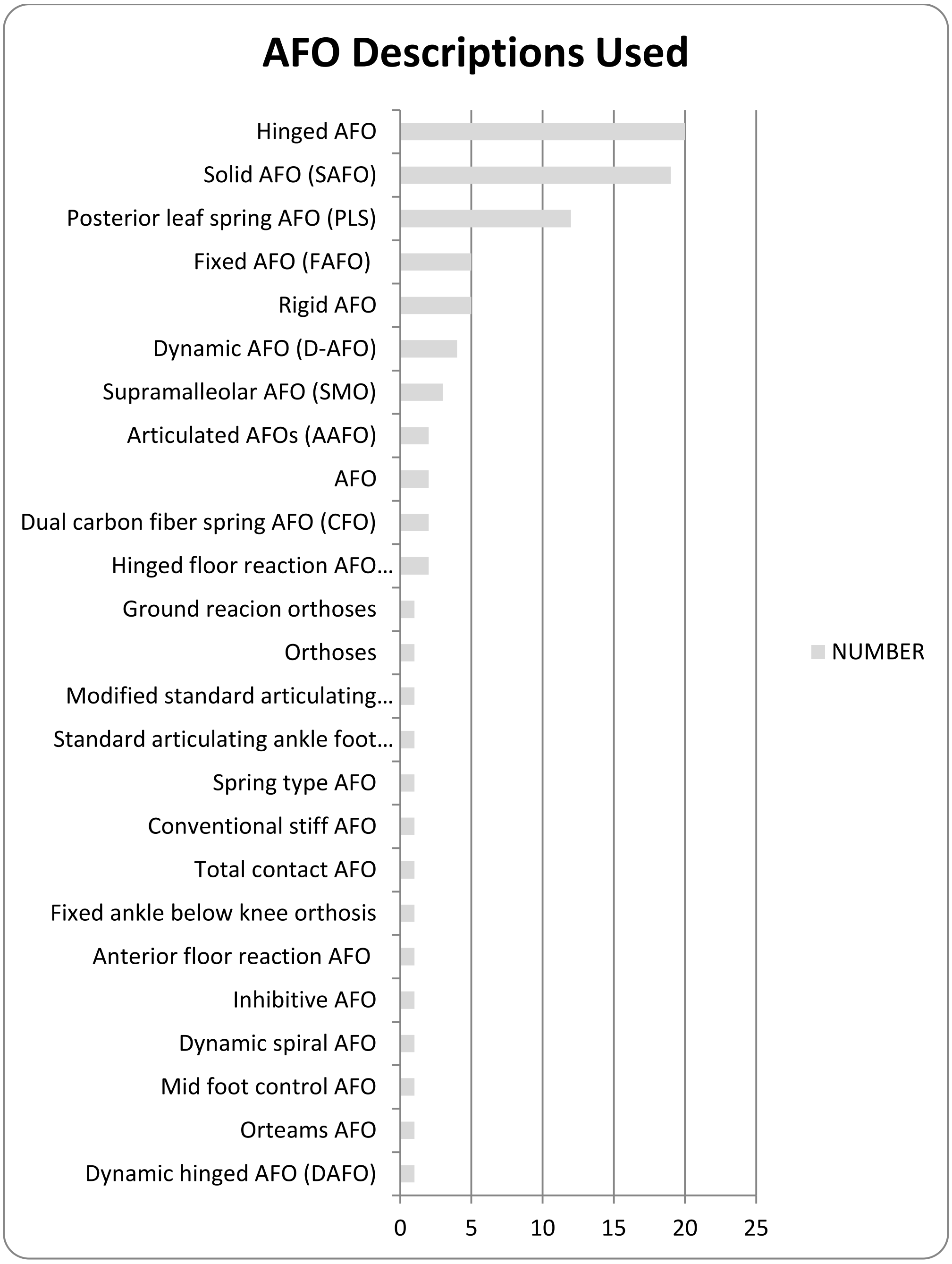


Figure 2.21.1: The descriptions used for AFOs within the extracted data.

The main results of this review show that the most commonly tested AFO is a bespoke (58.2%), hinged AFO (21%). The AFO material most commonly used of those who stated the chosen material (43.6%) was polypropylene (83.3%) in 3mm thickness (n=7). The outcome most commonly measured was lower limb kinetics, kinematics and temporal-spatial parameters during gait (n=25).

Only 3.6% of the papers reviewed carried out stiffness testing on the AFO intervention they used. 61.8% of papers failed to give any description of the footplate, the trim-lines at the ankle (69%), the height of the AFO (67.3%), the material thickness (72.7%) and the AAAFO (54.5%).

2.22 Discussion

The research included within this study examined the effect of AFO use on a range of outcome measures in children with CP. As stated in previous reviews(92,103,107,146), there was considerable variety in both the level and quality of the details reported. The results show that none of the papers reviewed adequately described the design and material of the AFO being studied. In all the papers reviewed, AFOs were the main intervention from which the outcome was measured. Thus, it is inconceivable that such a lack of detail on the main intervention should be provided. In many cases, this lack of detail limits any assessment of intervention quality and the impact that this may have on the confidence of findings. This variability also means that it is not possible to analyse or pool the data in a structured way to conduct some sort of meta-analyses which can summarise results across studies to provide substantial evidence for treatment practices.

The paucity of detail regarding AFO design and justification in the current literature may be responsible for producing the variation in reported outcome measures as documented in chapter 1. Van Gestal et al.(121) stated that when reading the literature, the researcher is confronted with contradictions in reported effects of certain AFOs on gait. However, this paper failed to report full details of; the material used in all AFOs studied, the footplate design and flexibility, the material thickness, ankle trim-lines and the AAAFO.

Similarly, Davand et al.(162) pointed out the importance of the choice of appropriate AFOs in these children being quite critical, and when an orthotic is given correctly, the participant will perform activities of daily living (ADLs) better and more independently. However, Dalvand et al.(162) failed to include the full details of the AFOs issued to their participants, including trim-lines at the ankle, type of hinged used, strapping system, footplate design, stiffness of the material used and the justification of the chosen AFO design.

Hinged AFOs (n=20) were the most common intervention in the studies reviewed (see figure 2.1.1). It is critical to ensure that the length of gastrocnemius can be accommodated in a hinged AFO, a failure to do so will result in compensations at the knee and hip(36,48,149). Without sufficient details regarding the prescription and clinical reasoning for the provision of a hinged AFO it is difficult to summarise its effectiveness.

Dursan et al.(134), Olama et al.(163), Kott and Held(164) and Mossberg et al.(78) do not state which type of AFO has been used and offer no other details of the AFO design. Thus, as the validity of the papers and repeatability are poor the results have limited clinical value, as one is unable to draw conclusions from the results.

32 papers used bespoke AFOs, and one paper used both stock/off the shelf and bespoke AFOs, however, 21 (38.2%) articles did not state whether the AFOs they tested, were stock or bespoke. For this reason, it is difficult to surmise whether the AFO used fits the participant appropriately and whether fit issues could have had an effect on the results. Only six papers stated the manufacturer used for the AFO, which suggest there is a possibility that the experience of the technician may have had an impact on AFO effectiveness.

Furthermore, the review confirmed the lack of standardisation for the terminology used to describe each type of AFO intervention studied (see figure 2.1.1). Although there is an accepted definition of what an AFO is there is currently no standardised terminology for the different types of AFOs available, therefore, when one researcher terms an AFO a “solid” AFO there is no clear definition of what this constitutes; is it rigid? Does it deform during stance phase? Or does it refer to the fact that the AFO finishes anterior to the malleoli? Others may use the term “rigid” AFO, is this the same as a solid AFO? Some researchers will describe the AFO as “standard” or “conventional” of which there is no standard definition and as such the reader cannot deduce what type of intervention is being studied, which may lead to misinterpretation of results.

Stating that an AFO is “solid” in design is not enough to determine its potential effects on gait, or ensure that a study is reproducible and its outcomes correctly evaluated. Although the literature reports several different types of AFOs, it is often not clear which type of AFO is being used for the intervention. For example, five of the papers reviewed termed their AFO as “rigid”, six used the term “fixed” and 19 used “solid”. Due to the lack of standardisation of terminology, it is unclear whether these papers are all using the same style of AFO.

Studies on AFO interventions must include details on the material type and stiffness, whether it deforms during stance phase, exact trim-lines, footplate design, strapping system, the height and the angle of the AFO, all of which will alter the kinetics and kinematics of gait.

Differences in the mechanical properties of the AFO can arise from small variations in AFO design such as trim-line position and choice of materials(107). A method of measuring the stiffness and neutral angle around the ankle and MTPJs has been demonstrated as clinically applicable(115,165). However, only two (3.6%) papers indicate the stiffness of the AFO during stance phase, which means that the control offered by the AFO is only known within these two articles. In the remaining articles, whether the AFO offered adequate control is unknown, potentially affecting the results of these studies.

31 (56.4%) papers didn’t state the material used in the AFO, of the 24 articles which did report the material, the majority (83.3%) used polypropylene. However, when stating polypropylene, researchers did not given details on the type of polypropylene used, e.g. natural or homopolymer polypropylene, both of which have different characteristics. Furthermore, 72.7% of researchers didn’t state material thickness. Current literature has indicated that both the material used and thickness influences the rigidity and flexibility of the AFO. The fact that researchers are not stating this means the reader is unable to tell if the results of the study are from the AFO being an inappropriate design in terms of the material or thickness, or whether the AFO intervention was unsuccessful. Of those papers who did state material thickness, the most common thickness used was 3mm (n=7), of which only two studies justified the reasons for giving the AFO material and thickness(90,97).

21 papers (38.2%) gave a partial description of the footplate design, and 34 papers (61.8%) failed to give any description at all. None of the papers included within this review offered sufficient details of the footplate design. The height of the AFO was described by 14 articles (25.5%) with only ten (18.2%) fully describing the trim-lines of the AFO at the ankle and six (10.9%) detailing a partial description of trim-lines at the ankle. As trim-lines have such a significant impact of the rigidity and function of an AFO, omitting these details means it is difficult to know the function of the AFO and how appropriate the design of the AFO was in trying to produce the desired outcome.

There was a failure in all studies reviewed to give a clinical justification for the AFO design tested. Thus, the chosen AFO prescription and desired function are unclear. The lack of such information prevents the reader from determining the nature of the optimal match between the participant and the AFO, and to determine the causes of the AFO's (in) efficacy. Gage(26) reports the selection of the correct orthotic design should be based on an understanding of the primary gait deviations of the patient. Therefore it is difficult to assess how the AFO design impacted the results, or whether the design was inappropriately chosen for the participant, and whether this had a detrimental effect on the results.

Only 15 (27.3%) papers detailed the AAAFO, the choice of which depends on clinical measures such as the passive and dynamic gastrocnemius muscle length and tri-planar foot stability. If there is severe spasticity or contracture in this muscle, it must be accommodated within the AAAFO to avoid limiting maximum knee extension or compromising the tri-planar stability of the foot(36,55). If the passive gastrocnemius length is also reported, in addition to the AAAFO, the reader can confirm that the AFO prescription is appropriate. Furthermore, if a study is reporting on a hinged AFO which allows free dorsi-flexion (a hinge with no dorsi-flexion stop) and such a device is being used on a participant with a plantar flexion contracture, the reader will be able to deduce that such a device will detrimentally affect knee extension and foot position.

A further issue highlighted by this review was the lack of consistency in outcomes reporting AFO efficacy. It has been suggested(166) that a core set of outcomes, covering measures on all domains of the international classification of functioning, disability and health (IFC) framework(167), should be used to evaluate the efficacy of AFOs on gait. The framework is considered as the international standard to describe and measure health and disability.

The CP consensus conference (The aim of which was to determine the evidence to support the efficacy of lower limb orthoses used for children with CP) in 1994 concluded that: '*The existing body of literature on the effects of orthotic intervention in cerebral palsy is, for the most part, seriously scientifically and experimentally flawed*(145). Unfortunately, regarding the description of device used, the situation appears to have changed very little in the last 20 years.

2.23 Recommendations

Based on the systematic appraisal of the current literature, future studies should include the following recommendations:

•The material of the AFO used as an intervention in a research study should be detailed, including type, thickness and any reinforcements.

•The full design of the AFO should be described, including trim-lines at the ankle, footplate design, length, medial and lateral flanges and flexibility, strapping arrangement and reinforcements.

•The stiffness of the AFO in stance phase should be described.

•The type of AFO used should be described, and a justification of the choice of design should be detailed.

•The AAAFO should be specified along with a rationale for the chosen AAAFO.

Randomised clinical trials are invaluable for evidence-based practice, but are not always feasible nor affordable for every possible intervention, question or comparison, and tend to equalize or minimize, rather than explore the nuances so common in clinical practice(10). However the study is designed, there must be agreed standardisations and reporting guidelines as documented above, to ensure good quality research which can accurately inform clinical practice. Transparent reporting permits replication of the study, and makes it possible to understand the variables that may affect intervention outcomes(107). Thus, it is recommended that journals reviewing future research on AFOs should reject papers which do not include the full details of the AFO intervention, as outlined above.

2.24 Limitations

One of the perceived limitations of this study could be that it did not assign quality scores or rank studies, or look at the sample sizes or method outside of the materials and AFO design. With this in mind, one could argue that the scope of this study is limited. However, the reported results indicate that there is a substantial lack of structured information within the published research which needs to be addressed.

2.25 Future research

Further research is needed on AFO prescription protocols, the AFO prescription process is largely empirical, resulting in confusing results regarding treatment efficacy. Development of prescription protocols will help ensure the design of AFOs in future research can be better compared and outcome measures validated, leading to improved clinical practice, based on evidence-based AFO provision. An agreed consensus on outcome measures will allow researchers to cross-reference research and enable validated meta-analyses to be performed. The terminology used to describe AFOs needs to be standardised to ensure studies can be reproduced and readily compared and evaluated.

Table 2.3: Details of all the studies included in the review

Author	Date	Type of AFO described?	AFO Bespoke or stock?	AAAFO?	Manufacturer?	Are the trim-lines of the ankle described?	Footplate design described: Length, flanges and stiffness?	Is the height of the AFO described?	Is the strapping system described?	Is the stiffness of the AFO in stance phase described?	If hinges are stipulated are these described?	Is the material used, stated?	Material thickness stated? (in mm)	Is there justification for choosing material, design, thickness?	Was Material stiffness testing carried out?	Outcome measure
Rosenthal et al. (168)	1975	Fixed ankle below the knee brace	Bespoke	Complete	-	Incomplete	-	-	Complete	Complete	-	Polypropylene	-	-	-	Genu recurvatum
Simon et al. (169)	1978	Fixed ankle below the knee orthoses	-	-	-	-	-	-	-	-	-	-		-	-	Kinetics and kinematics of gait
Harrington et al. (58)	1984	Anterior floor reaction AFO	Bespoke	Complete	Complete	-	Incomplete	Incomplete	-	Complete	N/a	Polypropylene	-	-	-	Level walking
Harris and riffle (170)	1986	Inhibitive AFO	-	-	-	-	-	-	-	-	N/a	-	-	-	-	Standing balance

Middleton et al(171)	1988	Rigid AFO and hinged AFO	Bespoke	Complete	-	-	-	-	Complete	-	Incomplete	Polypropylene	-	-	-	Kinetics and kinematics of gait
Mossberg et al. (78)	1990.	AFO	-	-	-	-	-	-	-	-	-	-	-	-	-	Energy expenditure
Butler et al. (62)	1992	Fixed AFOS	-	-	-	-	-	-	-	-	N/a	-	-	-	-	Kinetics and kinematics of gait and temporal-spatial parameters
Ounpuu et al.(144)	1996	Posterior leaf spring AFO (PLS)	Bespoke	-	-	Complete	Incomplete	Complete	Complete	Complete	N/a	Polypropylene	-	-	-	Ankle function
Radtka et al. (120)	1997	Dynamic AFO hinged (DAFO) solid AFO	Bespoke	-	Complete	Complete	Incomplete	Complete	Incomplete	-	-	Polypropylene	2.4mm, 4.8mm	-	-	Kinetics and kinematics of gait
Hainsworth et al.(172)	1997	Hinged AFO fixed AFO	Bespoke	Complete	-	-	-	-	-	-	-	-	-	-	-	Kinetics and kinematics of gait
Carlson et al. (132)	1997	Fixed ankle-foot orthosis (AFO) and supra malleolar (SMO)	-	-	-	-	-	-	-	-	-	-	-	-	-	Kinetics and kinematics of gait

Wilson et al. (114)	1997	Total contact AFOS	Bespoke	-	-	-	-	-	Complete	-	--	Polypropylene	3mm	-	-	Sit to stand transfers
Abel et al.(66)	1998	Solid AFO	Bespoke	Incomplete	-	-	-	-	-	-	N/a	Polypropylene	-	-	-	Kinetics and kinematics of gait
Brunner et al. (123)	1998	Conventional stiff AFO and spring type AFO	Bespoke	Incomplete	-	-	-	-	Complete	Complete	N/a	Polypropylene	-	-	Complete	Kinetics and kinematics of gait
Burtner et a.(173)	1999	Solid AFO and dynamic spiral AFO	Stock and bespoke	-	-	Incomplete	-	-	-	-	N/a	Polypropylene graphite	-	-	-	Standing balance
Rethlefson et al. (130)	1999	Fixed AFO (FAFO), articulated AFO (AAFO)	Bespoke	Complete	-	-	-	-	-	-	Complete	-	-	-	-	Kinetics and kinematics of gait
Suzuki et al (80)	2000	Hinged AFO	Stock	-	Complete	-	-	-	-	-	-	Polypropylene	-	-	-	Energy expenditure

Crenshaw et al. (139)	2000	A standard articulating ankle-foot orthotic (AFO), a modified standard articulating ankle-foot orthotic with tone reducing features (TRAFO) and a supra malleolar orthotic (SMO).	Bespoke	-	Complete	-	Incomplete	Complete	-	-	-	Copolymer	3mm, 5mm	-	-	Kinetics and kinematics of gait
Bill et al.(174)	2001	Mid foot control AFO	Bespoke	Incomplete	-	-	-	-	-	-	N/a	Homopolymer and polypropylene	-	-	-	Skin tissue pressure and mobility
Buckon et al.(79)	2001	Hinged AFO (HAFO), posterior leaf spring (PLS) solid AFO (SAFO)	Bespoke	Incomplete	-	Complete	Incomplete	Complete	Complete	-	Complete	Polypropylene	4mm, 5mm	Incomplete	-	Ankle range of motion, gait analysis, energy consumption, and functional motor skills
Maltais et al.(75)	2001	Hinged AFO	-	-	-	-	-	-	-	-	-	-	-	-	-	Energy expenditure
Beals(175)	2001	Solid AFOS	-	Complete	-	-	-	-	-	-	N/a	-	-	-	-	Trunk posture
Dursun et al.(134)	2002	AFO	-	-	-	-	-	-	-	-	N/a	-	-	-	-	Kinetics and kinematics of gait

White et al.(68)	2002	Solid AFO	Bespoke	Incomplete	-	Complete	Incomplete	Complete	Complete	-	Complete	Polypropylene	3.2mm-4.8mm	-	-	Temporal-spatial parameters of gait
Romkes and brunner(135)	2002	Hinged AFO (H-AFO) dynamic AFO (D-AFO)	-	Incomplete	-	-	Incomplete	Incomplete	Complete	-	Incomplete	-	-	-	-	Kinetics and kinematics of gait
Thompson et al.(124)	2002	Rigid AFO	Bespoke	Incomplete	-	Complete	-	-	-	-	N/a	Polypropylene	3mm	-	-	Hamstring length
Sienko et al.(176)	2002	Solid AFOS, hinged AFOS, posterior leaf spring AFOS (PLS)	Bespoke	Incomplete	-	Complete	-	-	-	-	Complete	-	-	-	-	Stair locomotion
Kott and held (164)	2002	Orthoses	-	-	-	-	-	-	-	-	-	-	-	-	-	Functional balance and ambulation
Smiley et al.(73)	2002	Solid, hinged and posterior leaf spring AFOS	Bespoke	-	-	Incomplete	Incomplete	Complete	Incomplete	-	Complete	Polypropylene	4mm	-	-	Energy expenditure
Wesdock and edge(143)	2003	Solid AFO	-	Complete	-	-	-	-	-	-	N/a	-	-	-	-	Standing balance and knee extension

Buckon et al.(47)	2004	Solid AFO (SAFO), hinged AFO (HAFO), posterior leaf spring AFO (PLS)	Bespoke	-	-	Incomplete	Incomplete	-	-	-	-	Polypropylene	4mm, 5mm	-	-	Kinetics and kinematics of gait, energy expenditure and functional outcome
Park et al.(177)	2004	Hinged AFO	Bespoke	-	-	-	Incomplete	Complete	Complete	-	-	-	3mm	-	-	Sit to stand transfers
Radtka et al.(82)	2005	Solid AFO and hinged AFO	Bespoke	Complete	-	Incomplete	Incomplete	Complete	Incomplete	-	Complete	Copolymer	4.8mm	-	-	Kinetics and kinematics of gait, energy expenditure and functional outcome
Lam et al.(133)	2005	Rigid AFO (AFO) and dynamic AFO (DAFO)	Bespoke	Complete	-	-	Incomplete	Complete	-	-	N/a	Polypropylene	4.8mm	-	-	Kinetics and kinematics of gait and electromyographic (emg) effects
Romkes et al.(126)	2006	Hinged AFO (HAFO)	-	Complete	-	-	Incomplete	Incomplete	-	-	-	-	-	-	-	Electromyographic (emg) signals of lower extremity muscle
Desloovere et al.(128)	2006	Dual carbon fiber spring AFO (CFO), posterior leaf spring AFO (PLS)	Bespoke	-	-	Incomplete	Incomplete	Complete	Incomplete	Incomplete	N/a	-	-	-	-	Kinetics and kinematics of gait

Bjornson (178)	2006	Dynamic ankle-foot orthosis (DAFO)	Bespoke	-	Complete	-	-	-	Complete	-	-	-	-	-	-	Gross motor function
Lucareli et al.(138)	2007	Hinged floor reaction AFO (FRAFO)	-	-	-	-	-	-	-	-	-	-	-	-	-	Kinematics of gait
Balaban et al.(76)	2007	Hinged AFO (H-AFO)	Bespoke	-	-	Complete	Incomplete	Complete	Complete	Complete	Complete	-	-	-	-	Energy expenditur e
Butler et al.(98)	2007	Fixed AFOS	-	-	-	-	-	-	-	-	N/a	-	-	-	-	Kinetics and kinematics of gait
Westberry et al.(179)	2007	Solid ankle orthoses, posterior leaf spring orthoses,, articulated orthoses and ground reaction orthoses	-	Complete	-	-	-	-	-	-	-	-	-	-	-	Static foot alignment
Brehm et al.(74)	2008	Solid AFO (SAFO) and posterior leaf spring (PLS)	Bespoke	-	Incomplete	-	-	-	-	-	N/a	-	-	-	-	Energy expenditur e

Van gestal et al. (121)	2008	Orteams AFO, posterior leaf spring AFO (PLS), dual carbon fibre spring AFO (CFO)	Bespoke	Incomplete	-	-	Incomplete	Complete	Incomplete	Incomplete	N/a	-	-	-	-	Kinetics and kinematics of gait
Jagdamma et al.(37)	2009	Rigid AFO and a dynamic AFO	-	-	-	-	-	-	-	-	N/a	-	-	-	-	Knee hyperextension during gait
Rogozinski et al. (180)	2009	Floor reaction ankle-foot orthosis		-	-	Complete	-	-	Complete	-	N/a	-	-	-	-	Kinetics and kinematics of gait
Rha et al.(181)	2010	Hinged AFO	Bespoke	Complete	-	-	Incomplete	Complete	-	-	-	Polypropylene	3mm	-	-	Standing balance
Degelean et al.(182)	2012	Solid AFO, posterior leaf spring (PLS)	-	-	-	Incomplete	-	-	-	-	N/a	-	-	-	-	Trunk postural control lower limb intersegmental coordination
Olama et al.(163)	2012	AFO	-	-	-	-	-	-	Incomplete	-	N/a	Incomplete	-	-	-	Standing balance
Bennett et al.(81)	2012	Hinged AFO (HAFOS) and solid AFO (SAFO)	-	-	-	-	-	-	-	-	-	-	-	-	-	Energy expenditure

Kerkum et al.(97)	2013	Hinged floor reaction orthosis (FRO)	Bespoke	-	Complete	-	Incomplete	-	-	Complete	Complete	Pre preg carbon	-	Complete	Complete	Kinetics and kinematics of gait, energy expenditure and functional outcome
Dalvand et al.(162)	2013	Hinged AFO (HAFO) and solid AFO (SAFO)	Bespoke	Complete	-	-	Incomplete	Complete	-	-	-	Polypropylene	3mm	-	-	Gross motor function
Liu et al.(183)	2014	Supra malleolar orthosis (SMO), solid AFO (SAFO), hinged AFO (HAFO)	-	-	-	-	-	-	-	-	-	-	-	-	-	Ankle joint and foot segment kinematics
Jagadamma et al.(90)	2 014	Rigid AFO	Bespoke	Complete	-	Complete	Incomplete	-	Complete	Complete	N/a	Polypropylene	3mm, 4.5mm, 6mm	Complete	-	Kinetics and kinematics of gait
Schweizer et al.(184)	2014	Hinged AFO (HAFO)	Bespoke	Complete	-	-	Incomplete	Incomplete	-	-	-	-	-	-	-	Pelvis, thorax, and arm kinematics

KEY: Complete = all information present, Incomplete = some information missing, N/A = not applicable to this paper, - = all information missing

Chapter 3: The effect of tuning ankle-foot orthoses and footwear (AFO-FC) on the gait parameters of children with cerebral palsy–A systematic review

3.1 Aim of the research

This structured review aims to detail and discuss the available literature on AFO-FC tuning to see if the process of tuning further impacts the kinetic and kinematics of gait in children with CP. The scope of this review is to look at the biomechanical effects and will work within the boundaries of general mechanical gait characteristics and will not focus on physiological measures.

3.2 Introduction

As previously documented, the current literature is equivocal as to which gait parameters AFOs can improve, for children with CP. One of the reasons for such variation is the lack of detail regarding the AFO intervention and lack of clinical justification for the AFO prescription(185). Another reason may be due to the lack of AFO-FC tuning.

3.3 Method

A thorough review of previous studies dated between 1959-2011 was conducted using the following phrases; ankle-foot orthosis, AFO, AFO-FC, Cerebral Palsy, Orthosis, Orthoses, Orthotic, Tuning, splint and gait between 1959 and spring 2011. The databases searched included PubMed, Cochrane Library, PEDro, OTSeeker, Lilacs, Sielo, EMBASE (Ovid), Science Direct, psychINFO, Medline (Ovid), APAIS Health (informit) PubMed, Recal, and Google Scholar. Hand searching of reference lists of review and publications was also undertaken.

3.4 Selection Criteria

Selection criteria were developed by the primary author based on the nature of the review as dictated by the research questions. To be included in the review, the research had to meet the following criteria:

- The intervention involved an ankle-foot orthosis.
- The participants were under 18 years old and had a diagnosis of cerebral palsy.
- The paper demonstrated the effects of an ankle-foot orthoses on gait.
- The study involved a tuning process which recognised either or both the shank to vertical angle (SVA) and the angle of the ankle in the AFO (AAAFO).
- The study was published in English as a full paper in a peer-reviewed journal.

3.5 Results

To date, there are 947 papers in the literature pertaining to the study of AFOs, of these, 153 study the use of AFOs in the gait of children with CP. All the studies included in this review were of a within-subjects design, and the evidence levels were low at 4-5 (based on the Oxford EBM levels of evidence(186)) as the research available tended to be of a retrospective within-subjects comparison study with no random controlled trials carried out.

27 papers implemented some form of AFO-FC tuning within the study; nine were rejected because they did not include research on both AFOs and children with CP (57,65,93,187–192). Research by Meadows(38) was rejected because it was not published in a peer-reviewed journal. Wesdock and Edge(143) was rejected because the research studied standing ability and not gait. Only 15 papers recognised the importance of either or all AAAFO, SVA and AFO-FC tuning in the gait of children with CP (37,58,61,62,91,94,98,99,121,168,169,193–196)(See table 3.1).

Furthermore, only Owen(91,94) recognised the full process of AFO-FC tuning and provided a complete description of the process although limitations in this research were evident. Only one paper provided quantitative kinetic and kinematic data comparing tuned against non-tuned AFO-FCs. The studies involved hemiplegic and diplegic subjects with varying degrees of disability and encompassed a range of ankle-foot orthoses and gait parameters/outcome measures.

3.6 Discussion

The review of the literature on AFO-FC tuning revealed a lack of quality research which demonstrates the effects of AFO-FC tuning on the kinematic and kinetics of gait compared with non-tuned AFO-FC. However, the studies reviewed did highlight the benefits and the potential of AFO-FC tuning.

All papers included in the review recognise a clear differentiation between the AAAFO and the SVA. However, none of the papers thoroughly explained the reasoning behind the chosen AAAFO for each subject. Owen(91) states that the AAAFO for each participant was recorded but didn’t offer an explanation of how the AAAFO was determined. Several of the early papers were clearly just beginning to recognise the importance of the AAAFO and experimented by setting different AAAFOs on subjects and observed the effects during gait. The AAAFO in these papers clearly didn’t reflect the length of gastrocnemius as is intended in AFO-FC tuning.

The SVA was often identified in the research but was not always described. Gans et al.(194), Sankey et al.(196) and Butler and Nene(61) identify the SVA but they do not describe the SVA used in degrees, and this cannot be deduced from the data.

The SVA identified by Jebson et al.(193) and Nuzzo(195) comes from a theoretical kinematic justification as tuning was either carried out on one patient or none at all. Butler et al.(61), Butler et al.(62), Butler et al.(98) and Stallard and Woollam(99) recognised the importance of tuning and describe the benefits on gait but do not provide the angle of the SVA.

Rosenthal et al.(168) Simon et al.(169) and Harrington et al.(58) did not report the tuned SVAs of AFO-FC on children with CP, although the SVAs can be deduced from the data. Owen(91,94), Van Gestel et al.(121) and Jagadamma et al.(37) all describe the SVA used in their research.

The SVAs reported or deduced from the data, range from 0-15° inclination. However, it is difficult to compare the individual figures because the process of AFO-FC tuning is variable in the literature with some papers not tuning the AFO-FC at all but still recognising the importance of the SVA and its effects on gait. In addition, the terminology used is ambiguous until it was described and standardised by Owen(48).

Early studies which began to recognise the importance of the effect of one or all of the AAAFO, SVA and the footwear on gait, didn’t offer great detail on the process involved with tuning. Instead, the research tends to be of a descriptive theoretical nature describing how the GRF can be manipulated by altering the angle of the ankle and the inclination of the tibia.

Nuzzo(195) studied ten cases of athetoid and ataxic CP children all of whom presented with genu recurvatum at heel strike/initial contact. Each subject wore a solid AFO which was set in dorsi-flexion. The tibial inclination was set between 7-10°. A posterior heel flare was added to the shoe of each subject in an attempt to manipulate the GRF thus causing a knee flexion moment. The results showed a decrease in knee hyperextension at initial contact which was deemed successful for seven of the subjects and unsuccessful for the three athetoid cases. The study demonstrated the potential to affect the kinetics and kinematics of gait by considering the AAAFO and the SVA, the footwear in this study was also modified to alter entry into gait at the first rocker.

Unfortunately, Nuzzo(195) does not describe the physical presentation of the subjects studied. There is also a lack of detail on the description of the AFO used, regarding design and stiffness. The research identifies the successful manipulation of the GRF and how gait can be affected by changing the AAAFO and SVA, but it does not describe optimal AFO-FC tuning for the individual subject/clinical presentation.

Butler and Nene(61) identified how even minimal changes to the AFO-FC could result in significant effects on the GRF. This research reported that a heel raise as small as 3mm can be significant in modifying gait parameters, representing an angular change of 2° of the floor/shank angle. Furthermore, this was the first study to use a video image of the patient overlaid with a thin white line representing the position and magnitude of the GRF to aid in clinical decision making. Unfortunately, the paper was descriptive and was based on theoretical principles rather than empirical data.

Butler et al.(62) investigated the effect of tuned AFOs in conjunction with balance training exercises. The study examined five children with CP who presented with hyperextension of the knee joint during mid-stance. Gait analysis was conducted before, and 4-to-6 months after, the start of the treatment. The high knee-extending moment arm decreased to a significant level ($p < 0.01$) and was closer to normal. Three out of five children retained the improvement in barefoot and were weaned from the AFOs. Butler et al.(62) attributed this effect to motor learning, which might have been facilitated through the use of tuned AFO-FCs.

However, the study presented some limitations. The participants underwent a number of treatments, and therefore the results cannot be attributed to AFO-FC tuning alone. In addition, the study did not provide details on the methods used for tuning and lacked comparison between tuned and non-tuned AFO-FCs. The authors also failed to provide sufficient information on the materials and design of AFOs and the prescription process of AFOs to each subject with regard to their clinical presentation.

Later research by Owen(91) studied independently ambulant children with neurological conditions, including CP, using solid AFOs via a transportable video vector generator (VVG). The tuning process is described as making fine adjustments to the tibial inclination angle of each AFO using a series of wedges under the subjects' heel, in an attempt to manipulate the position of the GRF. The research reported that in all the subjects tested, optimal knee and hip kinetics were all achieved with the tibia inclined regardless of the AAAFO. While the mean SVA for all the AFO-FCs (n = 112) after tuning was 11.36° ± 2.08° (range = 7–15), the mean for AFO-FCs used by children with CP (number of legs = 69) after tuning was 11.86° ± 2.05°. The author went on to suggest that 10-12° SVA was a good starting point from which to begin tuning AFO-FC.

The study indicates that AFO-FC tuning has a positive effect on gait by manipulating the GRF thus affecting its relationship to the lower limb joints. Whilst the study describes the process of tuning; explaining how to manipulate the GRF, it doesn't provide quantitative kinetics and kinematics of the gait of children with tuned and non-tuned AFOs. Furthermore, the research measures the SVA at mid-stance whilst the patient is static however, there is no research to suggest that the SVA measured statically will represent the SVA at mid-stance during gait.

Further research by Owen(94) involved a retrospective comparison study of 12 CP children using Solid AFOs with point loading rocker modifications, in an attempt to align the GRF for terminal stance by adjusting the design of the footwear. Owen(94) reports that GRF alignment anterior to the knee and posterior to the hip in terminal stance, of normal barefoot gait, is achieved by combination of maintenance of a relatively fixed ankle appropriately dorsi-flexed and the use of MTPJ extension at the third rocker, producing appropriate inclination of the shank relative to the vertical. The study suggests that an AFO can correct this, but inappropriate accompanying footwear may reduce the chances of success.

This research reported that the rocker modifications resisted early exit from stance in crouch gait. The study concluded that point loading rockers were most successful with the apex in front of the MTPJs at 78% the length of the footwear. Although an AFO can retard tibial progression, it may prove inadequate if the third anatomical rocker allows the knee centre to pass in front of the GRF too early in terminal stance. Thus, the theory behind the anterior placed point loading rocker is to resist tibial progression further by manipulating the GRF away from the joint centre, producing a high moment arm anterior to the knee and encouraging knee extension.

Unfortunately, the physical presentation of the subjects studied in Owen's(91,94) research was not reported, and no detail was given on how the prescription of the AFO was devised, and if gastrocnemius was fully accommodated although the author states such data was collected, it is not reported. The design of the AFO regarding its material, stiffness and the footwear combination is recognised as playing an integral part in the ability to produce an optimal gait pattern when prescribing AFOs, however, the research lacks detail on the material and stiffness used for the AFO and a detailed design of the AFO.

A later study by Stallard and Woollam(99) aimed to establish the potential of the portable video vector gait equipment to achieve, in a community setting, more effective orthotic outcomes for patients in whom alignment of the GRF is an important treatment objective. 61 children were studied, all of whom had their gait assessed and then optimally tuned in line with the principles of AFO-FC tuning by Butler and Nene(61). The authors reported that improved biomechanical alignment of the lower limbs was achieved in 68% of subjects, with only two of the 61 subjects failing to show a significant improvement. The study also noted that the AFO design must have appropriate mechanical properties. From this study, it was concluded that tuning with kinematic and kinetic monitoring should become routine clinical practice.

Stallard and Woollam(99) did not produce any quantitative kinetic or kinematic data instead reporting in a qualitative manner; there was also no description of which joints were being investigated. Successful tuning was decided by assessment features, e.g. "improvement of alignment of the GRF by a minimum of 10mm to the ideal specified by the physiotherapist". The study also failed to describe the neurological disorders which the participants presented with or the extent of the gait pathology. Unfortunately, the only description of the AFOs used was a solid AFO made from polypropylene. There is no mention of the type or thickness of polypropylene, the physical presentation of the patients and the justification of the orthotic prescription, although the study did note this was all confirmed and agreed before tuning.

Further research by Butler et al.(98) tried to establish the characteristics of children with CP that could be identified as predictors of successful tuning. Data from 21 children was retrospectively analysed. Parameters were determined by statistically comparing the data from children, who were successfully tuned, with data from children who were not. The study concluded that analysis of knee kinematics prior to AFO use would be a good predictor of potential success.

The research concluded that the most successful predictors were maximum knee flexion no more than 20° in the initial one-third of stance phase, and movement towards knee extension in the second third of stance to 10° flexion or less. Poor prognostic signs were considered to be knee flexion greater than 35° in the first third of stance and greater than 15° in mid-stance, a popliteal angle in excess of 45° and a hip flexion contracture greater than 15°. Although the study suggested that ataxic gait was not successfully tuned, it referred to only one subject.

One of the issues with this study is that the authors considered kinematics and kinetics of the knee and failed to recognise the effects on the proximal joints. Furthermore, the comparison of data was between barefoot and tuned AFO-FCs rather than tuned and non-tuned AFO-FCs; therefore, it is unclear how much of the improvement was due to the AFO intervention and how much was due to tuning.

In addition, the only reference to the AFO used in Butler et al.'(98) study was "a fixed AFO" and no further description was given. This lacks the detail required to ensure optimum AFO prescription and assessment had been realised. Information on the footwear used was also omitted. However, unlike previous studies, Butler et al.(98) did provide data on the physical examination of each participant; albeit, there was no explanation of how the physical presentation of each participant related to the AFO prescribed. Although this paper aimed to determine a screening tool for AFO-FC tuning, the investigation used did not offer any details on the tuning process used for these children, the details of which are required to ensure accuracy.

Van Gestel et al.(121) studied 36 children with hemiplegic CP. The study compared three different types of AFOs, each permitting dorsi-flexion. The study reports that the AFOs fitted to these children were optimally tuned. The description used for optimal tuning was having the shank in alignment ranging from neutral to a maximum of 10° inclined. Unfortunately, the process of determining how the AFOs were considered to be optimally tuned was not described. It is difficult to see how a dorsi-flexion permitting AFO could be optimally tuned throughout stance phase. Furthermore, the study describes the subjects as a "homogenous" group. It is difficult to see how this term could be applied to a group of children with a diagnosis of CP.

The only description of the clinical presentation of the subjects was that they all presented with a plantar flexion–knee extension couple. The AFOs are described as being individually selected and adapted, but no detail is offered to justify the prescription, although a detailed description of the design of the AFOs is given. The research states that gait analysis determined the amount of flexibility in the orthosis. The study also reports that bilateral AFOs were issued for hemiplegic subjects to promote symmetry but doesn't offer any research to justify this theory. The study also fails to recognise the importance of the AAAFO in AFO-FC tuning and the available length of gastrocnemius.

The only paper to provide quantitative kinematic and kinetic data for tuned and non-tuned AFO-FCs was Jagadamma et al.(37). This pilot study involved a small group of five

CP children who all presented with knee hyperextension during stance phase. Gait analysis was carried out before and after tuning the child's current AFO-FC prescription. The results show mean maximum knee hyperextension decreased from 2.6° extension to 3.7° flexion. However, velocity, cadence and stride length all decreased in the tuned AFO-FC, although not significantly. This may have been due to a lack of familiarisation in the tuned AFO-FC as the participants were not given any time to acclimatise to the new device. The study lacked power and statistical significance which is most likely to be due to the small sample size.

Unfortunately, Jagadamma et al.'(37) study doesn't describe the physical characteristics of the participants, there is no information regarding the AAAFO or how the prescription for the AFOs were justified. The study fails to provide detail on the design and material of the AFOs used and their justification. The footplate of the AFOs should have been flexible at the MTPJs with the medio-lateral trim-lines posterior to the MTPJs in order to reduce knee hyperextension, however, this crucial aspect of the AFO design was omitted, blocking the third rocker and potentially inducing an increased extension moment at the knee. The research only focused on the knee joint, and as such, proximal joints were not considered. Critically, this study provided group mean data rather than utilize a case series approach. Thus, the results offer very little in terms of indicating the individual effect of AFO-FC tuning on each child and informing clinical practice.

3.7 Summary

Whilst the research described in this manuscript indicates an improvement in the gait of children with CP, following tuning of their AFO-FCs, there is still a paucity of research with quantitative data on the effects of kinematics and kinetics of AFO-FC tuning, comparing non-tuned with tuned AFO-FCs. Current research doesn't identify the benefits of tuning to the patient, whilst improvements in kinematics are usually studied in isolation, e.g. improvement of knee hyperextension at initial contact, without studying the effects on the proximal joints. Thus, whether the reported improvement in some gait parameters results in a more efficient gait for the patient, still requires investigation. Current research does not identify how energy consumption is affected by tuned AFO-FCs.

From current research, it is unclear whether tuned AFO-FCs can maintain/increase muscle length and hence prevent/reduce deformity developing over time. Further research is required to investigate the effect on the triceps surae in an optimally tuned AFO-FC when the foot is in a plantarflexed position. If the muscle increases its passive range of motion over a period of time whilst the subject ambulates in a tuned AFO-FC, this may indicate that the posterior musculature is achieving a significant stretch, a principal aim of treatment when prescribing AFOs to children with CP. Longitudinal studies may be required to measure the actual effects AFO-FC tuning has on the triceps surae.

Further research is also required to determine whether the cosmesis of the modified footwear, which forms part of the tuned AFO-FC, affects patient compliance.

In 2008 the international society of prosthetists and orthotists (ISPO) recognised the importance of AFO-FC tuning(92). In 2009 NHS Scotland reported the provision of a solid AFO without tuning can introduce further neuro-biomechanical challenges to patients and recommended that AFO-FC tuning should be standard clinical practice when issuing an AFO(95). It is recognised that a sub-optimal AFO-FC may have an immediate detrimental effect on function and in the longer term, it may contribute to deterioration(149). Despite this, AFO-FC tuning is still not routine clinical practice. Further research is required to explore the barriers preventing AFO-FC tuning in clinical practice.

There appear to be barriers to tuning in current practice; the algorithm produced by Owen(159) may be deemed as complicated, however, it allows consistency in AFO prescription. Current literature recommends the use of 2D gait analysis(149) which is not always easily accessible to the majority of clinicians. However, there is no available research to demonstrate whether 2D gait analysis is essential to tune AFO-FCs. Measurement of the SVA statically is recommended to estimate the SVA at TMST; however, there is no evidence that this is a reliable method to measure the dynamic SVA at TMST.

The design of the AFO and the correct prescription for the patient regarding material stiffness, type and trim-lines are critical and is yet to be standardised. The lack of a clear, definitive process of how such an assessment and AFO prescription should be devised has led to studies lacking crucial details which fail to inform future research and prevents generalisation and replication in the clinical setting.

3.8 Recommendations:

In light of this review it is recommended that future research on AFO-FC tuning should include the following details, several of which were also recommended by Bowers(92).

- Full detailed description of the subjects, including age, diagnosis and accurate classification of CP and presenting gait pathology, along with the use of any walking aids.

- Full detailed physical assessment of the subjects' lower limbs, including the passive and dynamic range of motion of all lower limb joints, highlighting whether range is attained with ease or difficulty. Particular reference should be paid to dorsi-flexion range with knee extended, which is an indication of gastrocnemius length and is critical in the prescription of AFOs. Any fixed deformities should be reported, together with an assessment of muscle spasticity, including tone, contractures, torsional abnormalities affecting the foot progression angle and alignment of the subtalar joint.

- Current and previous treatment of each subject, including surgery, therapy and in particular botulinum toxin.

- Details of the AFO and footwear should be described and include; material and thickness used, flexibility and stiffness properties in stance, trim-lines, fastenings, stiffeners, hinges, range of motion, AAAFO and SVA and the process used to achieve these. The design of footwear, heel type height and pitch, addition of rockers and stiffeners and materials used. Critically there should be a reasoned clinical justification for the individual prescription of the AFO-FC with detail of how the length of gastrocnemius has been accommodated.

- Studies should give sufficient detail on the effect of tuned versus non-tuned AFO-FCs with the provision of quantitative kinematic and kinetic data. Researchers should be clear on whether tests have been conducted on the same or different days, whether there has been a period of acclimatisation, an order of testing and whether subjects and controls have been tested with or without footwear.

3.9 Conclusion

There is emerging evidence that tuning AFO-FCs can improve their effectiveness. However, the paucity of research into AFO-FC tuning, the lack of access to 2D gait analysis for the majority of clinicians, the time and cost required to tune AFO-FCs and the lack of research into the benefits to the patient, are potentially significant contributing factors to why AFO-FC tuning is not currently standard practice. Furthermore, the poor design of research studies on tuning and the lack of details provided in such studies prevent a definite conclusion on the effects of tuning on gait, inhibits replication of studies and most importantly prevents research being converted into clinical practice.

Table 3.1: Studies recognising AFO-FC tuning

Authors	Number and age range of Subjects	CP classification	Type of AFO/ Footwear	Average SVA	AAAFO Recognised?	Research Design	Evidence Level	Key Findings
Jebson et al.(193)	N/A	Mixed	Solid AFO	Theoretical 10° inclined	No	Descriptive theoretical paper.	5	Recognised the importance of the SVA inclination of the shank was theoretical. No description of the AAAFO
Rosenthal et a(168)	n=12	Spastic Mixed	Solid AFO/ Regular Oxford Shoe	Not described but deducible from the data	5° Dorsi-flexion	Prospective within-subjects comparison design	4	Used a solid AFO set in dorsi-flexion in an attempt to control genu recurvatum. Followed subjects up after 26 months and reported that genu recurvatum was well controlled and gait was improved.
Simon et al.(169)	n=15	Spastic	Solid AFO Regular Oxford	10-15° inclined	7-10° Dorsi-flexion	Retrospective within-subjects comparison design	5	Ambiguity in description of AAAFO and SAF, Kinematic tuning was by use of a variable inclined walk way. Studied genu recurvatum, reported that the tuned AFO produced more normal moments about all joints especially the knee and in 3 cases genu recurvatum was controlled fully.
Gans et al.(194)	N/A	Spastic and Athetoid	Soft, pliable wrap around AFO	Not Given	Plantigrade	Descriptive theoretical paper	5	Recognised that the limitation of adjustability of dorsi-flexion can be compensated by heel or sole shoe lifts.
Harrington et al.(58)	n=11 Age = 3.9 years – 16.2 years	Spastic hemiplegic and diplegic	Anterior Floor reaction AFO	Not given	5° dorsi-flexion 5° plantar flexion 10° Plantar flexion	Prospective between subjects comparison design	5	Recognised the importance of the AAAFO described as the angulation angle. Recognised the importance of the stiffness of the AFO. Demonstrated how knee flexion can be controlled by manipulating the GRF.

Nuzzo(195)	n= 10 7-12	Mixed	Solid AFO	7-10°	Recommends dorsi-flexion, plantigrade, plantar-flexion according to clinical findings.	Prospective within-subject comparison study	4	AFO-FC tuning successfully treated knee hyperextension in 7 of the subjects, unsuccessful for 3 athetoid subjects. Researcher uses posterior Flare on footwear.
Sankey et al.(196)	n=29	Hemiplegic Spastic	ambiguous	Not described	Dorsi- flexion and plantar flexion	Retrospective between subjects comparison study	5	The research involved issuing 16 of the subjects with dorsi-flexed AFOs and 13 with plantarflexed AFOs. They reported that 9 of the 13 subjects issued with a plantaflexed AFO later required surgery, whilst only 1 of the 16 subjects issued with a dorsi-flexed AFO required surgery.
Butler and Nene(61)	N/A	Spastic hemiplegia	Solid AFO	Not described	Plantigrade recommended	Descriptive theoretical paper.	5	Recognised the effect of using wedges on footwear to manipulate the GRF. Recognised mid-stance as a vital phase in the gait cycle for AFO-FC tuning. Recognised the effects of tuning on proximal joints. Reported that a heel raise as small as 3mm can be significant in modifying gait parameters, representing and angular change of 2° floor/shank angle.
Butler et al.(62)	n=5	Spastic diplegia and hemiplegia	Solid AFO	Not described	Not described	Prospective cohort study	3	Subjects presented with knee hyperextension. Gait analysis was conducted before, and 4-to-6 months after, the start of the treatment. The high knee-extending moment arm decreased to a significant level ($p < 0.01$) 3 out of 5 children retained the improvement in barefoot, and were weaned from the AFOs
Owen(91)	n= 74 CP n = 50 Age not given	Mixed	Solid AFO	11.86° Tibial inclination	Dorsi- flexion, plantar flexion and plantigrade determined by subjects' clinical presentation	Retrospective within-subjects comparison study	4	Knee and hip kinetics were optimised with tibia inclined regardless of AAAFO. Full process of AFO-FC tuning described. Recognised mid-stance as a vital phase in the gait cycle for AFO-FC tuning.

Stallard and Woollam(99)	n=62 Age = 1 year 10m – 15 years 2 months	Not described	Solid AFO	Not described	Not described	Retrospective within-subjects comparison study	4	Improvement in GRF alignment via tuning in more than 68% of subjects. Suggested that tuning should be routine clinical practice. Suggested that the design of the AFO must have appropriate mechanical properties to successfully manipulate the GRF.
Owen(94)	n=12 Age not given	Mixed	Solid AFO	11.86° Tibial inclination	Dorsi- flexion, plantar flexion and plantigrade determined by subjects' clinical presentation	Retrospective within-subjects comparison study	4	Used point loading rockers to resist early exit from stance phase in crouch gait. Recognised mid-stance as a vital phase on the gait cycle for AFO-FC tuning
Butler et al.(98)	n=21 4 years – 12 years 11 months	Mixed	Solid AFO	Not described	Not described	Retrospective within-subjects comparison study	4	Concluded AFO-FC tuning can improve kinematics and kinetics of gait. Suggests popliteal angle in excess of 45^0 and hip flexion contracture greater than 15^0 poor prognostic sign Also Suggests that ataxic gait seems to resist tuning.
Van Gestel et al.(121)	n=36 Age = 4 years – 14 years	Hemiplegia	PLS dual carbon spring AFO. Orteam AFO	0-10° inclined	Not described	Retrospective Cohort study	4	Concluded that AFOs are optimally aligned when the tibia is inclined between 0-10°

Jagadamma et al.(37)	n=5 5-12 Years	Mixed	Solid AFOs	Mean 10.8°	AAAFO was not mentioned in the study.	Prospective within-subject comparison study	4	Compared knee flexion and extension, velocity, cadence and stride length in tuned versus non-tuned AFO-FC. In children who presented with knee hyperextension during stance phase. Knee flexion increased when AFO-FC was tuned, to 3.7° flexion from 2.6° hyperextension (mean maximum knee extension) compared with non-tuned AFO-FC.

Chapter 4: AFO-FC tuning: An investigation into common clinical practice in the United Kingdom

4.1 Aim of the research

- To identify what knowledge Orthotists in the United Kingdom (UK) have regarding the key principles of AFO-FC tuning and to scope the current practice amongst UK Orthotists with regards to AFO-FC tuning.
- To identify any factors which prevent clinicians from using AFO-FC tuning as routine clinical practice.

4.2 Clinical relevance

The available literature indicates a potential benefit of AFO-FC tuning; best practice statements suggest it should be standard clinical practice. There is no research available which shows how prevalent AFO-FC tuning is in the UK and any potential barriers to practice. Identifying such obstacles will inform and improve clinical practice.

4.3 Method

A questionnaire was devised (see appendix 12.1) which included both closed and open ended questions, to investigate current knowledge and clinical practice of tuning AFO-FCs in the UK. The questionnaire was sent via post, email and issued in person to approximately 150 Orthotists. The questionnaire was also uploaded onto the British Association of Prosthetists and Orthotists' (BAPO) website where BAPO members could easily access it. BAPO at the time of writing this manuscript had 333 members who stipulated their practice includes orthotics.

4.4 Participants

The intended target population was UK registered Orthotists currently working for a commercial company or in private practice. Due to the nature of ethical approval, the NHS employees could only answer in their capacity as a private practitioner. Since Orthotists are the main group of professionals responsible for the assessment, design and issue of AFOs they were deemed the most appropriate participants for this study. The Health and Care Professions Council (HCPC), with which all practising Orthotists must be registered, reported there were 890 registered Prosthetists/Orthotists in the UK as of May 2012(197), of which it is estimated approximately 55% are practising Orthotists. The total number of Orthotists who completed the questionnaire was 41. This represents approximately 9% of the target population.

Although this questionnaire was not validated by any previous studies, the authors are either experienced clinicians or researchers, and it was felt these questions were appropriate after initial discussions between the authors and the extended clinical group, where the authors are affiliated. The questions covered a wide range of issues relating to the prescription and the use of AFO-FC tuning.

4.5 Results

The results of this study are detailed in table 4.1. A total of 95% of participants stated they understood AFO-FC tuning, but their responses to individual questions indicate that this may not be the case due to their inability to name the contraindications of tuning. As indicated earlier, to successfully tune an AFO-FC, one needs to consider (1) the design of AFO and AAAFO (2) the physical characteristics of the patient and (3) The SVA. From the results, it is indicated that the participants do not understand these principals, although they reported they did.

Some of the headline results indicate that 87% of the participants tune by visual inspection alone. Only 50% of participants report they use tuning as standard clinical practice. Furthermore, there was confusion about how participants were deciding who would be a candidate for AFO-FC tuning, with 49% reporting they follow set criteria, 46% reporting they tune all the AFO-FCs they prescribe and 42% stating it depends on whether they have enough time. Similar issues are highlighted in table 4.1.

The most prevalent factor stated for not tuning routinely was a lack of access to 3D gait analysis, the second most prevalent reason (27%) was a lack of time. 49% of participants reported they do not take the design of the AFO into consideration when deciding to tune the AFO-FC. Furthermore, 26% state they also don’t take the physical characteristics of the patient into account when choosing to tune their AFO-FCs.

4.6 Discussion

AFO-FC tuning is an essential aspect of clinical treatment when prescribing AFOs. Therefore it vital that the prescribing clinician has the knowledge and skills to carry out the tuning process, to prevent issuing a sub-optimal AFO-FC, which may have an immediate detrimental effect on function, and in the longer term potentially contribute to deterioration.

The results of the questionnaire show that all participants of this study were aware of AFO-FC tuning, of which only 5% reported that they did not fully understand the theory and process. However, 50% of the participants said that they do not use tuning as standard practice on their patients, as shown in table 4.1. When asked to state which factors are preventing them using tuning, the most prevalent reason stated (34%) was a lack of access to 3D gait analysis, although 3D gait analysis is not essential to successfully tune AFO-FCs. Other methods of augmented gait assessment have been recommended as being suitable; they include video recording to enable slow motion and freeze frame qualitative kinematic analysis and 2D video vector systems, to allow a combination of qualitative kinematic and kinetic analysis(8). The second most prevalent response (27%) was because respondents felt tuning was too time-consuming, as shown in figure 4.5.1. Indicating that there is a need to simplify the tuning process described within the current published and unpublished literature.

The majority (51%), stated they do not have a set criterion for deciding who would benefit from tuning, of the 49% of participants who do have a set criteria, the ability to ambulate was the most common (33%) criteria used, as shown in figure 4.5.2. Indicating a lack of understanding of the process and aims of AFO-FC tuning, as tuning is indicated for walking, stepping and standing(198).

Although 49% of participants indicated they had a set criterion when deciding who would benefit from tuning, 46% stated they tune all the AFO-FCs they prescribed and in the following question, 42% indicated time was the deciding factor. Suggesting possible confusion regarding how the participants are deciding to tune AFO-FCs.

Previous research has stated that the design of the AFO and the AAAFO are crucial elements of successful tuning and if the angle of the AFO does not correctly accommodate the length of the patient's gastrocnemius, optimum AFO-FC tuning will not be possible(36,48,118). However, 49% of participants stated they do not take the design of the AFO into account when deciding on tuning. Of the 51% who reported they do take the design of the AFO into account, only one participant correctly identified inadequate stiffness, incorrect AAAFO and a hinged AFO as being factors which would prevent successful tuning.

Previous research states there are clear physical presentations which will limit the success of tuning(36,98,149). However, 26% of respondents reported they do not take the physical ability of the patient into account when deciding whether to tune an AFO-FC. Of the respondents who indicated they do take physical ability into account, the most common physical presentation which was identified as being the factor which would prevent tuning of an AFO-FC was an inability to ambulate (18%). The majority (54%) of responses named physical characteristics which have not been identified in current literature as preventing successful AFO-FC tuning, with 94% of participants failing to name all four physical characteristics identified in research as being potential limiting factors of successful tuning.

As shown in figure 4.5.3, all respondents were qualified Orthotists, the majority (41%) had 1-5 years post graduate experience in orthotics. When asked about the exact methodology they employ to tune AFO-FCs, 87% of participants stated they tune by eye alone and don't use any other method of gait assessment. However, it has been suggested that for a successful tuning, it is necessary to utilise some form of augmentative clinical gait assessment.

Whilst it was not the intention of this preliminary study to focus on the international clinical practice, the results from the UK highlight a clear need for further training which could be reflected within the professional practice in other countries. One of the limitations of this study could be that it represents only 9% of the practising orthotists, which could be attributed to the recruitment method. However, the results indicate that there is a substantial need to conduct such a study in other countries and develop a consensus regarding processes and procedures related to AFO-FC tuning.

4.7 Summary

The results of the study indicate an apparent lack of understanding regarding the key principles of AFO-FC tuning amongst the UK Orthotists who participated in this study. Whilst the majority of participants stated that they understood the principles behind tuning, the subsequent questions revealed their limited knowledge.

AFO-FC tuning is not yet standard clinical practice amongst the UK Orthotists who participated in this study, the main reasons cited were; a lack of access to 3D gait analysis and a lack of time. However, the study also seems to indicate that the tuning principles are not well understood. 3D gait analysis is not essential to tune AFO-FCs, the design of the AFO, the AAAFO and the physical presentation of the patient are crucial factors of tuning. However, the most prevalent element identified as being essential to tuning by participants, was the patient's ability to ambulate. Furthermore, of all responses (n=41) the number of participants who named all the contraindications to AFO-FC tuning was one.

The majority of participants who took part in this study were relatively newly qualified; this may indicate a need to expand training on tuning in the current undergraduate programs or as a part of post-graduate curriculum.

Whilst one could argue that some of the questions relate to the individual's interpretation of AFO-FC tuning, as it is possible that participants may have been using their own understanding and definition of tuning and not that of which is in the literature, as the definition is yet to be standardised. In the authors' opinion it directly links to the participant's knowledge regarding tuning. The authors also recognise that this study has a relatively small subject group and this may have a bearing on the results.

However, this study may indicate one crucial reason why AFO-FC tuning is not yet standard clinical practice, in that the underlying principles are not fully understood by clinicians. Possibly due to a lack of access to AFO-FC tuning at both undergraduate and postgraduate level and the process of AFO-FC tuning may need to be simplified in the literature and made more accessible and easily understood.

This study provides an important insight into standard clinical practice amongst the clinicians who participated in this research and potentially highlights important reasons why AFO-FC tuning is not standard clinical practice. There is no other available research into the prevalence of tuning amongst UK Orthotists in the current literature for which to compare the results of this study.

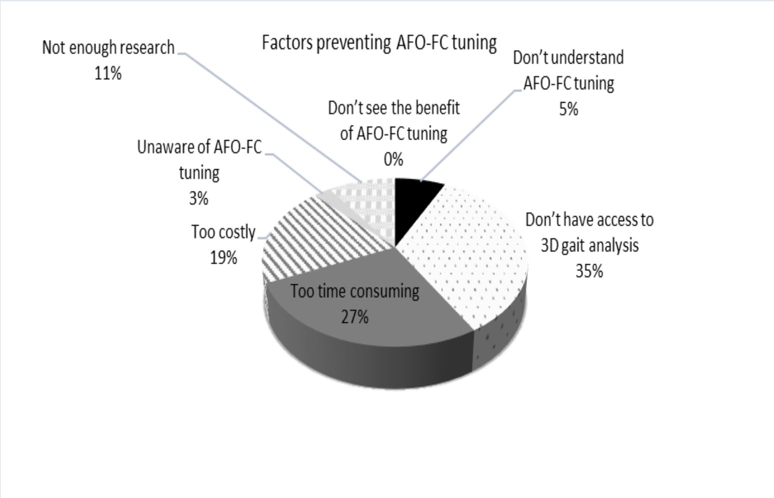


Figure 4.5.1: Factors preventing orthotists using AFO-FC tuning.

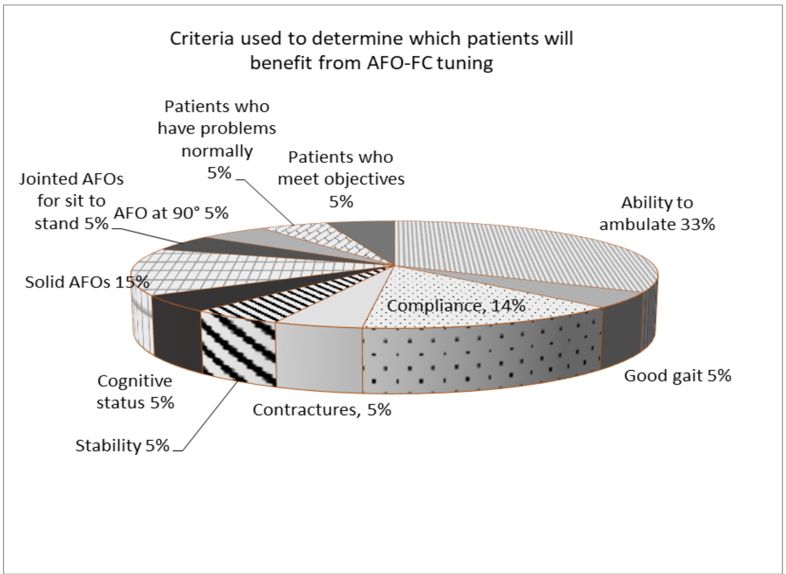


Figure 4.5.2: Criteria used to determine which patients will benefit from AFO-FC tuning

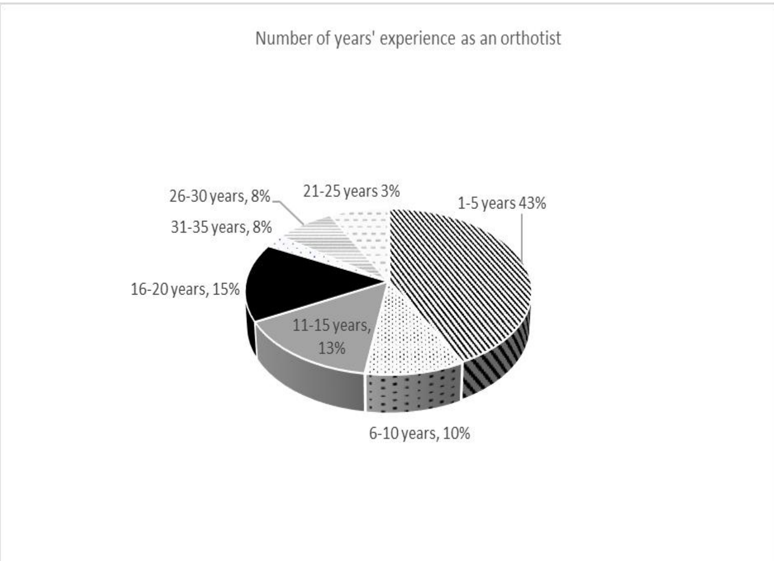


Figure 4.5.3: Number of years' clinical experience of participants

Table 4.1: Results from the questionnaire on AFO-FC tuning, issued to UK orthotists.

Question	Response Item	Frequency	Percentage
Question 1: Are you aware of AFO-FC tuning?	Yes	41	100%
	No	0	0%
	Total Responses	**41**	**100%**
Question 2: Do you fully understand AFO-FC tuning?	Yes	39	95%
	No	2	5%
	Total Responses	41	100%
Question 3: Do you use AFO-FC tuning as standard practice on all patients who are prescribed with an AFO?	Yes	20	50%
	No	20	50%
	Total Responses	**40**	**100%**
Question 4: If No, what is preventing you from using AFO-FC tuning?	I Don't fully understand it	3	7%
	I Don't have access to 3D	14	34%
	It's too Tim- consuming	11	27%
	It's Too costly	8	20%
	I'm unaware of AFO-FC tuning	1	2%
	There's not enough quality research	4	10%
	Tried it but didn't see any benefit	0	0%
	Total Responses	**41**	**100%**
Question 5: How do you decide which patients will benefit from AFO-FC tuning?			
A) I have a set criteria	Yes	18	49%
	No	19	51%
	Total responses	**37**	**100%**
B) If yes Name set criteria (open ended question)	Ability to ambulate	7	33%
	Good gait pattern	1	5%
	Compliance	3	14%
	Contractures	1	5%
	Stability	1	5%

	Cognitive status	1	5%
	All patients with a solid AFO	3	14%
	Consider Jointed AFOs when patient does a lot of sit to standing	1	5%
	Angle of AFO is set at 90°	1	5%
	Patients who have problems normally	1	5%
	Patients who meet objectives	1	5%
	Total Responses	**21**	**100%**
C) I tune all patients who are prescribed with an AFO	Yes	17	46%
	No	20	54%
	Total Responses	**37**	**100%**
D) It depends whether I have enough time	Yes	15	42%
	No	21	58%
	Total Responses	**36**	**100%**
Question 6: Do you use 3D gait analysis to tune AFO-FC's?	Yes	6	17%
	No	30	83%
	Total Responses	**36**	**100%**
Question 6.1 Do you use Video analysis?	Yes	17	46%
	No	20	54%
	Total Responses	**37**	**100%**
Question 6.2 Do you tune by eye alone?	Yes	33	87%
	No	5	13%
	Total Number of responses	**38**	**100%**
Question 6.3 Do you use any other method? (open-ended question)	2D gait analysis	2	29%
	Static Goniometers	2	29%
	Scan force plate	1	14%
	Line of progression	1	14%
	Timing	1	14%
	Total number of responses	**7**	**100%**
Question 7: Do you take AFO design into consideration when deciding whether to tune an AFO-FC?	Yes	20	51%
	No	19	49%

	Total responses	**39**	**100%**
Question 7.1: If yes, please state the design criteria which would prevent you from tuning the AFO-FC? (open-ended question)	Angle of AFO	1	6%
	Hinged	5	28%
	Fixed	1	6%
	PLS AFO	4	22%
	Flexible AFO	4	22%
	Inadequate AFO stiffness	1	6%
	Inadequate AAAFO	1	6%
	Inadequate AFO	1	6%
	Total Number of Responses	**18**	**100%**
Question 8: Do you take physical ability of the patient into account when deciding whether the AFO-FC should be tuned?	Yes	29	74%
	No	10	26%
	Total number of responses	**39**	**100%**
Question 8.1: If yes, please state physical criteria which would prevent you from tuning an AFO-FC (open-ended question)	Significant hip contractures	4	10%
	Hip adduction	1	3%
	High tone	1	3%
	Quad weakness	3	8%
	Non ambulant	7	18%
	Gross knee instability	1	3%
	Offloading a forefoot ulcer	1	3%
	Patient has dorsi-flexion	1	3%
	Blindness	1	3%
	Ataxia	1	3%
	Significant knee contractures	4	10%
	Significant rotational deformity	2	5%
	Athetosis	1	3%
	Dyskinsea	1	3%
	When tuning one segment adversely affects another segment	2	5%
	Instability	5	13%
	Plantar flexion contracture of 12-15°	1	3%
	Bilateral need for AFOs	1	3%
	Significant contractures	2	5%
	Total number of responses	**40**	**100%**

Chapter 5: Methods – Instrumentation, materials and study protocols

In this project kinetics and kinematics of gait, energy expenditure and measurement of the SVA were primarily investigated to conclude how the biomechanical optimisation of AFO-FCs can affect children with CP. Thus, kinetic and kinematic data, the SVA statically and dynamically and the energy expenditure during gait, were measured. Data collection was carried out in one laboratory – at Staffordshire University. This chapter outlines all methods and protocols used in the primary study, to date, there has been one paper published from the primary research(199).

5.1 Kinematic data acquisition

Kinematic data was collected using the VICON motion analysis system (Oxford Metrics Ltd., Oxford, UK). The VICON motion analysis system is a self-contained, computerised system with hardware and software components that provide a clinically validated solution for gait analysis.

Vicon's systems are the most accurate on the market(200). From 1.3-16 megapixels, every Vicon optical camera captures highly detailed grayscale information, which helps the system define the centre of each marker to sub-millimetre accuracy. Fully calibrated and synchronised high definition video overlay is delivered in Nexus with Vicon's dynamic video calibration(200).

Hardware includes: camera units, Vicon data station, personal computer, calibration wand and markers

Software includes: Vicon workstation software and Vicon body builder software

5.2 Camera units

An 18 camera optoelectronic motion analysis system (Vicon, Oxford, UK) was utilised (see figure 5.2.1).

Figure 5.2.1: opto electronic motion analysis camera

5.3 Set up of the laboratory

The area was a dedicated thermostatically controlled gait laboratory with a figure of 8 track to ensure walking was continuous with no abrupt turns. The walkway measured 30.5 metres in total (see figure 5.3.1). Its design also precluded bias to the same leg on corners by balancing the number of left and right turns. Two sets of timing gates were set up on the walkway to measure the participant's speed and distance (see figure 5.3.2).

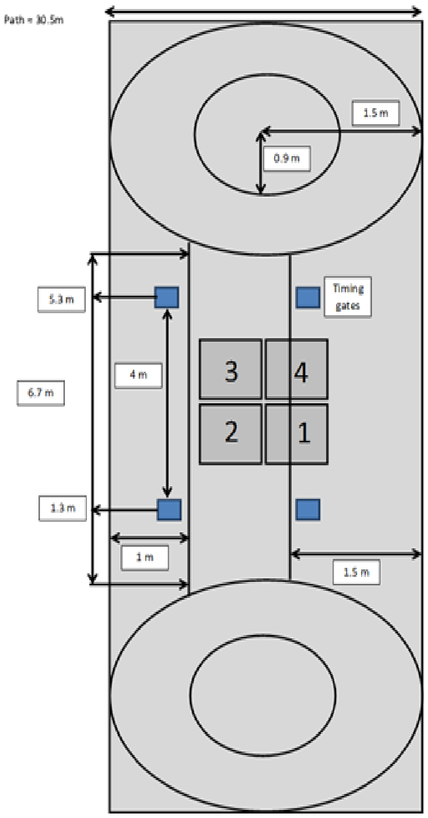


Figure 5.3.1: Diagram of the layout of the walk way

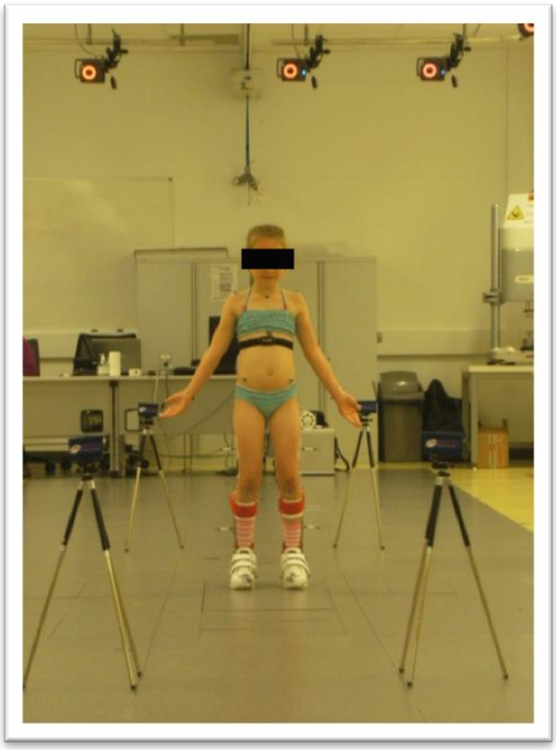


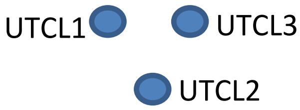
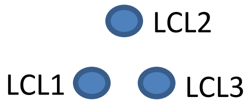
Figure 5.3.2: Timing gates

5.4 Marker set up

There are several marker sets which can be used for gait analysis; they differ in relation to the number of markers they use and the positioning of those markers on the participant's body. For this study, the Plug-in-Gait (P.I.G) model(201,202), which is a modified version of the Helen Hayes model(201,203), was used for the lower limbs. In addition, a custom trunk model was used incorporating the P.I.G model for the thorax (C7 to T10) and a custom cluster at T3 and L3. The ISB (International Society of Biomechanics) model(204) was used for the upper limbs. The medial knee and medial malleolus markers were used for static model processing but removed for dynamic trials as they often fall off during gait. The six degrees-of-freedom model was created using bodybuilder software (Vicon Motion Systems, Oxford, and UK). Marker positions from the static trial were used to define joint centres.

The term "marker" refers to spheres with a retro-reflective outer material. This study used markers which were 9.5mm in diameter (see figure 5.4.1). The markers were attached to the participant's body using double-sided tape. A total of 52 markers, four wands and two clusters were used in this study. See table 5.1 for details of the position of each marker, see figures 5.4.2- 5.4.8 for position of the markers on the participant, and see figures 5.4.9 for how the markers were represented in the Vicon Nexus software. For detailed information on the placement of the P.I.G markers, see appendix 12.2.

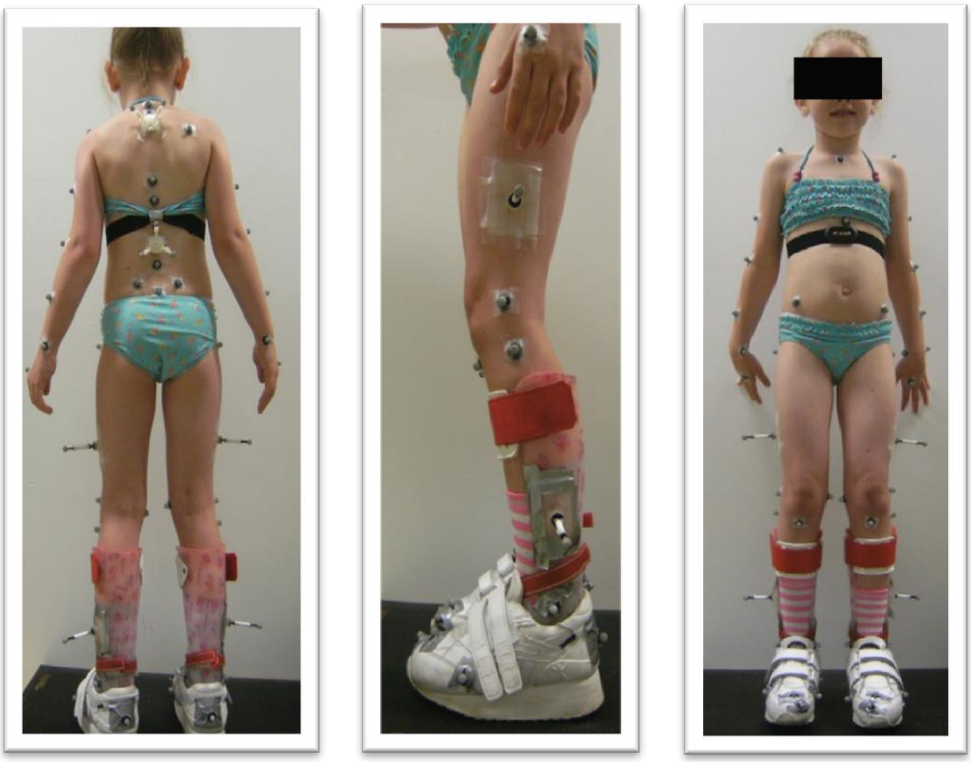
Figure 5.4.1: Example of retro-reflective marker

Torso (9 markers + 2 clusters)	
1) C7	7th Cervical Vertebrae
2) T2	2nd Thoracic Vertebrae
3) T3 (**CLUSTER**)	3rd Thoracic Vertebrae 
4) MAI (approx. T8)	midpoint between the inferior angles of most caudal points of the two scapulae
5) T10	10th Thoracic Vertebrae
6) L1	1st Lumbar Vertebrae
7) L3 (**CLUSTER**)	3rd Lumbar Vertebrae 
8) L5	5th Lumbar Vertebrae
9) CLAV	Clavicle (Jugular notch where the clavicles meet the sternum)
10) STRN	Sternum (Xiphoid process of the Sternum)
11) RBAK	Right Back (Placed in the middle of the right scapula)
Arms (7 x 2 = 14 markers)	
1) LAC/RAC	Left Acromion/Right Acromion (Placed on the Acromio-clavicular joint)
2) LUPA/RUPA	Left/Right Upper Arm (on the upper arm between the elbow and shoulder markers)
3) LELB/RELB	Left/Right Elbow (lateral epicondyle approximating elbow joint axis)
4) LFRA/RFRA	Left/Right Forearm (Placed on the lower arm between the wrist and elbow markers)
5) LWRA/RWRA	Left/Right wrist (thumb side)
6) LWRB/RWRB	Left/Right wrist (fifth finger side)
7) LFIN/RFIN	Left/Right Finger (On the dorsum of the hand just below the head of the second metacarpal)

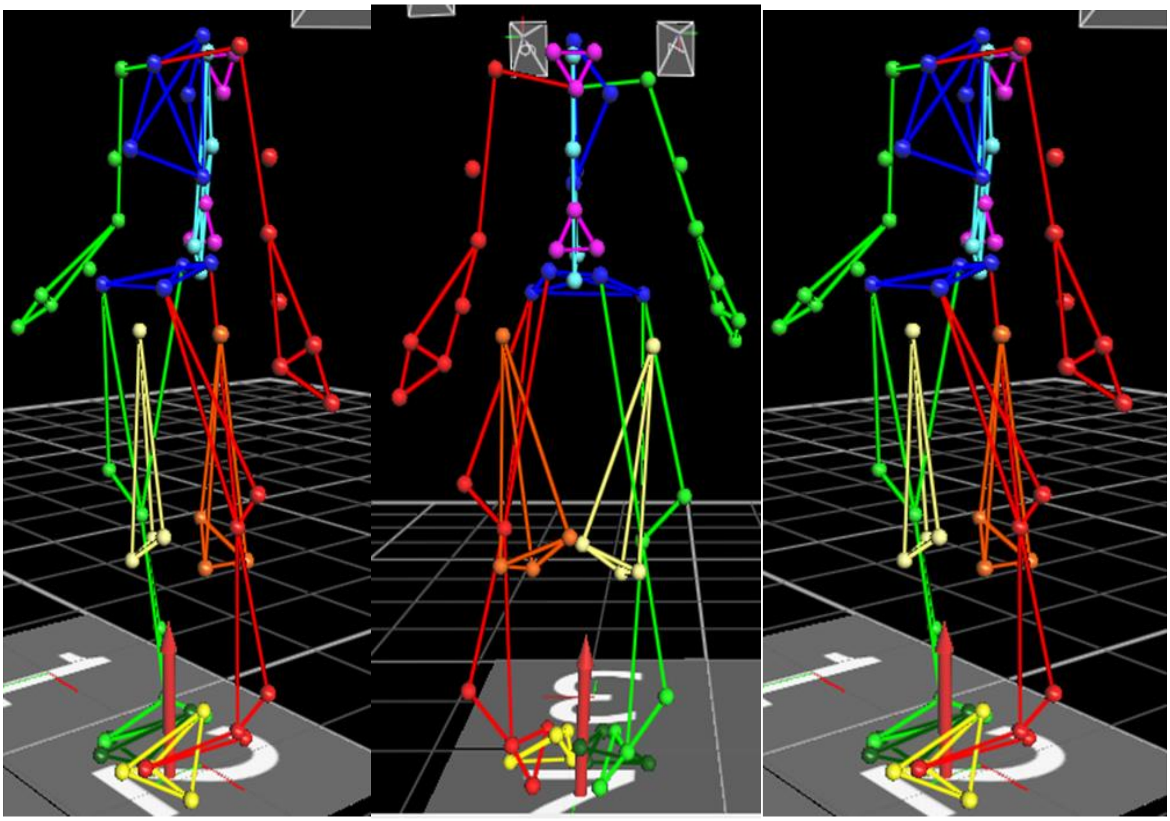
Pelvis (5 markers)	
1) LASIS/RASIS	Left/Right Anterior Superior Iliac Spine
2) LPSIS/ RPSIS	Left/Right Posterior Superior Iliac Spine
3) SACR	Sacrum (not in line with LPSI and RPSI, must be below these)
Legs (12 x 2 = 24 markers + 4 wands)	
1) LGTR/RGTR	Left/Right Greater Trochanter (lateral prominence)
2) LTHI/RTHI (WAND)	Left/Right Thigh (lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical)
3) LLKN/RLKN	Left/Right Knee (lateral epicondyle)
4) LHF/RHF	Left/Right Head of the Fibula (Proximal tip)
5) LTT/RTT	Left/Right Tibial Tuberosity (most anterior border)
6) LMKN/RMKN (calibration only)	Left/Right Knee (medial epicondyle)
7) LTIB/RTIB (WAND)	Left/Right Tibia (lower 1/3 of the shank)
8) LLM/RMM	Left/Right Ankle (lateral malleolus)
9) LCA/RCA	Left/Right Calcaneus (On the calcaneus at the same height above the plantar surface of the foot as the toe marker)
10) LSM/RSM	Left/Right 2nd Metatarsal Head (dorsal aspect)
11) LMM/RMM (calibration only)	Left/Right Ankle (medial malleolus)
12) LFM/RFM	Left /Right First Metatarsal Head (dorsal margin)
13) LVM/RVM	Left/Right Fifth Metatarsal Head (dorsal margin)
14) LPM/RPM	Left/Right Proximal Phalanx of the Hallux (most distal and dorsal point of the head)

Table 5.1: marker set up

Figures 5.4.2– 5.4.5 Example of marker set up on the participant, with no AFOs



Figures 5.4.6 – 5.4.8: Example of marker system on the participant, with AFOs and footwear.



Anterior View Posterior View Lateral View

Figure 5.4.9: Marker set up on Vicon Nexus

5.5 Calibration

Calibration is an essential aspect of data collection. Dynamic and static calibration was carried out prior to each session of data collection, using the required triangular frame and T-Cal wand.

5.6 Force measurement system

Ground reaction forces were recorded using four force plates (model AMTI Optima OPT464508HF), sampled at 1080Hz, embedded into the walkway (see figure 5.6.1). Each force plate measured 464mm × 508mm × 82.5mm (width × length × height) and can be adjusted for stride length. Consecutive force plate strikes of the left and right foot were acquired where possible.

The force plates measure both the force and moment components in X, Y and Z axes. The force plates follow a right-hand rule co-ordinate system; which means that the positive Z-axis is oriented upwards, the positive Y-axis is oriented to the right, and the positive X-axis anteriorly (see figure 5.6.2).

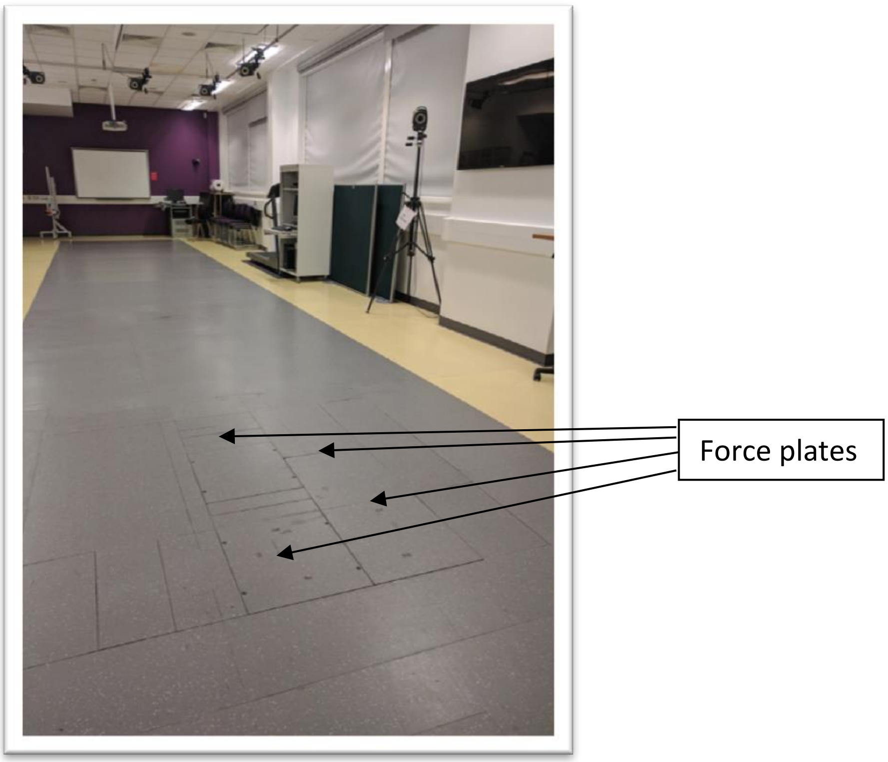


Figure 5.6.1: The force plate arrangement

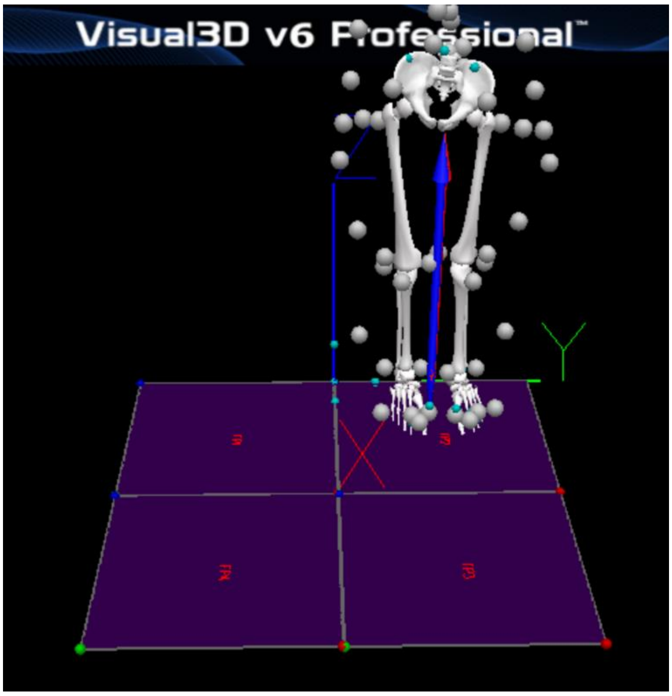


Figure 5.6.2: Laboratory co-ordinate system

5.7 Measurement of VO_2

A portable gas analyser system (3B Metamax® cortex, Germany) was used to measure oxygen uptake, see figure 5.7.1. The 3B MetaMax® is a portable cardiopulmonary exercise system (CPX) for pulmonary gas exchange measurements. During a CPX test with 3B MetaMax®, the participant wears a small facemask, breathing out through a volume transducer fixed to the facemask, which measures volume continuously and simultaneously determines expired CO_2 and O_2 concentration and thus energy expenditure can be estimated from this. From these recordings the caloric uptake can also be determined via the ratio of VCO_2 to VO_2, defined as the respiratory exchange ratio [RER]). The equipment was calibrated before each participant was tested.

Figure 5.7.1: The 3B Metamax® cortex

Participants also wore a gas analyser mask and heart rate monitor (model Polar FT2 heart rate monitor watch and Polar H1 heart rate sensor set) around their chest (see figure 5.7.2).

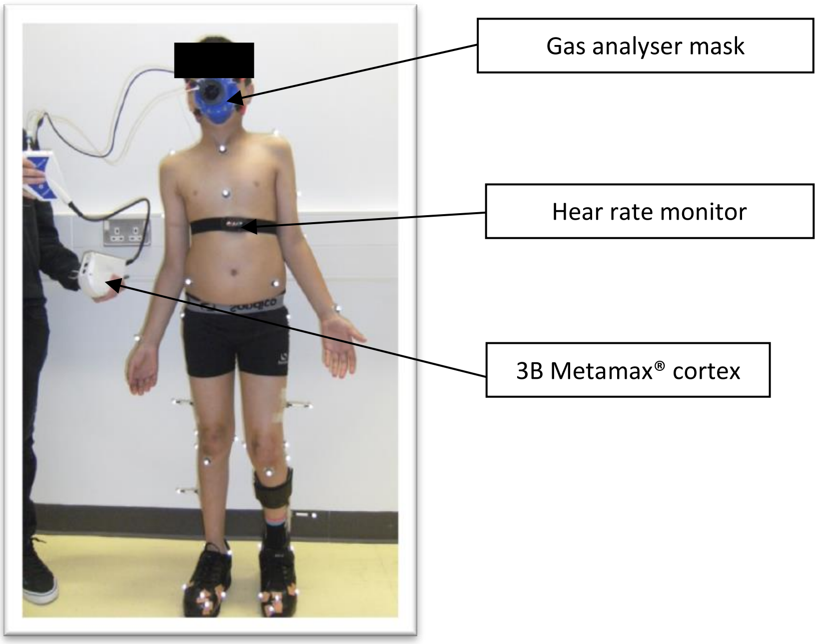


Figure 5.7.2: A participant wearing the gas analyser mask and heart rate monitor

5.8 AFOs

Each participant was assessed by an experienced orthotist and prescribed with a bespoke solid homo polypropylene AFO. The AFOs (see figure 5.8.1 and 5.8.2 for an example of the solid AFOs used) used in this study were deemed appropriate for each participant on an individual basis and ensured there was no visible movement of the AFO regarding deformation during stance phase. (See table 5.2 for AFO design details). The term "Solid" AFO in this research means the AFO blocked movement in the ankle in all three planes with no deformation of the AFO in stance phase.

The trim-lines at the ankle finished anterior to the malleoli. The height of each AFO finished 30mm below the fibula head. All the footplates were full length. The AAAFO was determined by an examination of the passive length of gastrocnemius with the knee extended, using a goniometer. If required the AFO had the addition of a shank angle to bench (SAB) build up (see figure 5.8.1) to ensure the resulting AFO captured the length of gastrocnemius but was then set at 90°. All participants were issued with the same over splint footwear (see figure 5.8.3) in either black or white (Blacky style; Salts healthcare), which had a heel-to-sole differential of 8mm before any adaptations were added.

Figure 5.8.1: Example of a solid AFO used, with SAB build up. Cast in plantarflexion.

Figure 5.8.2: Anterior view of a solid AFO

Figure 5.3: Example of unmodified over splint footwear used

5.9 Tuning materials

Temporary tuning wedges and point loading rockers (PLR) were used to tune the AFO-FCs in this study, following Owen's(159) algorithm, to determine the optimum SVA. The wedges were custom made by an experienced technician, the material used was high-density Ethyl Vinyl Acetate (EVA) (see figure 5.9.1). Wedges start at the posterior heel and terminate at the MTPJs. Length of the wedge and the height determine the resultant wedge angle. Wedges ranged from 2°, 4°, 6°, 7°, 8°, 10°, 12° and 15°.

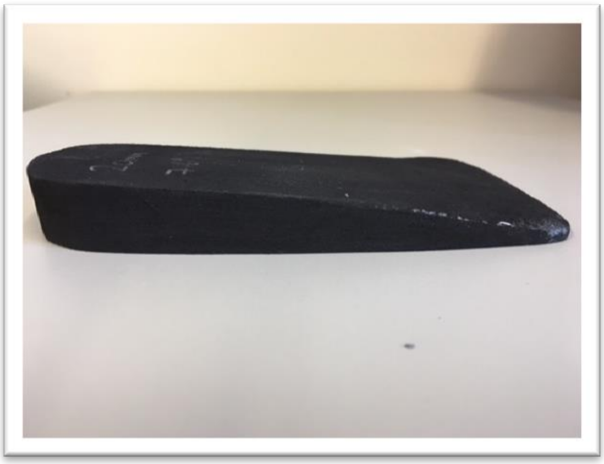


Figure 5.9.1: An EVA tuning wedge.

Temporary PLRs were made from high density plasterzote (see figure 5.9.2). The PLR was positioned at 75% - 80% the length of the footwear with a toe spring angle (TSA) of 30° then adjusted until gait was optimum.

Figure 5.9.2: A temporary point loading rocker in plasterzote.

5.10 Participants

Five children aged between 7-11 years with a diagnosis of spastic CP and a gross motor function classification system (GMFCS) of two, as determined by an experienced paediatric physiotherapist, took part in this study. All participants were long-term AFO users (long-term is defined as having worn an AFO for five years or more).

5.11 Inclusion exclusion criteria

INCLUSION CRITERIA

- Independent ambulators.
- The participant must already wear either unilateral or bilateral AFOs; there is no time limit on how long the participant has been wearing AFOs.
- The participant must be deemed to be GMFCS one or two.
- Aged between 5 – 11 years old.
- Informed consent received.

EXCLUSION CRITERIA

- Excessive contractures at the hip or knee (more than 25°).
- Excessively exaggerated stretch reflex.
- Excessive foot progression angle.
- Any orthopaedic surgery or medical intervention which may influence mobility, in the last six months
- Planned surgery.

Gender was not considered in the recruitment process. All participants underwent an assessment of maturity status. The criteria for the participant to be independently ambulant without excessive knee and hip flexion contractures will limit the level of disability of the participants included. A gross motor function classification system evaluation was performed on all participants by a qualified paediatric physiotherapist.

5.12 Ethics and consent

This study was granted ethical approval by the National Research Ethics Service (NRES), Ethics Committee West Midlands South Birmingham (Ref: 12/WM/0378), The Royal Wolverhampton NHS Trust Research (Ref: 12PAE06) and Development Directorate and a local University Ethics Committee. Parents/guardian provided written informed consent and the child's verbal assent prior to inclusion in the study (see appendix 12.3 and 12.4 and consent forms).

5.13 Recruitment procedure

All participants were recruited from the author's paediatric orthotic clinic. All children with CP who met the inclusion criteria, set out in this study, were invited to take part in the study. An information sheet was given to the participant and their parent/guardian (see appendix 12.5 and 12.6 for information sheets). All participants were given a minimum of 24 hours to read the information sheets and ask any questions before committing to take part in the study.

5.14 Study design

Within-subjects design – case series analysis approach was chosen based on the underlying premise that identification of the sources of individual variation in treatment responses is a critical next step towards advancing evidence-based practice in rehabilitation for children with CP(10), rather than the use of mean group differences which does not imply that this intervention was effective for each study participant or ensure positive outcomes for all with CP(10).

The objectives of the research were addressed through various sections of the proposed research; some parts of which were questionnaire based. The experimental aspects were carried out simultaneously.

5.15 Testing procedure

Visit One: The Royal Wolverhampton NHS Trust

All participants visited the orthotic clinic at the Royal Wolverhampton NHS Trust to undergo a full lower limb physical assessment with an experienced orthotist and paediatric physiotherapist (See appendix 12.7 for participant physical assessment form).

The baseline physical examination involved the assessment of passive range of motion (PROM), muscle strength, muscle tone and leg length discrepancy. For muscle strength, manual muscle testing was carried out using Oxford scale(205). Muscles were scored for strength, ranging from zero to five. Muscle tone was examined using the Modified Ashworth Scale (MAS)(206), in which muscle tone was scored between zero and five. The spine was examined for any visible deformity and a full medical history was taken.

Each child was classified using the GMFCS(20). (See table 5.3 for participant anthropometrics). The children who met the inclusion criteria had their gait assessed in clinic and were then cast for an AFO (see table 5.2 for individual participant AFO prescriptions) based on their individual clinical needs.

Participant ID	**CP Classification**	**GMFCS**	**Sex**	**Body Mass (kg)**	**Age (Years)**	**Stature (cm)**	**Passive length of gastrocnemius with knee extended**	**Barefoot gait classification**
1	Spastic hemiplegic right side affected	2	F	23.6	8	122	5° dorsi-flexed	Group II (Winters(23))
2	Spastic diplegic with right side predominately affected AFO right only	2	M	55.1	11	145	90°	Group IV (Winters(23))
3	Spastic diplegic AFO bilaterally	2	F	27.7	7	131	90°	Group IV (Winters(23))
4	Spastic diplegic with left side predominately affected. AFO left only.	2	M	31.6	10	140	8° plantarflexed	Group IV (Winters(23))
5	Spastic diplegic with right side predominately affected. AFO	2	M	25.8	9	131	90°	Group II (Winters(23))

	right only.								

Table 5.3 Participant anthropometrics

Participant ID	AAAFO	AFO	Material	Material Thickness	Footplate	Strapping	Optimum SVA
1	90°	Right solid AFO	Homopolymer Polypropylene	4.5mm	Full length with lateral flange distal to 5th MTPJ to control fore foot abduction. Flexible at the MTPJs to facilitate 3rd rocker. Flexible sole rounded profile.	Figure of 8 at the ankle and Velcro ring pull strap at the calf	12°
2	90°	Right Solid AFO	Homopolymer Polypropylene	5mm	Full length, M-L flanges distal to MTPJs to block 3rd rocker and limit knee flexion during stance. Sole unit stiffened with a rounded forefoot rocker.	Figure of 8 at the ankle and Velcro ring pull strap at the calf	12°
3	90°	Left and Right solid AFO	Homopolymer polypropylene	4.5mm	Full length stiffened with carbon fibre, with M-L flanges distal to MTPJs to block 3rd rocker and limit knee flexion during stance. Sole unit stiffened with a point loading rocker.	figure of 8 at the ankle and a velcro ring, ring pull at the calf	13◦
4	8° Plantar Flexion SAB 90°	Left Solid AFO	Homopolymer Polypropylene	4.5mm	Full length, M-L flanges distal to MTPJs to block 3rd rocker and limit knee flexion. Sole unit stiffened with a forefoot rounded rocker.	Figure of 8 at the ankle and Velcro ring pull strap at the calf	13°
5	90°	Right solid AFO	Homopolymer Polypropylene	4.5mm	Full length, M-L flanges proximal to MTPJs flexible to facilitate 3rd rocker. Flexible sole rounded profile.	Figure of 8 at the ankle and Velcro ring pull strap at the calf	11°

Table 5.2: Participant AFO design (AAAFO = angle of the ankle in the AFO, SVA = shank to vertical angle)

Visit Two: The Royal Wolverhampton NHS Trust

Participants attended the orthotic clinic approximately three weeks after casting, to have their AFO/s fitted by the same orthotist.

Testing took place over two days, three weeks apart at the Staffordshire University gait laboratory: Room temperature and time of testing were kept constant on both testing days to control for time-of-day effects. Day one consisted of barefoot and non-tuned AFO-FC trials and day two consisted of tuned trials. Participants were issued with their non-tuned AFO-FC three weeks before visit one, to enable them to acclimatise to the AFO-FC.

Visit Three: Barefoot and Non-tuned AFO-FC Staffordshire University

Participants were restricted from eating for two hours before the start of the trial, sipping water was permitted. Before testing commenced, participants had a series of anatomical measures taken, to provide information for data processing (see appendix 12.8 for participant trial information sheet). Retro-reflective markers were then placed on the lower and upper limbs and the spine, to capture kinetics and kinematics of gait. Each participant was fitted with the gas analyser and a heart rate monitor (see figure 5.7.2).

Once fitted with the equipment, each participant was given a 20 minute habituation period to allow familiarisation with the testing area, equipment and procedure. Following this, there was a rest period of 30 minutes to allow the heart rate to return to approximately pre-exercise levels. The order of testing for barefoot and non-tuned conditions was randomised.

Testing commenced with each participant sitting for two minutes prior to walking, to establish baseline heart rate and oxygen consumption data. The participant was asked to walk at a self-selected speed, around the track for 3 x 4-minute trials, resting (supported sitting) for eight minutes in-between trials. Each trial commenced once the participant's heart rate was 100 beats per minute or less.

The Metamax equipment was held by the researcher who walked beside the participant to ensure the extra weight of the equipment didn't impede the participant's gait, as such equipment can potentially distort performance(207). The researcher holding the equipment also wore the heart rate monitor watch and was prompted every 60 seconds by the second researcher, to read aloud the participant's heart rate, this was recorded by the second researcher on the dedicated information sheet (see appendix 12.9 for the heart rate recording sheet).

It was deemed essential to allow the participant to walk at a self-selected speed to ensure speed and distance could be compared between conditions. During testing a third researcher recorded the time of each full lap of the walkway in conjunction with the timing gates (see appendix 12.10 for the timing gate recording sheets) and also recorded whether the participant contacted the force plate or not (see appendix 12.11 for the force plate recording sheet). There was a 60 minute rest period between conditions.

The second condition (barefoot or non-tuned AFO-FC) was carried out on the same day, following the same protocol.

At the end of the testing period on visit three, each participant had their AFO-FC tuned by an experienced orthotist, by eye and then again using 2D video vector analysis, to establish the optimum SVA. The tuning process followed Owen's(159) algorithm. Non-tuned in this study means the AFO-FC was not set to an optimum SVA and the footwear was not adapted to optimise entry and exit from mid-stance. However, it was deemed unethical to supply the participants with an AFO, which did not have the correct angle of the ankle in the AFO (AAAFO) to represent the length of gastrocnemius, as doing so may have caused the participant pain and put them at risk of a pressure sore. Temporary wedges and where necessary point loading rockers (PLR), were added to the sole of the footwear via masking tape until the optimum SVA was determined.

Once the SVA was determined, the footwear was then sent for permanent modification (see figure 5.15.1-5.15.3). Participants were given the tuned AFO-FC to take home and acclimatise to, for three weeks before testing.

Figure 5.15.1 – 5.15.3: Examples of tuned AFO-FC

Visit Four: Tuned AFO-FC trials Staffordshire University

Participants followed the same protocol as visit three, this time wearing tuned AFO-FC. See appendix 12.12 for study procedure flow chart.

5.16 Data acquisition

Data recording using the force plates, cameras, Metamax cortex, timing gates and heart rate monitor was commenced simultaneously, recording throughout in parallel.

5.17 Data analysis

The kinetic and kinematic data were analysed using Visual 3D software.

5.18 Data processing

Marker trajectories of one static and 3 x 4-minute walking trials for each condition, at a self-selected speed, were collected at 100Hz. Ground reaction forces were simultaneously acquired at 1000Hz using four force platforms. Vicon Nexus 2.5 (Vicon Motion Systems, Oxford, UK) was used to label and filter marker trajectories and filter force plate data, with filters being a Butterworth 4th order zero-lag dual-pass, low pass filter with a cut-off frequency of 6Hz, which is typically used for walking data(208)

Five complete gait cycles were identified for each participant, in each of the three conditions. This data was then analysed using Visual 3D software (version 6 x 64) which created a model of the data.

The mean average of the data series of five complete gait cycles, for each of the participants, were established and extracted to 51 data points. From this data, the mean and standard deviations for each participant were calculated. Further data analysis was conducted by comparing data for barefoot with non-tuned and tuned AFO-FC gait. Descriptive statistics, including means and standard deviations, were estimated for all the data points for all three conditions. Speed and distance were calculated using the full data from the 3 x 4-minute trials. A database of normal paediatric gait was used to compare the results of the data from this study(209).

Chapter 6: Shank – to – Vertical - Angle in AFOs: A comparison of Static and dynamic assessment in a series of cases

6.1 Aim of the research

- To compare the SVA measured statically with the SVA at temporal mid-stance (TMST) during gait

6.2 Clinical Relevance

AFO-FC tuning is considered an essential aspect of AFO prescriptions(36,48,95,149). The SVA is a key principle of AFO-FC tuning(36,48,91,102,118,149,159). The SVA as a parameter to evaluate tuning of AFOs has been investigated(96,155). Kerkum et al.(96) reported that the SVA is responsive to changes in heel height and reflects concomitant changes in lower limb kinetics and kinematics and thus supported the use of the SVA as a parameter to evaluate AFO-FC tuning. However, the method for determining the SVA has yet to be tested to ensure the static measurement correlates to the dynamic measurement during gait.

6.3 Method

Four participants took part in this study, case study five was excluded as he wears an AFO on the left leg and this was not captured on the static force plate via the sagittal camera.

Each participant was asked to stand on the force plate in the tuned AFO-FC with the AFO-FC sagittal to the video camera, ensuring the GRF point of application was in the middle of the foot (See figure 6.3.1). The image was recorded and uploaded onto video analysis software (Kinovea 0.8.15) to enable the angle of the SVA of the AFO-FC to be measured using Owen's(48) method; this determined the static SVA angle.

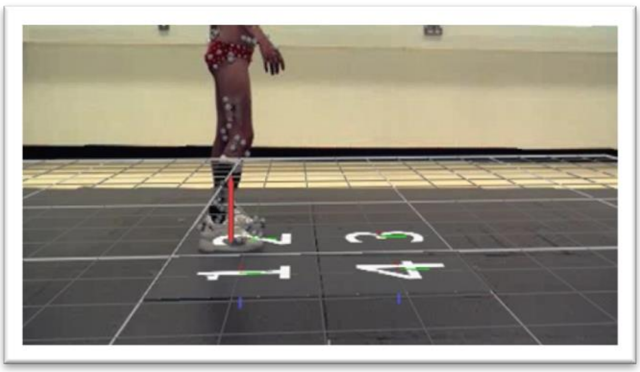


Figure 6.3.1: Particpant stood on the footplate sagittal to the camera with the GRF visible.

The gait analysis protocol included the use of two high-speed video cameras, one placed in the frontal plane and the other in the sagittal plane. The cameras enabled 2D analysis of gait and posture, in addition to sophisticated 3D analysis.

TMST was identified, as described by Gibson et al.(210) as occurring at 30% of the gait cycle. During TMST the pelvis, the trunk and the head are directly over the foot, and the GRF appears to be vertical. The knee of the swing limb can just be seen anterior to the stance limb, and the heel of the swing limb can be seen posterior to the stance limb(198). The corresponding frame of video was identified and uploaded onto the 2D analysis software, so the dynamic SVA angle could be measured using Owen's(48,118,159) method.

6.4 Results

The results of the SVA of the AFO-FC during relaxed standing and during five walking trials were measured for four participants (see table 6.1). The SVA of the AFO-FC measured whilst the participant was static correlated with the SVA measured at TMST to within 0.25°-0.4°, see figures 6.4.2 and 6.4.3 for representative illustration of the static measurement and the corresponding dynamic measurement for the same participant.

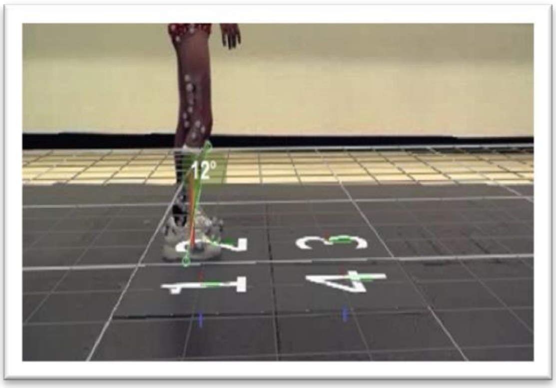


Figure 6.4.2: Case study 1 static SVA

Figure 6.4.3: Case study 1 dynamic SVA at mid-stance

Figure 6.4.4: Case study 2 static SVA

Figure 6.5.5: Case study 2 dynamic SVA at mid-stance

Figure 6.6.6: Case study 3 static SVA

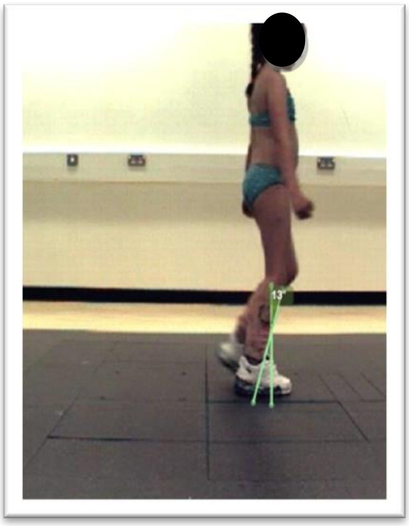


Figure 6.7.7: Case study 3 dynamic SVA at mid-stance

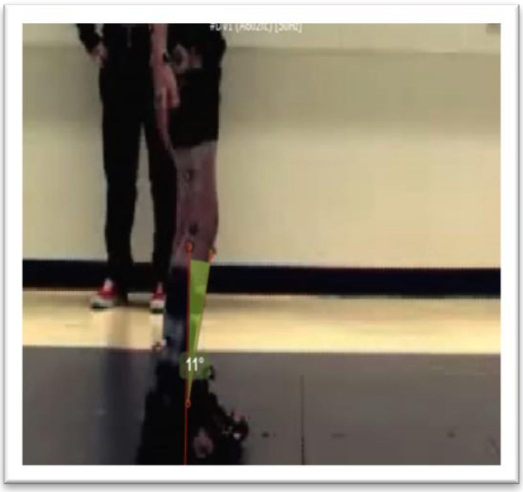


Figure 6.7.8: Case study 5 Static SVA

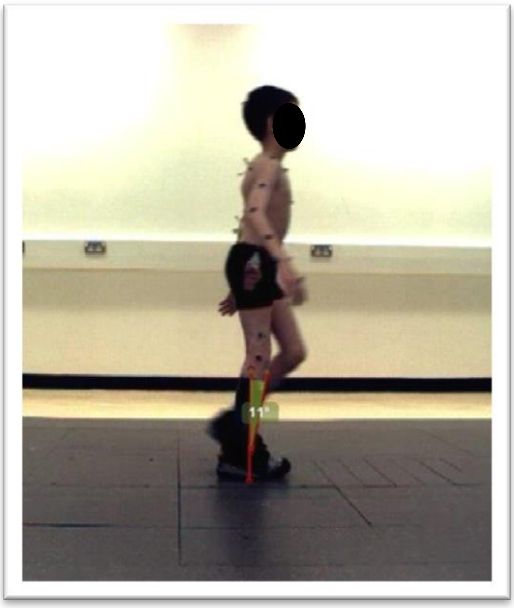


Figure 6.8.9: Case study 5 dynamic SVA at mid-stance

Participant	Static SVA (degrees)	Dynamic SVA (degrees)					Mean Dynamic SVA (degrees)	Average difference in static versus dynamic SVA (degrees)
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
1	12°	12°	10°	12°	12°	12°	11.6°	0.4°
2	12°	12°	12°	10°	12°	12°	11.6°	0.4°
3	13°	14°	13°	13°	14°	13°	13.4°	0.4°
5	11°	11°	14°	11°	11°	11°	11.6°	0.6°

Table 6.1: Static and dynamic SVA measures

6.5 Discussion

The present study demonstrates that the SVA of the AFO-FC measured statically (ISO defines static alignment as "'*Static alignment: Process whereby the bench alignment is refined while the prosthesis or orthosis is being worn by the stationary patient*"(211)) correlates to the SVA measured at TMST during gait (ISO defines dynamic alignment as *"process whereby the alignment of the prosthesis or orthosis is optimized by using observations of the movement pattern of the patie*nt"(211)). All four participants' SVA measurements statically correlated to the dynamic SVA measurement to within 0.4°– 0.6°. The results of this study support Owen's(48,198) method of measuring the SVA. This study aimed to measure the SVA statically and compare it with the SVA dynamically at TMST, ensuring ecological validity.

Whilst measuring the SVA in relaxed stance, each participant placed both lower limbs on the footplate. This method was chosen as opposed to only one foot on the footplate, to reduce the risk of distorting the participant's normal relaxed stance position and ensuring the weight was distributed evenly between both lower limbs.

The authors are aware that not all clinicians have access to 3D gait analysis equipment. Eddison et al.'(212) study on the common clinical practice of AFO-FC tuning in the UK, reported that 34% of respondents reported they don't use tuning because they don't have access to 3D gait analysis; and a further 27% said that the process is too time-consuming. Thus, the method used in this study, of uploading an image and using video analysis software to determine the SVA angle was purposely chosen to ensure the technique is clinically applicable and accessible to all clinicians. It is also important to note that the static SVA can also be measured using a simple goniometer.

Currently there is no other study in the literature which has measured the SVA at mid-stance and compared it to the SVA measured statically. Although we have not subjected the data to any detailed statistical tests due to low participant numbers, the results pave the way to design further structured studies with accepted statistical power. In addition, reported values will also inform future studies which investigate the effects of AFO-FC tuning on gait parameters.

As stated, the aim was to ensure the method used remained clinically applicable; however, there is a limitation with using video analysis software, as most of the commercially available ones measure the angle to the nearest whole degree. Another limitation of the study was the inability to ensure the participant was in the true sagittal plane to the camera during the dynamic SVA measurement. During gait it is not possible to ensure a child with pathological gait remains in the true sagittal plane at the point they pass the video camera.

Although the case series analysis shows clinical applicability, the robustness of this validity has to be established with larger participant groups. It might be possible in a research setting to overcome the limitations posed by video analysis by introducing other technologies such as Inertial Motion Sensor-based systems.

6.6 Conclusion

This study appears to indicate that measuring the SVA of the AFO-FC statically is an accurate way of determining the dynamic SVA at TMST during gait.

Chapter 7: Exploratory investigation into energy expenditure using tuned versus non-tuned ankle-foot orthoses- footwear combinations in children with cerebral palsy

7.1 Aim of the research

- To determine the effects of AFO-FC tuning on the energy expenditure of children with CP, compared to non-tuned gait.

7.2 Clinical relevance

Currently, there is no available research informing clinical practice on the potential effects of a tuned AFO-FC on the energy expenditure of children with CP. Improving the amount of energy CP children expend is a crucial aspect of orthotic treatment in order to enhance their activities of daily living.

7.3 Introduction

CP is the most common cause of physical disability affecting children in developed countries(2). A widely accepted definition of CP stresses two key factors: 1.The disorder is an injury to the immature brain and 2. It is non-progressive(1). Thus, the term CP can be used to describe a range of motor problems(9).

Children with CP commonly expend two to three times as much energy to walk as typically developing children(39,74,213,214), thereby predisposing children with CP to early fatigue.

The association between physical and neurological impairments, gait deviations and the increased energy consumption during gait in CP is not yet fully understood. However, abnormal lower limb kinematics and kinetics are considered to be key features. Common gait deviations in CP which have been associated with an increase in energy expenditure include; excessive knee flexion during stance(39,213), increased internal knee extension moments, which requires high muscle forces to ensure posture is maintained(215), reduced ankle range of motion and ankle push-off power generation. Such deviations commonly result in a reduced walking speed(46,214), subsequently increasing walking energy cost(216–218). Measuring the energy expenditure during walking provides a way to quantify the physiological strain resulting from pathological gait(219).

There is a debate as to how pathological changes in gait effect energy expenditure, Saunders, Inman and Eberhart(35) propose that a set of kinematic features help to reduce the displacement of the body's centre of mass (COM). This theory assumes that the vertical and horizontal displacements of the COM require increased energy. However, recent studies indicate that three of the determinants listed (stance phase knee flexion, pelvic rotation and fore-aft axes) may contribute very little to reducing the vertical displacement of the COM(88). Thus the "six determinants" are perhaps better described as "six kinematic features of gait"(88). Conversely, the inverted pendulum theory(86) proposes that it requires less energy for the stance limb to act like a pendulum with the COM following an arc profile. The pendulum theory also presents a dilemma in that if pendulums can swing freely, why is there an energy cost to walking?(88). The mechanical explanation of the features of pathological gait remains unresolved.

In rehabilitation, interventions which improve physical mobility by reducing energy expenditure are important treatment modalities to maintain or enhance independent functioning(46). Equivocal findings exist in the literature as to whether the intervention of an AFO can reduce the metabolic cost of walking in CP patients(47,73–76,78,79,81,82,97). Maltais et al.(75) reported no effect on heart rate or respiratory exchange ratio at slow, fast and self-selected walking speeds. Balaban et al.(76) state oxygen consumption was significantly reduced in participants only where speed was kept constant.

Mossberg et al.(78) reported that 13 subjects demonstrated a decrease in Physiological Cost Index (PCI) at self-selected speeds. Contrastingly, Buckon et al.(79) demonstrated that at self-selected speed, there were no significant changes in oxygen consumption or energy cost, however, in all three AFO interventions, self-selected speed significantly increased. Smiley et al.(73) compared the effect of three different AFO designs to shoes alone, on the energy cost at self-selected walking speeds. The measure used was the Energy Efficiency Index (EEI), no significant differences were reported.

The current literature seems to indicate that when walking speed in CP children wearing AFOs is standardised, there is a reduction in oxygen consumption, but not at self-selected walking speeds, although self-selected walking speed tends to increase. A noticeable issue with these studies is that they tended to compare different AFOs with each other, on the same subject.

Furthermore, there is no detail regarding the clinical justification for the AFO design and a dearth of information regarding the design of the AFOs used; thereby, contravening the best practice reporting guidelines for research on AFO interventions in children with CP(107).

Tuning of an AFO-FC has demonstrated improvements in the kinetics and kinematics of pathological gait(37,91,93,220), in particular, knee flexion during mid-stance and knee extension at terminal stance; which are widely accepted to be key factors in an energy efficient gait(35). However, Maas(221) stated that to conclude what the most optimal SAV is to improve mobility in children with CP, who walk with an AFO, further research on the relationship between the SAV and energy cost during walking should be performed.

There is currently no research which has looked at the effect of using a tuned AFO-FC compared to non-tuned on energy expenditure. This study aimed to examine energy expenditure in children with CP, in three conditions: 1) Barefoot, 2) Non-tuned AFO-FC and 3) Tuned AFO-FC, walking at self-selected speeds, to better inform clinical practice. The barefoot condition was deemed necessary, to provide a baseline measure of the participants' natural gait with no intervention.

All data was taken as an average of the three trials in each condition, from minute 5-6 of each trial (minute 3-4 of the walking trial), ensuring cardiovascular steady state had occurred (See figure 7.3.1). Steady state occurs when the body has adjusted to the workload and oxygen uptake plateaus. It has been previously reported that steady state whilst walking, usually takes place between minutes two and four(42,222,223).

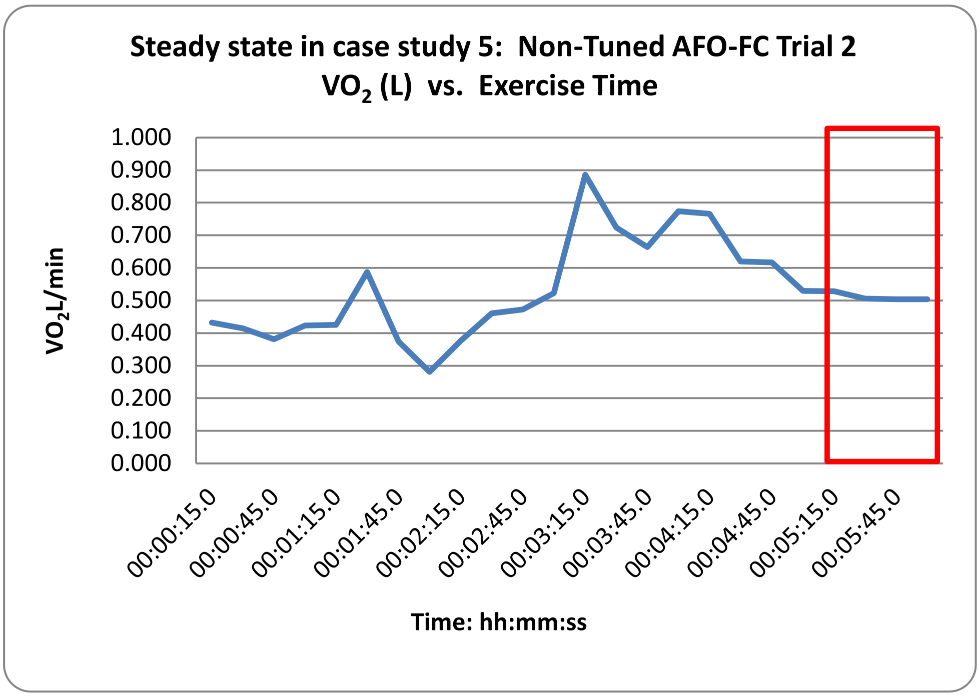


Figure 7.3.1: Graph showing steady state

7.4 Calculating energy cost measures

The following calculation methods were used:

- Gross submaximal energy expenditure (VO_2mL/minute/metre)

VO_2 (Volume of oxygen uptake per mL/min/m). Gross energy expenditure is a measure of energy cost i.e. it measures the energy used per unit of distance and thus the total energy required for an activity, net energy expenditure subtracts resting energy from the total energy produced. Net energy expenditure reduces the effects of the variables that may change over time such as altered cardiac or pulmonary function(224) and is recommended for studies interpreting follow-up measurements of energy expenditure in children who have not yet reached their full stature. As testing for all conditions in this study was only three weeks apart, this was not a relevant factor to consider. Therefore, gross rather than net energy expenditure was calculated for this study. mL/min/m corrects for differences in inter-individual differences in stride length and stride frequency. So, this is the energy cost per metre travelled and distance travelled is a product of stride length and stride frequency and is an estimate of energy cost not power.

- Walking speed

Walking speed = metres per minute

$$\frac{\text{Distance (metres)}}{\text{Time}}$$

- Calorie uptake

Measured in kilocalories (kcal)

Average volume of oxygen in litres (VO_2L) during walking minute 3-4

Respiratory quotient (RQ)

RQ value corresponds to a caloric value for each litre (L) of O_2 produced.

RQ = CO_2 eliminated / O_2 consumed

VO_2L x Calorific equivalent of O_2 = kcal per minute

- EEI based on O_2

The EEI based on O_2 indicates the amount of energy required to walk a specified distance and reflects energy economy(225) and is measured by O_2 uptake per kilogram of body weight per minute (VO_2mL/kg/min), divided by walking speed (m/min).

Statistical methods

Inferential statistics cannot be used as the sample size is less than 10; therefore descriptive statistics will be used due to the heterogeneity of CP.

Dependent variables:

- VO_2
- Speed
- Distance
- Energy expenditure (kcal)

7.5 Results

Gross submaximal energy expenditure

The results indicate a reduction in gross VO_2 in three of the four participants tested when using a tuned AFO-FC. The reductions ranged from 10.2% - 33.7%. Results for participant five show that gross VO_2 increased by 14% in the tuned condition compared to barefoot walking, and there was very little difference between the tuned and non-tuned conditions (3%). (See figure 7.5.1. and table 7.1)

EEI (O_2)

The results also indicate that the EEI(O_2) was lowest for the same three out of the four participants in the tuned condition, with one participants showing no difference between the tuned and the non-tuned condition. The reductions ranged from 3.2% - 31%. (See table 7.1)

Distance, speed and calories (kcal) used

All of the participants covered the most distance in the tuned condition compared to non-tuned, the speed of all participants was also highest in the tuned condition when compared to non-tuned, and ranged from an increase of 1.5% to 12.4%. (See figure 7.5.2).The number of calories (kcal) increased in the tuned condition when speed also increased, for participants four and five. However, for participants one and three, the number of calories (kcal) they used reduced in the tuned condition compared to non-tuned. (See table 7.1).

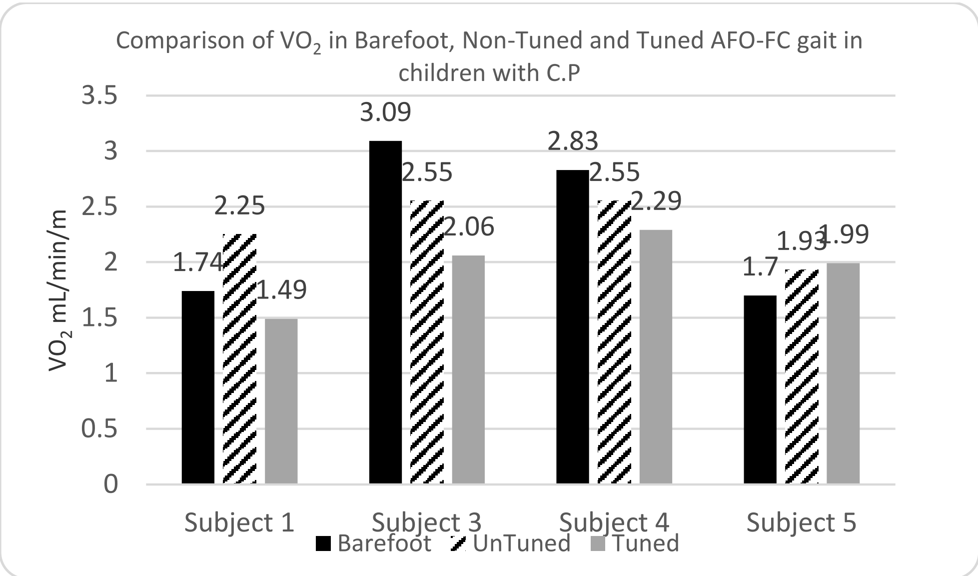


Figure 7.5.1: A graph showing VO_2 comparison between conditions

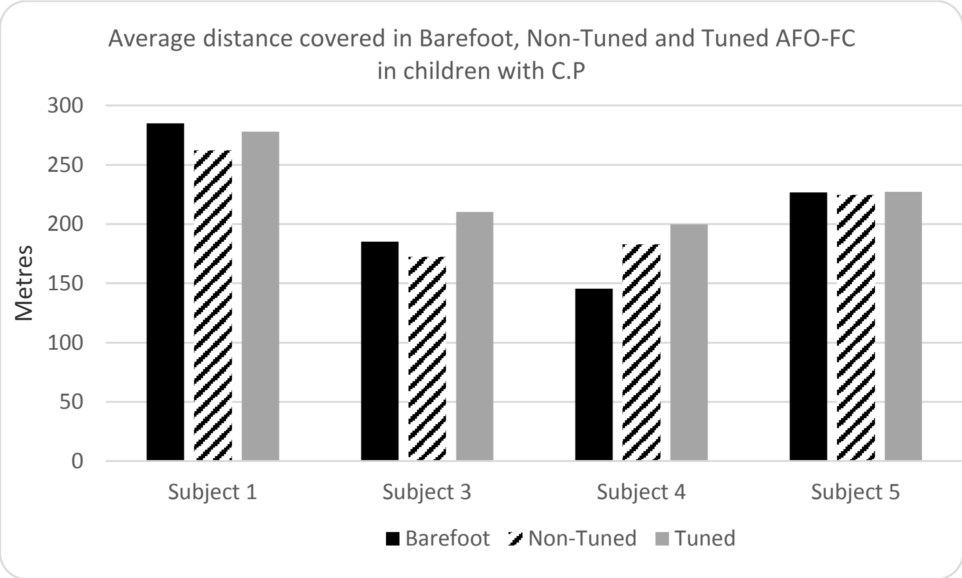


Figure 7.5.2: Graph showing average distance per condition

Participant / Condition	Speed (metres per minute)	Distance (metres)	Energy expenditure (kcal per hour)	EEI (O_2)	Mean average VO_2 mL/min/m
1					
Bare foot	71.25	285	145.6	0.3	1.74
Non-tuned AFO-FC	65.5	262	172.2	0.38	2.25
Tuned AFO-FC	69.5	278	126.3	0.29	1.49
3					
Bare foot	46.27	185.1	171.1	0.4	3.09
Non-tuned AFO-FC	44.29	177.2	131.4	0.36	2.55
Tuned AFO-FC	52.39	210.2	126.8	0.29	2.06
4					
Bare foot	36.4	145.6	118.8	0.36	2.83
Non-tuned AFO-FC	45.6	182.7	133.8	0.32	2.55
Tuned AFO-FC	49.91	199.7	139	0.31	2.29
5					
Bare foot	56.6	226.6	112	0.27	1.7
Non - tuned AFO-FC	56.13	224.5	127.6	0.3	1.93
Tuned AFO-FC	57.17	227.3	143.7	0.3	1.99

Table 7.1: Energy expenditure index (EEI) based on O_2 per participant per condition. speed, distance and energy expenditure per participant, per condition

7.6 Discussion

This study is the first to measure the metabolic responses during gait in children wearing a tuned versus non-tuned AFO-FC.

The results reveal that gross submaximal energy expenditure, (VO_2mL/min/m, which will be referred to as gross VO_2), when walking, was lower with a tuned AFO-FC for three out of the four participants tested (see table 7.1). The decrease in gross VO_2 ranged from 10.2% - 33.7%, a change in gross VO_2 which meets or exceeds 10% is considered clinically relevant(226). EEI (O_2) was also lowest for the same three out of the four participants in the tuned condition, with one participant showing no difference between the tuned and the non-tuned condition (see table 7.1). The findings of this study are in line with the mean economical EEI(O_2) for children with CP, reported by Rose et al.(44) which is 2.9 times higher than that of healthy children. This is important because interventions that decrease the O_2 cost of walking could potentially benefit activities of daily living in children with disabilities(75).

The high O_2 cost of walking in CP is associated with excessive co-activation in the lower limb(75,227). It has been reported that an AFO can provide increased stability during stance, decreasing the co-activation in the lower limb, and reducing the O_2 cost of walking(75). The results demonstrated in this study may indicate that the tuned AFO-FC improved the positioning of the ankle during stance, resulting in a reduction of gross VO_2. Previous studies(75,76) which showed no reduction in O_2 uptake, at self-selected speeds, are in contrast to the results of this study. However, the AFO-FCs used in this study were all biomechanically optimised, and this may explain why energy expenditure was reduced at self-selected speeds.

All participants covered the most distance in the tuned condition compared to non-tuned (increase range 1.2% - 16.6%). In three of the four participants tested, wearing a non-tuned AFO-FC decreased the distance they covered compared to barefoot gait (range 0.9%-8.1%, see table 7.1). Thus, possibly indicating that the intervention of a non-tuned AFO-FC, rather than improve, actually hindered their gait. These findings are in contrast to Jagadamma(90) who reported no difference in speed and distance in a tuned AFO-FC but an increase in the non-tuned condition. However, the results presented were mean group differences, furthermore, the participants were tested immediately after they had their AFO-FCs temporality tuned with no habituation period, immediately following testing of the non-tuned AFO-FC.

Similar results are shown in the speed of each participant, all of whom increased their speed in the tuned condition when compared to non-tuned; with the increase ranging from 1.5% to 12.4%. Interestingly, although speed was increased in the tuned condition, three participants also reduced their gross VO_2. The increase in the gross VO_2 in the non-tuned condition (compared to tuned) may be due to the reduction in their speed, which increases the mechanical power required to maintain the body in motion(44). Three of the four participants had a speed of 49-58 m/min, which is significantly below that of the speed of healthy children(207).

Not surprisingly, the number of calories (kcal) used increased in the tuned condition when speed also increased for participants four and five. However, for subjects one and two the number of calories (kcal) used reduced in the tuned condition compared to non-tuned even though their speed increased, which suggests the tuned AFO-FC provided a more efficient gait pattern (see table 7.1).

In summary, participant one performed better against all measures, in the tuned AFO-FC versus non-tuned, with the non-tuned condition resulting in deterioration against all measures. Similarly, participant three's results indicate the same improvements in the tuned condition, compared to non-tuned. Participant four demonstrated an improvement in all parameters except calories (kcal) used when compared to the non-tuned condition. However, the increase in calories (kcal) is not unexpected since speed and distance both increased. Participant five's results indicate an improvement in speed, distance and calories (kcal) in the tuned condition compared to non-tuned, but an increase in of gross VO_2 and no difference in EEI (O_2).

The increase in gross VO_2 for participant five is not in line with the results from the other participants, although the increase versus the non-tuned condition is only 3%, the increase against the barefoot condition is 17%. The increase in speed and distance may have contributed to the increase in gross VO_2, although the reason why this occurred in this participant and not the other three is unknown.

Limitations of the study

The authors recognise that the sample size used in this study is small. However, CP is an extremely heterogeneous disorder, and as such, the aim was to look at the effects of the intervention on the individual participant, in contrast to the vast majority of studies in the available literature, which emphasise group and mean differences(10).

The AFOs in the non-tuned condition had the correct AAAFO as dictated during the patient assessment; this is an essential aspect of biomechanical optimisation. It is hypothesised that setting the AFOs to an incorrect AAAFO, as is common in clinical practice(212), would have further increased energy expenditure but this was deemed unethical. A treadmill was considered to ensure constant velocity; however, treadmills are impractical in clinical applications involving participants with CP as participants with disabilities have difficulty adjusting to imposed speeds and walking on a treadmill(39,46). Furthermore, if data is to be used to aid clinical decision making, it is preferable for it to be collected on level ground(228). Additionally, unregulated walking reduces so-called velocity artefacts that result from artificially imposed conditions(78). The literature also notes that in both disabled and able-bodied individuals, the most efficient rate of ambulation is very close to the individual's freely chosen velocity(78) and enforcing the participants' speed may result in modifications to the gait pattern.

The researcher held the portable gas analyser system, whilst the participant walked ahead; it is possible that this affected the participants' self-selected walking speed. However, the researcher was an able-bodied adult, therefore; it is unlikely that they would not be able to maintain the walking speed of a disabled child.

7.8 Conclusion

The results of this study indicate that tuning an AFO-FC can potentially reduce energy expenditure and increase speed and distance covered during gait, in children with spastic cerebral palsy. Whilst a non-tuned AFO-FC has the potential to decrease energy expenditure at the detriment of a reduction in speed and distance and can potentiality increase energy expenditure in some cases.

Further research is required on a larger sample to validate these findings and learn more about which patients benefit the most from AFO-FC tuning, and why.

Chapter 8: The effects of AFO-C tuning on the kinetics and kinematics of gait in children with CP

8.1 Aim of the research

- To compare and analyse the kinetics and kinematics of gait in three conditions:
  I. Barefoot (to provide a baseline of gait).
  II. Non-tuned AFO-FC.
  III. Tuned AFO-FC.

8.2 Introduction

The current literature is equivocal on the effects AFOs have on the gait of children with CP. A detailed account of the effects of AFOs in children with CP is given in chapter three. The lack of consensus within the literature may be due to the heterogenous nature of CP, with studies grouping together the results of differing presentations of CP or at most only differentiating between hemiplegic and diplegic CP. Other factors include comparing different AFOs against each other, a lack of detail regarding the AFO intervention used (see chapter five), a lack of clinical justification for the AFO prescription and a lack of detail regarding the physical presentation of the participants being studied.

Studies have also reported mean results across groups of CP children which may skew the results and misinform practice. A more personalised case study approach has been advocated when researching CP children(10). A lack of AFO-FC tuning within the studies may also be a factor on the ambiguity in reported results. The effects of biomechanically optimised AFO-FCs on children with CP, within the current literature, are detailed in chapter four.

This study will compare the sagittal plane kinetics, kinematics and spatial-temporal parameters of each participant in barefoot, non-tuned AFO-FC and tuned AFO-FC conditions, on the limb which is predominantly affected and on which they wear an AFO. Clinical interpretation of instrumented gait analysis first identifies how the participant differs from normal and then the likely cause of the deviation. However, it is important to recognise that kinematic deviations are not bijective and thus the same impairment may result in a range of kinematic deviations(229).

8.3 Normal gait

The normal gait of children and adults has been well documented (28,34,230–232). In this thesis the gait cycle (G.C) will be described using the Ranchos Los Amigos terminology(233), which consists of Initial contact (I.C) 0-2% of the G.C, loading response (L.R) 2-10% of G.C, mid-stance (MSt) 10-30% of G.C, terminal stance (TSt) 30-50% of G.C, pre-swing (PSw) 50-60% of G.C, initial swing (ISw) 60-73% of G.C, mid-swing (MSw) 73-87% of G.C and terminal swing (TSw) 87-100 of G.C. As previously described in chapter ten, temporal mid-stance (TMST) occurs at 30% of the gait cycle. During TMST the pelvis, the trunk and the head are directly over the foot, and the GRF appears to be vertical. The knee of the swing limb can just be seen anterior to the stance limb, and the heel of the swing limb can be seen posterior to the stance limb(198). See figure 8.3.1.

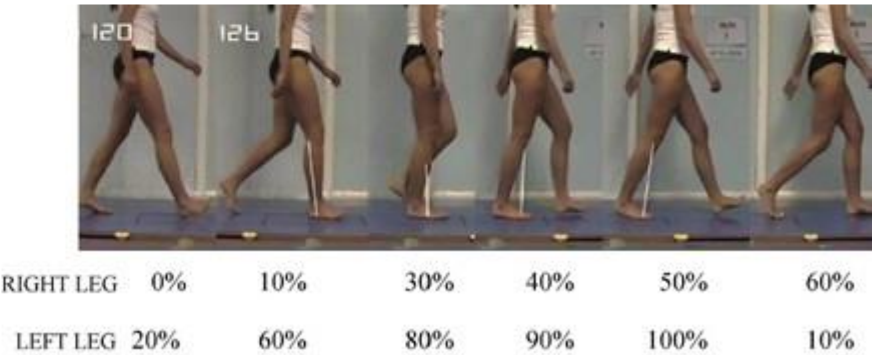


Figure 8.3.1: A depiction of the gait cycle(232,234)

During normal gait, the ankle is positioned at approximately 90° at I.C, and the knee is flexed at 5° and the hip at 30°; initiating the first ankle rocker. The forward reach of the limb tilts the tibia upwards 15° and positions the heel as the lowest segment of the foot(28). Ankle plantarflexion and eversion are initiated to decelerate the impact of the falling body. During L.R the knee is flexed to approximately 20°, and 5° of ankle plantar flexion is required in order to reduce the heel rocker effect so that the tibia doesn't advance too rapidly(28). If the ankle were to remain at 90°, the tibia would accompany the foot through its rapid arc of motion(28). A second advantage of plantarflexion at this stage of the G.C is shock absorption.

During MSt knee flexion decreases to approximately 15° with the hip moving towards extension, the full foot is in contact with the floor providing a stable position and the second rocker is initiated. Progression of the limb is continued by dorsi-flexion of the ankle moving from an initial 5° plantarflexed to 5° dorsi-flexed. This is followed by a rapid movement into dorsi-flexion of between 10°-15° which continues through MSt. The ability to dorsi-flex the foot during MSt is essential to allow the forward rotation of the tibia and forward progression of the trunk over the stance limb. Of the five pre-requisites for normal gait(28) it is stability which also contributes to the other four factors(232). It is the importance of stability which highlights MSt has being a crucial aspect of the G.C, as it is at this stage of the G.C when the foot is in full contact with the floor, producing a stable alignment of the foot segment coupled with a virtually stationary and inclined shank at TMST which places the knee joint centre over the centre of the foot, providing a very stable base of support(232).

As TSt begins the femur continues to advance over the stable tibia, knee flexion is reduced, and maximum knee extension occurs (approximately 5°) at 40% of the G.C. The heel begins to rise, the sub-talar joint moves into an inverted position locking the mid-tarsal joints. The forefoot is now supporting the bodyweight. The MTPJs and phalanges provide the third foot rocker allowing the body vector to advance for continued progression. Peak hip extension occurs at 50% of the G.C.

During PSw passive knee flexion occurs and the hip moves into approximately 10° extension. The bodyweight is transferred from the trailing limb to the forward limb during this period of double foot to floor contact(28). During the remainder of the swing phase, knee and hip flexion peak and the ankle is held at 90° to clear the floor.

Another important aspect of normal gait is the ability to support one's own bodyweight and decelerating the downward velocity of the centre of mass in late stance phase; this is demonstrated in the ground reaction force (GRF). This is often a significant issue for children with CP (235), and without corrective action the limb would collapse into flexion. The GRF provides information concerning the magnitude, direction and point of application of the impact forces. The vertical GRF shows the least variability between and within subjects(236,237)

8.4 Normative data

The results were compared with a database of normal children(209) with a change in a parameter towards normal considered an improvement; and the opposite a deterioration. The normative reference data is in routine use at Gillette Children's Specialty Healthcare (GCSH). The normative reference data was created using data from 81 patients, with an age range between 4 and 17 years, at one centre. All data was collected at self-selected walking speed, with a Vicon kinematic measuring system (Oxford, UK) and AMTI force plates (Watertown, MA, USA). Data were sampled to 51 values during the gait cycle(209). This data set has been shown to have a high degree of consistency when compared to another highly regarded gait analysis service(209). Normative data will be displayed in grey on all kinematic graphs.

The force data has been normalised by the participant's bodyweight and is shown in N/Kg. The weight of an object is the force acting on it due to gravity. The gravitational field strength of the Earth is 9.81N/Kg (9.81 Newton's per kilogram). This means an object with a mass of 1kg would be attracted towards the centre of the Earth by a force of 9.81N. Therefore, the bodyweight line is shown as 9.81N/Kg on the force vertical force graphs.

8.5 Clinical relevance

This study will provide qualitative and quantitative data on the effects of tuned AFO-FCs on the gait of children with CP, to better inform clinical practice on the potential benefits.

8.6 Case study one

The participant was an eight year old female with spastic hemiplegia, right side upper and lower limbs affected, weighing 23.6Kg and 122cm in height. No history of any surgical intervention, the participant had a botoxilium injection into the right gastrocnemius in 2008, and started a daily physical therapy regime in 2006.

During the static physical examination, it was noted that the participant had a popliteal angle of 19°, which is within the normal range for her age(238). 5° dorsi-flexion of the foot/ankle could be archived with the knee extended on the right side, thus suggesting a loss of PROM in gastrocnemius of approximately 20°(239) and 24° with the knee flexed, suggesting a loss of PROM in soleus. There was a reduction in subtalar joint (STJ) PROM in inversion, of approximately 9°(239).

There was an actual leg length discrepancy of 15mm short on the right side; she presented with a foot position rated as eight on the foot posture index (FPI)(240). There was a spasticity rating of 0/5 in the hamstrings, 1/5 in the quadriceps and dorsi-flexors and 3/5 in the plantar-flexors, using the modified Ashworth Scale(241). Muscle power was reduced in the dorsi-flexors (3/5), plantar-flexors (4/5), and inversion and eversion (2/5) on the Oxford scale(205). All other tests were within normal ranges and the left limb was within normal parameters.

The participant walked independently at a rate of 71.25 m/min barefoot which is considered a normal paediatric walking speed(44,207). The barefoot step length on the right measured 0.45m and was shorter than normal, cadence was 130 steps/min, which is considered normal(209). (See table 8.1 for participant temporal- spatial parameters). The participant presented with I.C at the forefoot with the foot plantarflexed at 12.1° (SD 1.42°) and a low heel resulting in hyperextension of the knee at MSt. The right upper limb was held in flexion at the elbow and wrist, with pronation of the forearm and was passively correctable.

The barefoot gait pattern was similar to type II of Winter's(23) classification for spastic hemiplegia, with I.C at the forefoot and a delayed heel contact. This is characteristic of an elastic contracture, the ankle yields as a larger portion of the bodyweight is loaded on to the limb during stance, and heel contact is then achieved. The foot then reverts to an equinus position during swing phase, most likely due to the over activity of the plantar-flexors (28,229) and a compensation for the leg shortening(28). The consequence of this deficit is the disruption of the heel rocker, forward progression of the tibia and shock absorption at the knee(28).

There was increased knee flexion at I.C (11.26° SD 1.1°) which is approximately 5° higher than normal (209), and less than 20° in the first third of stance phase which is a good predictor of successful tuning(98). There was hyperextension of the knee during stance phase (-3.8° SD 0.9°) which peaked at TMST rather than TSt where peak knee extension should occur(118). The hyperextension of the knee is most likely caused by a rigid reverse rocker due to heel contact coming after I.C with the forefoot, which drives the heel to the floor and the tibia backwards(28).

At 30% of the gait cycle, the participant demonstrated 0.12° (SD 1.48°) dorsi-flexion. Limitation of dorsi-flexion which is less than 5° by this stage of the gait cycle represents an abnormal restraint, progression is limited, and the contralateral step length is shortened, as demonstrated by this patient. The knee hyperextension and the anterior pelvic tilt all represent efforts to move the trunk forward of the plantar-flexed foot, placing a significant demand on the hip and back extensors(28).

The participant walked with the pelvis retracted on the right side, and peak hip flexion was 40.4° (SD 1.4°) which is lower than that described by Winters(23), the participant also demonstrated hyperextension of the hip (-15° SD-1.9°) approximately 10° higher than normal (209). See figures 8.6.1 – 8.6.4.

The AFO intervention consisted of a solid AFO on the right leg, which was cast with an AAAFO of 90°, made from 4.5mm homopolymer polypropylene, the trim-lines were anterior to the malleoli and had a full length footplate. The lateral flange of the footplate was distal to the 5th MTPJ in an attempt to control forefoot abduction caused by a pronated foot position. In order to reduce the hyperextension of the knee, one would ideally place the flanges behind the MTPJs; however, it was deemed important to control the abduction of the forefoot in this case. The footplate material was made as flexible as possible at the MTPJs with a rounded forefoot rocker adaptation to the sole unit to facilitate the third rocker due to the extended lateral flange. The AFO had a loop through calf strap and a figure of 8 ankle strap. The optimum SVA for this participant was 12°. The leg length discrepancy was accommodated in the AFO-FC prescription.

8.7 Results

Kinematic and kinetic data points were compared between barefoot baseline, non-tuned and tuned AFO-FC gait.

Temporal-spatial parameters

The mean (SD) of the temporal-spatial parameters for barefoot, tuned and non-tuned AFO-FCs are given in Table 8.1. The results indicate that the tuned condition increased the participant's step length bilaterally to within normal parameters and increased the distance covered. The non-tuned condition increased step length bilaterally but not to within normal values and decreased the participant's walking speed and distance covered compared to the barefoot baseline.

Kinematics

Whilst wearing a non-tuned AFO-FC the participant demonstrated a decrease in knee flexion at I.C to 5.96° (SD 5.54°) whilst peak knee flexion in stance increased and peak knee hyperextension increased to -6.1° (SD 1.55°). Overall knee ROM increased further from normal ranges. At TMST the patient demonstrated knee hyperextension of -1.04° (SD 3.29°). Anterior pelvic tilt increased and continued to show the single bump pattern as with barefoot gait, and there was an increase in pelvic tilt ROM which was more than double that of the normal range.

With a tuned AFO-FC, knee flexion at I.C decreased to 9.07° (SD 7.37°) which was still higher than normal. Peak knee flexion in stance increased to 24.4° (SD 5.3°) which occurred during MSt. At TMST the knee was flexed at 17.08° (SD 3.7°), peak knee flexion decreased closer to normal values and knee extension decreased to 0.5° (SD 2.1°). Knee ROM also reduced closer to normal values. (See figures 8.7.1 – 8.7.10).

Case study 1: Descriptive analysis	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal
Item	Mean Average	Mean Average	Mean Average	Mean Average
Left Step Length (m)	0.49 (0.03)	0.52 (0.05)	0.58 (0.08)	0.57
Right Step Length (m)	0.45 (0.04)	0.54 (0.04)	0.56 (0.04)	0.57
Steps / Minute (Cadence)	130.21 (14.7)	128.19 (8.73)	110.68 (9.21)	123.18
Metres per minute (Walking speed)	71.25	65.5	69.5	69.6

Distance covered (m)	285	262	278	

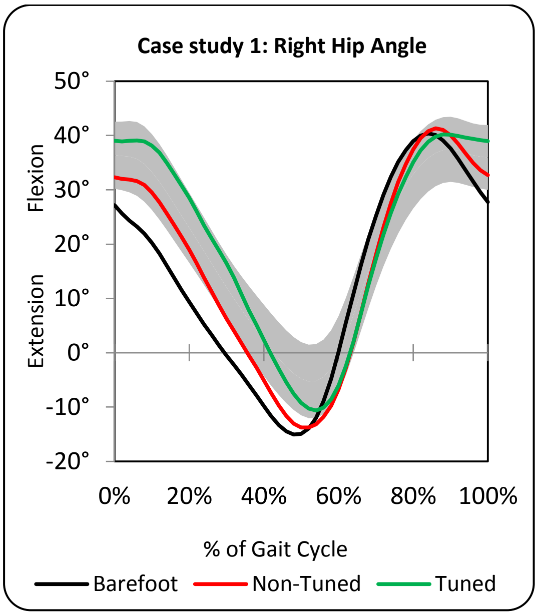
Table 8.1: Case study 1: Temporal-spatial parameters

Case study 1	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal (SD)
Pelvic Kinematics				
Peak anterior pelvic tilt	9.52 (4.02)	10.1 (3.35)	10.48 (4.02)	12.9 (5.3)
Peak posterior pelvic tilt	5.11 (1.02)	5.2 (0.91)	7.79 (0.92)	10.9 (5.1)
Pelvic tilt ROM	4.41 (3.0)	4.86 (2.43)	2.7 (3.09)	2 (0.2)
Hip Kinematics				
Peak Hip flexion	40.4 (1.4)	41.3 (3.42)	40.2 (1.72)	37.5 (6)
Peak Hip extension	-15 (-1.9)	-13.8 (-3.83)	-10.6 (-1.94)	-5.3 (6.8)
Peak hip flexion (stance)	27.2 (3.2)	32.3 (2.4)	39.1 (2.52)	36.37 (6.2)
Hip ROM	55.41 (5.17)	55.09 (4.12	50.83 (5.61)	42.72 (1.29)
Knee Kinematics				
Knee flexion at IC	11.26 (1.1)	5.96 (5.54)	9.07 (7.37)	6.66 (5.24)
Peak knee flexion (stance)	13.9 (3.1)	17.5 (3.0)	24.4 (5.3)	19.52 (6.89)
Peak knee extension	-3.8 (0.9)	-6.1 (1.55)	0.5 (2.1)	3.7 (5.3)
Peak knee flexion	74 (9.9)	72.8 (10.34)	67 (8.04)	60.41 (3.69)
Knee ROM	77.71 (8.92)	78.91 (8.71)	66.29 (5.9)	56.72 (3.8)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.				

Table 8.2: Case study 1: Right hip and knee kinematic data

Case study 1: Ankle Kinematics	**Barefoot (SD)**	**Normal (SD)**
Dorsi-flexion at I.C	-12 (1.42)	-3.08° (5.12)
Peak Dorsi-flexion	4.9 (3.6)	11.4° (5.72)
Peak Plantar flexion	-13.02 (1.16)	-20.63° (8.62)
Ankle ROM	17.91 (2.44)	32° (7.33)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.		

Table 8.3: Case study 1: Right Ankle kinematic data



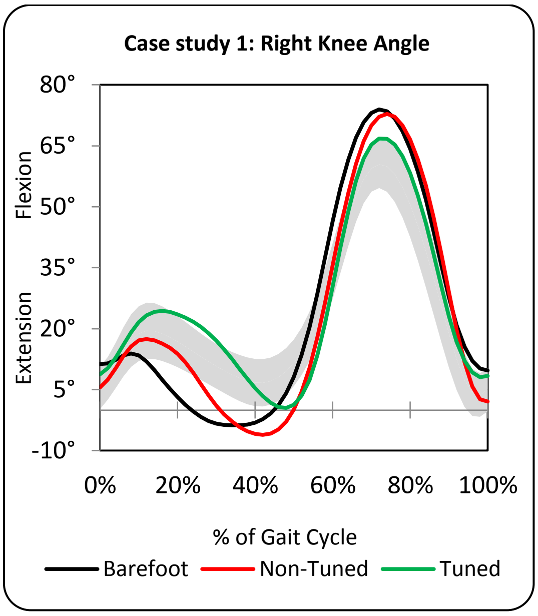
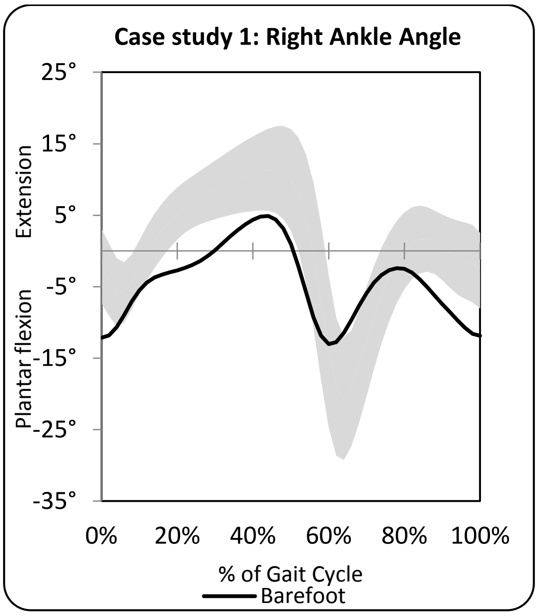


Figure 8.7.1: Graph showing right hip angle

Figure 8.7.2: Graph showing right knee angle



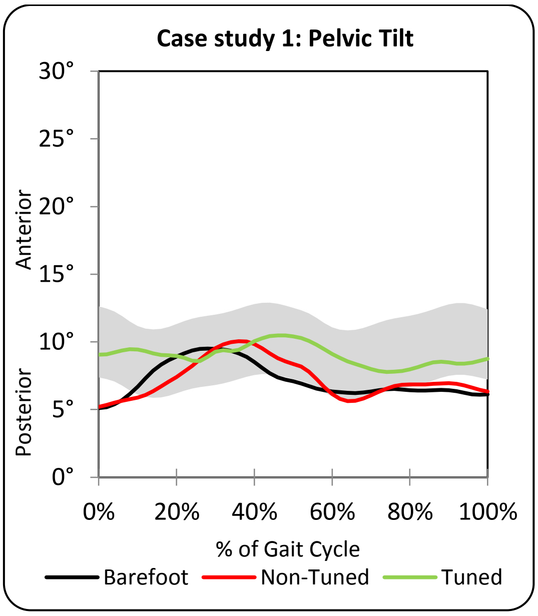


Figure 8.7.3: Graph showing right ankle angle

Figure 8.7.4: Graph showing pelvic tilt

Kinetics:

Case study 1: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FZ_1 (Peak 1) N/Kg	9.38(1.06)	10.7(0.67)	11.24(1.37)
FZ_2 (Peak 2) N/Kg	10.86(0.42)	11.9(0.57)	11.15(0.8)
FZ_0 (Trough) N/Kg	7.0(0.60)	6.3(0.79)	7.3(1.83)
Vertical Ground Reaction Force data mean average: Key: SD- Standard deviation. The black horizontal line in all vertical force graphs demonstrates the bodyweight line at 9.81N/Kg .			

Table 8.4: Case study 1: Right vertical ground reaction force data

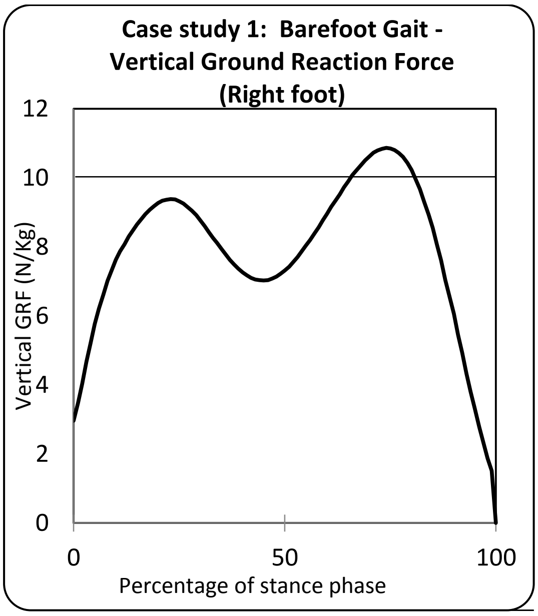


Figure 8.7.5: Graph showing barefoot vertical GRF

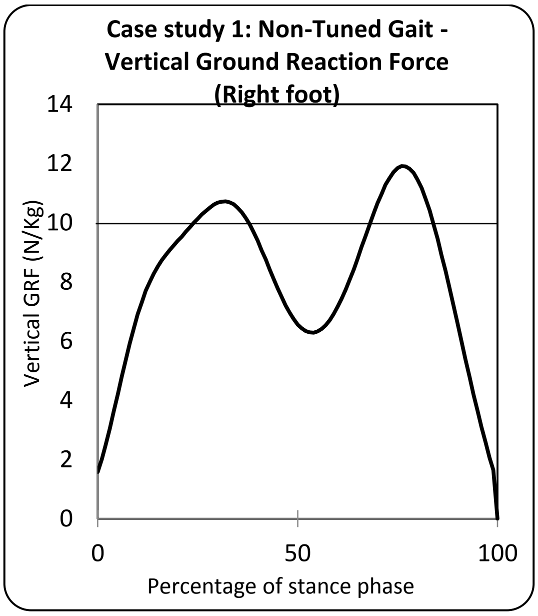


Figure 8.7.6: Graph showing non-tuned vertical GRF

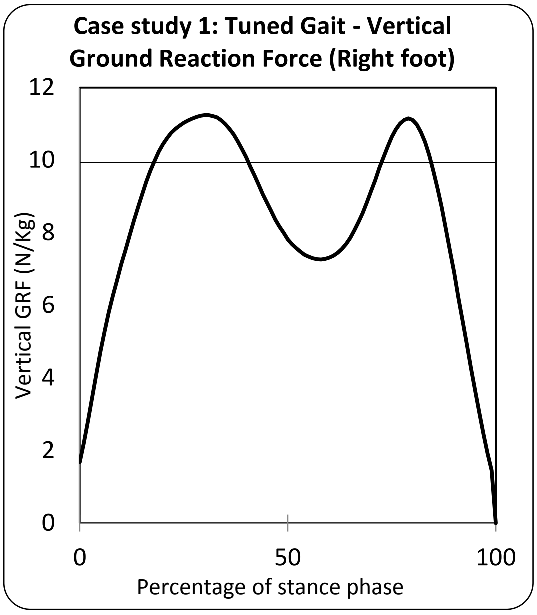


Figure 8.7.7: Graph showing tuned vertical GRF

Case study 1: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FX_4 (Posterior) N/Kg	-1.33 (0.33)	-0.98(0.19)	-1.45 (0.58)
FX_5 (Anterior) N/Kg	1.54 (0.22)	1.43 (0.22)	1.06 (0.23)
Anterior-Posterior Ground Reaction Force data mean average: Key: SD- Standard deviation			

Table 8.5: Case study 1: Right anterior-posterior ground reaction force data

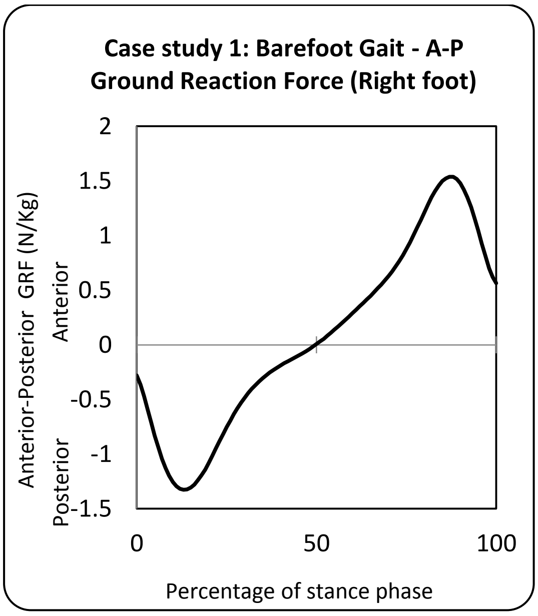


Figure 8.7.8: Graph showing barefoot anterior-posterior GRF

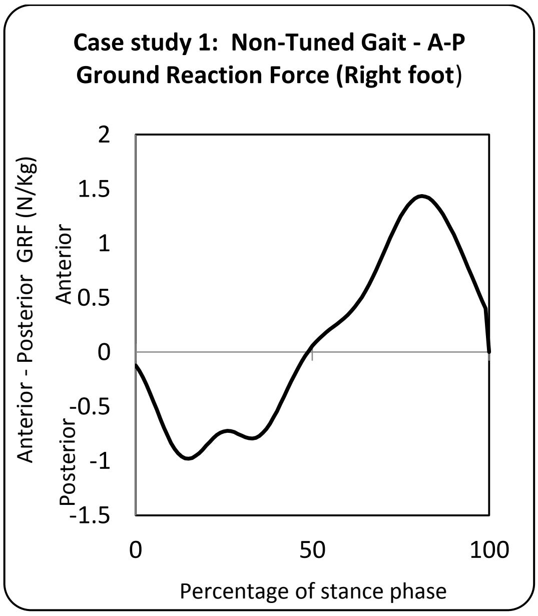


Figure 8.7.9: Graph showing non-tuned anterior-posterior GRF

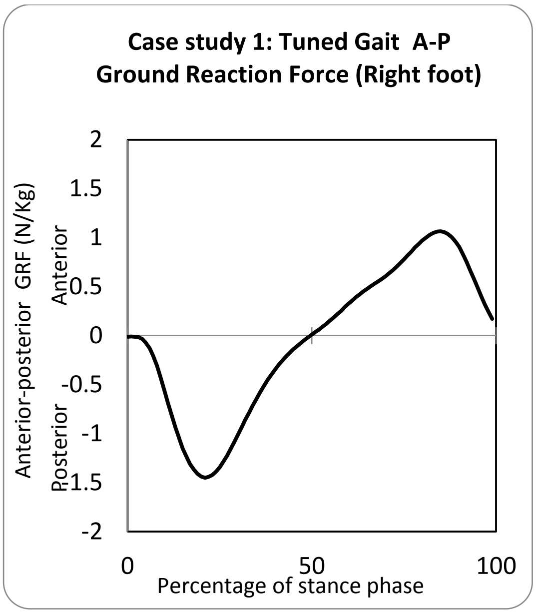


Figure 8.7.10: Graph showing tuned anterior-posterior GRF

8.8 Discussion

The decrease in knee flexion at I.C to 5.96° (SD 5.54°) in the non-tuned condition is closer to normal. Although peak knee flexion in stance increased, it was still lower than normal. The main gait deviation for this participant was knee hyperextension during stance. In the non-tuned condition peak knee hyperextension increased to -6.1° (SD 1.55°) thus, further debilitating the participant's gait and at TMST the patient demonstrated knee hyperextension of -3.34° (SD 3.2°). The lack of inclination of the shank at TMST reduces stability because the shank is vertical the thigh cannot move to an inclined position unless the knee is placed in hyperextension(118). This is also demonstrated in the "double bump" of the A-P force in the non-tuned condition (figure 8.7.9) which shows an acceleration, then a deceleration then an acceleration between loading response and MSt. This is likely to be caused by the shank arrest during knee hyperextension; once maximum hyperextension has been reached the shank begins to move again. Although knee hyperextension is present in the barefoot condition, albeit to a lesser extent, the double bump feature is not present in the barefoot A-P graph. Thus, it is possible that the participant might be able to accommodate the deceleration and lack of stability due to the movement of the ankle, which is fixed in the non-tuned condition.

To maintain the centre of gravity over the foot, pelvic lordosis and pelvic anterior tilt increased, this is demonstrated in this patient's barefoot and non-tuned gait pattern. The participant also demonstrated hyperextension of the hip during stance along with early extension of the hip. Resulting in excessive knee flexion during swing in an attempt to clear the floor of the trailing limb.

With a tuned AFO-FC the participant's hip flexion at I.C was within the lower range of normal. Peak knee flexion in stance increased to 24.4° (SD 5.3°) which occurred during MSt. At TMST the knee was flexed at 17.1° allowing the participant to benefit from a more stable gait, enabling the thigh to become inclined at TSt with a reduced knee extension and a more energy efficient gait pattern(14), in line with Jagadamma's(37) findings in a similar study. There was also an improvement in peak hip extension within the lower end of normal range occurring at the correct stage of the gait cycle (50%). Peak hip flexion also improved to within the higher end of normal along with pelvic tilt.

During barefoot gait the participant was unable to support her bodyweight during the first peak (FZ_1), which relates to the amount of loading the participant puts on to the front foot (see table 8.4). A reduced first peak could relate to the presence of pain or discomfort, poor functional movement of the joints or a slow walking speed(242). Walking speed was normal for this participant in the barefoot condition, so this is an unlikely cause, and there was no pain reported. Thus, the lack of ability to support the bodyweight is likely to be due to the poor functional movement of the lower limb. The first peak increased in the non-tuned condition and increased further in the tuned condition; in both AFO conditions, the participant was able to support their own bodyweight.

The data also shows that the participant was able to adequately move over the stance limb (as dictated by the trough FZ_0) in all three conditions. Trough to second peak is caused by the heel lifting and the foot pushing down back into the ground by the action of the posterior muscles of the ankle joint, the second peak relates to the amount of vertical propulsive force which drives the person upwards(242). Williams et al.(235) reported that the majority of CP children demonstrate a reduction in the second peak of the vertical GRF (FZ_2), which implies they are unable to control the descent of the centre of mass (COM) appropriately. However, this participant demonstrated an adequate second peak in all three conditions. The barefoot and non-tuned conditions show an abnormality in that the first peak is lower than the second peak, which is uncommon. Stansfield et al.(243) reported that in normal children's gait, with respect to speed, the first peak averages approximately 120% bodyweight and the second peak averages 110%.

The A-P force graphs indicate forces closer to normal in the barefoot condition. FX_4 which is heel strike to posterior peak represents the deceleration of the lower limb after initial contact. This force should be in the region of 0.2 times the person's body weight(242), in all three conditions the force was below this level, with the non-tuned condition being further away from normal values. This force can be affected by the speed of gait and the person's confidence in loading the front foot. The posterior component reduces as the body attempts to move over the stance limb. At the point where the horizontal force is zero the body is directly positioned over the foot, indicting Mst and normally occurs at 55% of stance phase(242). Cross over occurred at 50% of stance phase during the barefoot and tuned conditions, but slightly earlier in the non-tuned condition. Crossover to anterior peak represents the heel lifting and the foot being pushed down by the action of the posterior musculature of the foot and ankle, this anterior force propels the body forward(242). As with the posterior force, this should be in the region of 0.2 times the person's body weight. All three conditions demonstrated a force below that of normal, with the tuned condition demonstrating the lowest force (1.06 N/Kg) which indicates that the participant is not propelling the body forward adequately.

8.9 Summary

The tuned condition offered the most improvement in 10 of the 12 kinematic parameters tested which is in line with Butler's(98) prediction for successful tuning, and the most deterioration in 1 of the 12 parameters. The non-tuned condition offered the most improvement in 2 of the 12 parameters and the most deterioration in 5 of the 12 parameters.

With a tuned AFO-FC the participant's hip and knee flexion/extension and anterior and posterior pelvic tilt all improved to within normal ranges along with step length and distance covered. Crucially knee hyperextension decreased and at TMST the knee was flexed. Conversely the non-tuned AFO-FC increased knee hyperextension, hip extension and anterior pelvic tilt to further outside of normal ranges. Indicating the non-tuned AFO-FC had a negative impact on the participant's gait, rather than its intended purpose of improving it. The vertical force data shows the most substantial improvement in the tuned condition during first peak and in the non-tuned condition for the second peak, the introduction of an non-tuned AFO-FC enabled the participant to support their own bodyweight during loading response although the A-P data showed this induced instability during loading response to MSt.

Conclusion

The clear message from this case study is the provision of a non-tuned AFO-FC caused an increase in the primary gait deviation compared to no intervention at all.

8.10 Case study two

This participant was an eleven year old male with spastic diplegia. The right side lower limb predominately affected. He weighed 55.1Kg and was 145cm in height. In May 2011 he underwent a distal tibial de-rotation osteotomy, with T plate fixation in January 2013; the participant also underwent a botoxilium injection into the right gastrocnemius in 2010, 2011 and 2012 followed by serial casting. The participant started a daily physical therapy regime in 2004.

During the static physical examination it was noted that the participant had a popliteal angle of 52° on the right, which is considered abnormal hamstring tightness(238) and is a poor prognostic sign for successful tuning(98). The left popliteal angle measured 45° which is just within the normal range for his age(238). He could achieve 90° at the foot/ankle with the knee extended on the right side, suggesting a loss of PROM in gastrocnemius of approximately 24°(239) and 3° with the knee flexed, indicating a loss of PROM in soleus of approximately 38°. On The left side, he had a reduction of 19° dorsi-flexion with the knee extended and 28° loss of PROM with the knee flexed to 90°. There was a reduction in subtalar joint (STJ) PROM in inversion of approximately 6°(239) bilaterally.

There was an actual leg length discrepancy of 10mm short on the right side. The right foot position was rated as ten on the FPI(240) with the left foot rated as neutral (FPI 6). There was a spasticity rating on the right side of 1/5 (0/5 on the left) in the hamstrings, 1/5 (0/5 on the left) in the quadriceps and 2/5 (1/5 on the left) in the plantar-flexors and dorsi-flexors, using the modified Ashworth Scale(241). Muscle power on the right was reduced in the hip extensors (4/5) (5/5 on the left) and hip flexors (4/5) bilaterally on the Oxford scale(205). All other tests were within normal ranges.

The participant walked independently at a rate of 41.48m/min barefoot, which is slower than the normal paediatric walking speed (44,207). The barefoot step length for the right measured 0.55m and was within normal ranges and cadence was 115 steps/minute, which is less than normal(209).

The barefoot gait pattern was similar to type IV of Winters'(20) classification for spastic hemiplegia. During barefoot gait, the participant presented with I.C at the forefoot with the foot plantarflexed at -14.96° (SD -0.97°) which yielded to increased bodyweight during stance with increased flexion of the knee at MSt and throughout stance. There was increased knee flexion at I.C (18.76° SD 1.38°) which is approximately 12° higher than normal, and an average of 24.91° (SD 1.74°) during loading response. Excessive knee flexion during loading response relates to a knee posture greater than 15°(28). As a consequence during MSt and TSt the inability to extend the knee to within 10° of neutral compromises weight-bearing stability(28). The patient also demonstrated excessive knee flexion during MSw which appears to be a secondary effect of increased hip flexion(28).

The excessive knee flexion throughout gait is most likely to be caused by excessive plantar-flexion as the distance between the hip joint, and the toe is increased, thus, when the swing limb must pass the stance limb knee flexion must accommodate the relative lengthening. To ensure foot clearance the limb is lifted, hip flexion is the primary action, whilst gravity, which holds the tibia vertical, flexes the knee; thus the knee flexion is only accomplished by excessive hip flexion(28) (see graph 8.9.1). The spasticity and contracture further compound the knee flexion deficit in the participant's hamstrings and hip extensor weakness, which often leads to increased hip flexion and a loss of knee extension with anterior tilt of the pelvis (229) (see graph 8.9.4). Knee flexion greater than 15° at mid-stance is a poor prognostic sign for AFO-FC tuning(98).

Total hip ROM was 30.8° (SD 1.8°) peaking at 51.09° (SD-0.64°) which is higher than normal and a lower range of 20.3° (SD-2.43) which is approximately 25° higher than normal. Hip flexion greater than 30° increases the demand on the hip extensors(28). There was also excessive anterior pelvic tilt (25.45° SD 2.62°) with a single bump pattern. See figures 8.11.1 – 8.11.4.

The participant wore a solid AFO on the right leg, which was cast at a 90° angle, made from 5mm homopolymer polypropylene, the trim-lines were anterior to the malleoli and had a full length footplate. The medial and lateral flange of the footplate was distal to the 1st and 5th MTPJs in an attempt to block the third ankle-foot rocker and reduce knee flexion in stance. The footplate material was made stiff at the MTPJs. The AFO had a loop through calf strap and a figure of 8 ankle strap. The optimum SVA for this participant was 12° with a forefoot rocker. The leg length discrepancy was accommodated in the AFO-FC prescription.

8.11 Results

Kinematic and kinetic data points were compared between barefoot baseline non-tuned and tuned AFO-FC gait.

Temporal-spatial parameters

The mean (SD) of the temporal-spatial parameters for barefoot, tuned and non-tuned AFO-FCs are given in Table 8.6. The results indicate that the tuned condition increased the participant's left step length but reduced the right step length, cadence was slightly reduced but distance covered increased. The non-tuned condition decreased the right step length but increased the left step length although this was less than the tuned condition, cadence reduced but speed and distance increased.

Kinematics

Whilst wearing a non-tuned AFO-FC the participant demonstrated an increase in knee flexion at I.C to 25.32° (SD 3.77°). Peak knee flexion decreased to 59.77° (SD 9.42°) but increased in stance to 30.36° (SD 6.55°), and peak knee extension decreased to 18.32° (0.77°). The participant demonstrated the same pattern of excessive knee flexion, hip flexion and anterior pelvic tilt in stance. Overall knee ROM decreased compared to barefoot. At TMST the patient demonstrated knee flexion of 21.91° (SD 6.1°)

With a tuned AFO-FC, knee flexion at I.C increased to 30.06° (SD 3.17°). Peak knee flexion in stance increased to 35.30° (SD 6.59°) which occurred during loading response (L.R) and might be caused by the addition of the external shoe wedges inclining the shank. Knee extension decreased to 18.17° (SD 1.65°). Knee ROM reduced to 37.57° (SD 8.2°). At TMST the knee was flexed at 22.19° (SD 6.5°). During swing, knee flexion returned to within normal ranges. Hip flexion and extension returned to normal throughout the gait cycle. Anterior pelvic tilt decreased to within normal range 12.2° (SD 2.22°) with an increase in the posterior pelvic tilt at the I.C and TSw.

Case study 2: Descriptive analysis	**Barefoot (SD)**	**Non-Tuned (SD)**	**Tuned (SD)**	**Normal**
Item	**Mean**	**Mean**	**Mean**	**Mean**
Left Step Length (m)	0.48 (0.03)	0.58 (0.04)	0.61 (0.03)	0.57
Right Step Length (m)	0.55 (0.02)	0.48 (0.04)	0.48 (0.07)	0.57
Steps / Minute (Cadence)	115 (3.5)	108.65 (6.16)	113 (9.41)	123.18
Metres per minute (Walking speed)	41.48	51.19	44.75	69.6
Distance covered (m)	165.93	204.8	190.4	

Table 8.6: Case study 2: Temporal-spatial parameters

Case study 2	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal (SD)
Pelvic Kinematics				
Peak anterior pelvic tilt	25.45(2.62)	28.99 (1.62)	12.2 (2.22)	12.9 (5.3)
Peak posterior pelvic tilt	19.9 (0.61)	19.97 (0.44)	5.04 (0.63)	10.9 (5.1)
Pelvic tilt ROM	5.57 (2.01)	9.03 (1.2)	7.14 (1.6)	2 (0.2)
Hip Kinematics				
Peak Hip flexion	51.09 (-0.64)	54.13 (-0.9)	40.29 (-1.69)	38.58 (-0.8)
Peak Hip extension	20.3 (-2.43)	15.7 (-6.4)	-3.3 (-4.9)	-5.16 (-3.23)
Peak hip flexion (stance)	50.56 (-0.63)	52.40 (-3.51)	37.52 (1.7)	38.6 (-3.23)
Hip ROM	30.8 (1.8)	38.45 (5.48)	43.6 (3.15)	42.72 (1.29)
Knee Kinematics				
Knee flexion at IC	18.76 (1.38)	25.32 (3.77)	30.06 (3.17	6.66 (5.24)
Peak knee flexion (stance)	27.60 (1.92)	30.36 (6.55)	35.30 (6.59)	19.52 (6.89)
Peak knee extension	15.87 (0.43)	18.32 (0.77)	18.17 (1.65)	3.7 (5.3)
Peak knee flexion	63.89 (4.80)	59.77 (9.42	55.74 (9.86)	60.41 (3.69)
Knee ROM	48 (4.29)	41.41 (8.59)	37.57 (8.2)	56.72 (3.8)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees				

Table 8.7: Case study 2: Right hip and knee kinematic data

Case study 2: Ankle Kinematics	Barefoot (SD)	Normal (SD)
Dorsi-flexion at I.C	-14.96 (-0.97)	-3.08° (5.12)
Peak Dorsi-flexion	5.69 (-0.1)	11.4° (5.72)
Peak Plantar flexion	-15.08 (-2.32)	-20.63° (8.62)
Ankle ROM	20.77 (2.22)	32° (7.33)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.		

Table 8.8: Case study 2: Right Ankle kinematic data

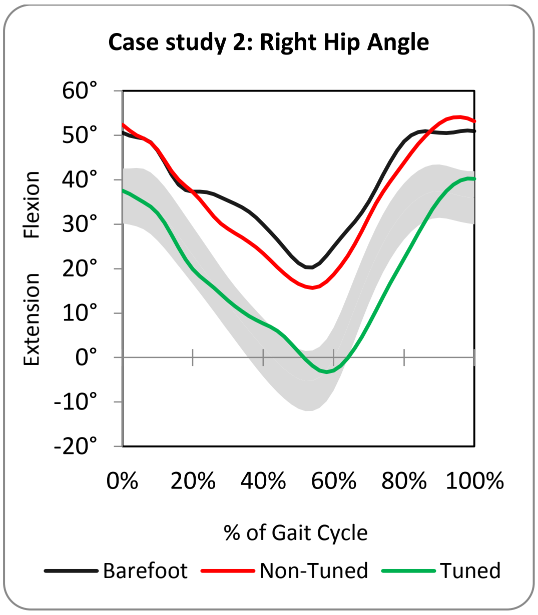


Figure 8.11.1: Graph showing right hip angle

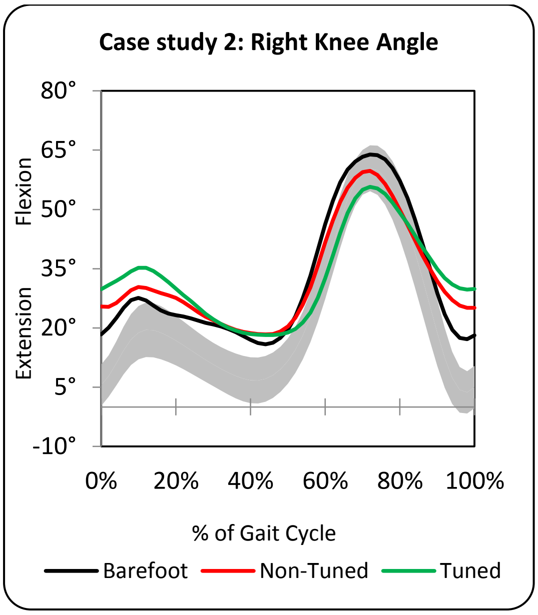


Figure 8.11.2: Graph showing right knee angle

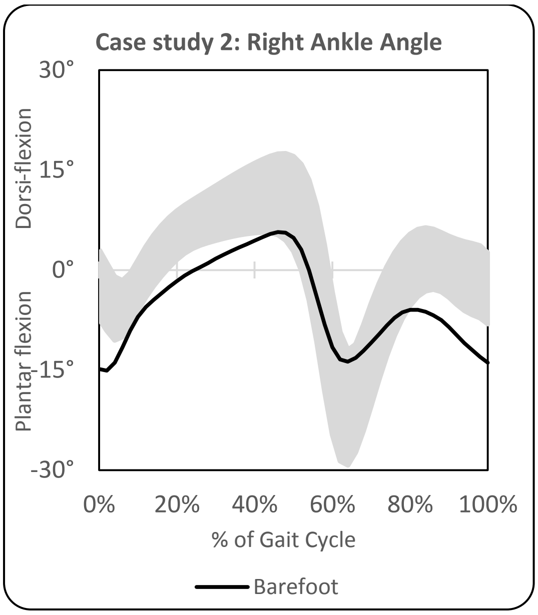


Figure 8.11.3: Graph showing right ankle angle

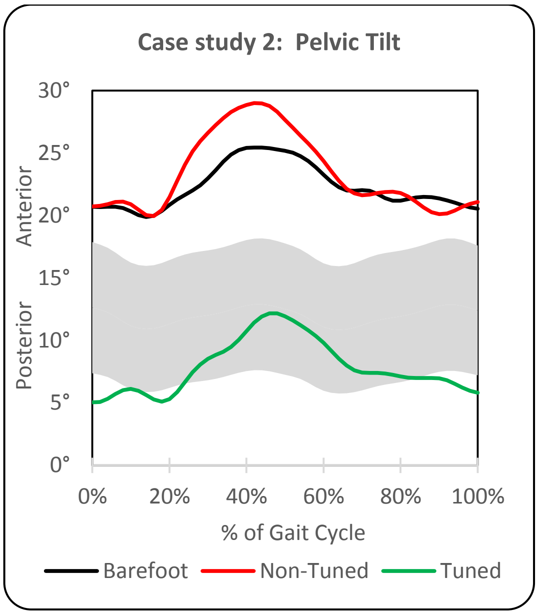


Figure 8.11.4: Graph showing pelvic tilt

Kinetics

Case study 2: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FZ_1 (Peak 1) N/Kg	9.46(1.3)	10.21(0.6)	9.47(0.3)
FZ_2 (Peak 2) N/Kg	9.64(0.28)	9.53(0.41)	9.45(0.41)
FZ_0 (Trough) N/Kg	8.18(1.0)	8.64(0.32)	8.58(0.22)
Vertical Ground Reaction Force data mean average: Key: SD- Standard deviation The black horizontal line in all vertical force graphs demonstrates the bodyweight line at 9.81N/Kg.			

Table 8.9: Case study 2: Right vertical ground reaction force data

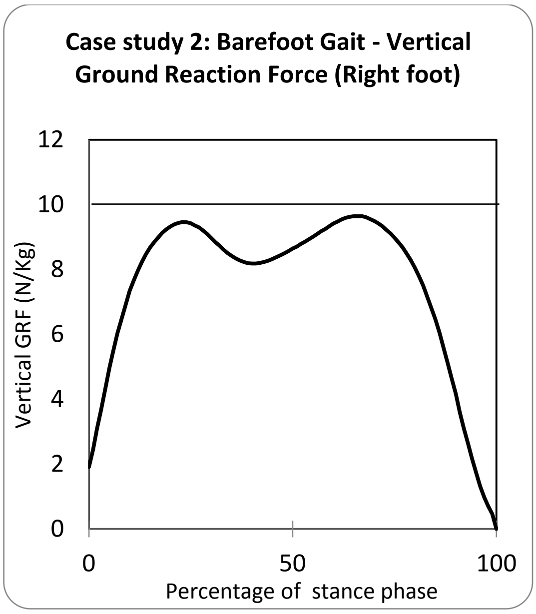


Figure 8.11.5: Graph showing barefoot vertical GRF

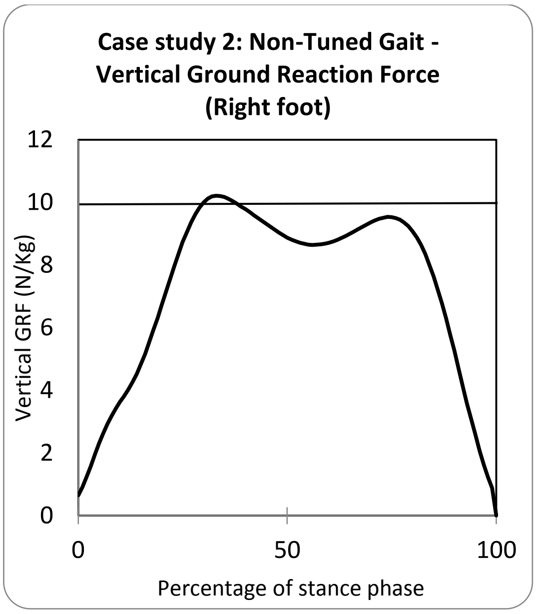


Figure 8.911.6: Graph showing non-tuned vertical GRF

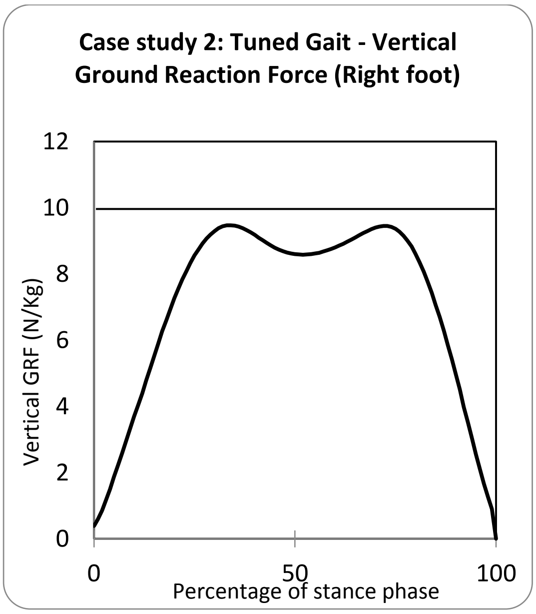


Figure 8.11.7: Graph showing tuned vertical GRF

Case study 2: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FX_4 (Posterior) N/Kg	-1.31(0.21)	-1.08(0.32)	-1.45(0.58)
FX_5 (Anterior) N/Kg	1.17(0.23)	1.3(0.09)	1.06(0.23)
Anterior-Posterior Ground Reaction Force data mean average: Key: SD- Standard deviation.			

Table 8.10: Case study 2: Right anterior-posterior ground reaction force data

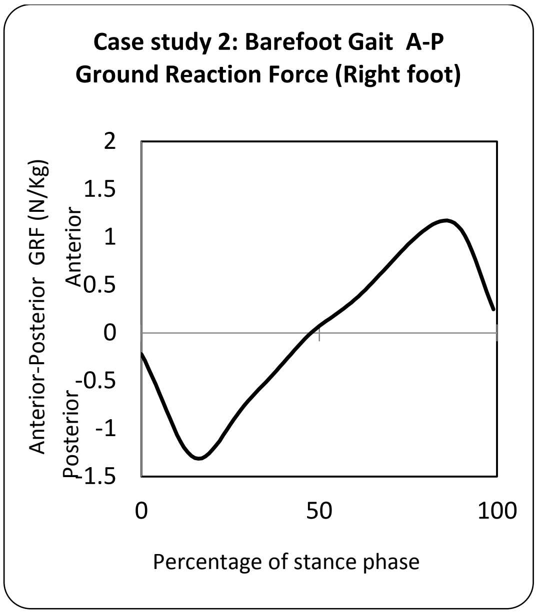


Figure 8.11.8: Graph showing barefoot anterior-posterior GRF

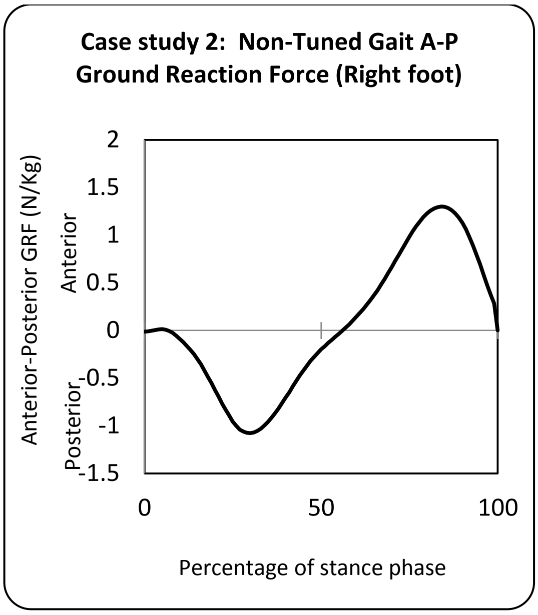


Figure 8.11.9: Graph showing non-tuned anterior-posterior GRF

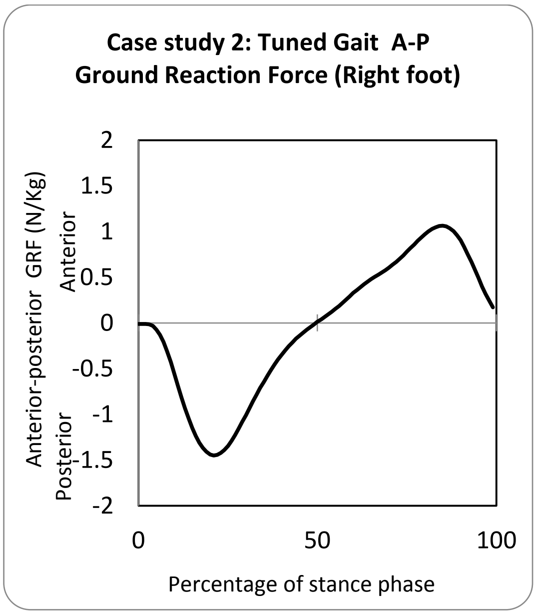


Figure 8.11.10: Graph showing tuned anterior-posterior GRF

8.12 Discussion

The non-tuned AFO-FC gait pattern was similar to the barefoot pattern but with increased hip flexion further outside the range of normal and an increase in the anterior pelvic tilt, most likely caused by the increased hip flexion(229).

With a tuned AFO-FC the participant's knee flexion during swing, hip flexion and extension were within normal range. The increase in knee flexion at I.C in the tuned condition was expected to be higher than normal due to the adapted footwear inclining the shank and is similar to findings by Jagadamma(37). Peak knee flexion decreased to within the lower range of normal. Peak knee extension only changed minimally compared to the non-tuned AFO-FC condition. It appears that the participant used posterior pelvic tilt in an attempt to increase knee extension which indicates the limb advancement was severely curtailed(28), this is often caused by tight hamstrings which this participant demonstrated. Anterior pelvic tilt was also reduced to within normal range in the tuned condition except for I.C, although the single bump pattern still remained.

This curtailing of limb advancement was also evident in the kinetic data. The participant was unable to support his own bodyweight in all three conditions, with the exception of the first peak (FZ_1) in the non-tuned condition. The inability to support one's body weight during the first peak is likely due to reduced function of the lower limb and slow walking speed. The trough was also very shallow on all three vertical GRF graphs, which demonstrates poor movement over the stance limb.

The A-P graphs indicate that the posterior force was also reduced in all three conditions, with the tuned condition being closer to normal values and the non-tuned condition being furthest from normal. In the barefoot and tuned conditions crossover occurred earlier than normal, whilst in the non-tuned condition cross over occurred at 55% of stance phase. The anterior force was reduced in all three conditions with the tuned condition showing the lowest value (1.06 N/Kg), indicating difficulty in propelling the body forward.

Although there was minimal difference between the knee kinematic data for all three conditions, the hip and pelvis data shows a marked improvement in the tuned condition. This could be due to the participant's hip flexion being more in line with their knee flexion in the tuned condition, which in turn produces an improvement in pelvic and trunk kinematics(28)

8.13 Summary

The tuned condition offered the most improvement in 6 of the 12 kinematic parameters tested and the most deterioration in 4 of the 12 parameters. The non-tuned condition offered the most improvement in 1 of the 12 parameters and the most deterioration in 6 of the 12 parameters.

The tuned AFO-FC improved anterior and posterior pelvic tilt, peak hip flexion and extension, hip ROM, walking speed and distance covered. Whilst the non-tuned AFO-FC resulted in several parameters moving further away from normal ranges, including; increased anterior pelvic tilt, increased pelvic ROM, increased peak hip flexion, increased hip flexion in stance. Both conditions increased knee flexion at I.C, peak knee flexion in stance, decreased peak knee extension and peak knee flexion and reduced knee ROM.

Knee extension may have been improved further in the tuned AFO-FC if a ground reaction AFO was used; however, the extent of the knee flexion during stance was not picked up at the initial gait assessment in the clinic, in the absence of kinetic and kinematic data.

Conclusion

The hip and pelvic kinematics were markedly improved in the tuned condition and deteriorated in the non-tuned condition. There was minimal difference in the knee kinematics between all three conditions. The effect at the knee is in line with Butler's(98)prediction regarding successful tuning on patients with hamstring contractures and knee flexion greater than 15° at mid-stance, however, the hip and pelvic kinematics did improve, which highlights the importance of studying the whole of the lower limb rather than focusing on knee kinematics alone.

8.14 Case study three

This participant was a seven year old female with spastic diplegia. She weighed 27.7Kg and was 131cm in height. There was no history of surgery or any medical intervention other than a daily physical therapy regime, which started in 2009.

During the static physical examination, it was noted that the participant had a popliteal angle of 52° on the right, and 48° on the left, which indicates an abnormal hamstring length on the right side(238) which are poor prognostic signs for successful tuning(98). She could achieve 90° at the foot/ankle with the knee extended on the right side, suggesting a loss of PROM in gastrocnemius of approximately 25°(239) and 12° with the knee flexed, indicating a loss of PROM in soleus of approximately 26°. On the left side, there was a reduction of 19° dorsi-flexion with the knee extended and 21° loss of PROM with the knee flexed to 90°. All other parameters were within normal range.

There was an actual leg length discrepancy of 10mm short on the right side. The right foot position was rated as six on the FPI(240). There was a spasticity rating on the right side of 1/5 (0/5 on the left) in the hamstrings, 0/5 in quadriceps bilaterally and 1+/5 (1/5 on the left) in the plantar-flexors, using the modified Ashworth Scale(241). Muscle power on the right was reduced in the hip abductors 4/5 bilaterally on the Oxford scale(205). All other tests were within normal ranges.

The participant walked independently at a rate of 46.27m/min barefoot, which is slower than normal paediatric walking speed(44,207). The barefoot step length for the right measured 0.45m and 0.48m on the left, which is shorter than normal. Cadence was 139.37 steps/minute, which is higher than normal(209). (See table 8.11 for participant temporal-spatial parameters).

During barefoot gait, the participant presented with I.C at the forefoot bilaterally, with the foot plantarflexed at –3.9° (SD-1.42°) on the left and -4.33° (SD -1.95°) on the right, increased flexion of the knee at I.C and delayed knee extension bilaterally at TSt.

The barefoot gait pattern didn't fit into either Winter's(22) or Rodda's(24) classification completely, but was most similar to type IV of Winter's(23) classification for spastic hemiplegia, with the foot in an equinus position at I.C and lacking the first ankle rocker. However, the foot did not remain in equinus throughout gait. There was increased knee flexion at I.C (20.49° SD 2.16 right and 22.71° SD 2.24° on the left) which is approximately 9-11° higher than normal(209). Peak knee flexion was also delayed during swing. Extension of the knee was lower than normal, and peak extension at TSt was delayed. Total hip flexion/extension ROM was lower than normal 25.12° (SD 1.68°) on the right and 26.29° (SD 2.99°) on the left. See figures 8.15.1 – 8.15.7. At TMST knee flexion was 14.5° on the right and 18.6° on the left, knee flexion greater than 15° at mid-stance is a poor prognostic sign for AFO-FC tuning(98)

The participant wore a solid AFO bilaterally, which was cast at a 90° angle and made from 4.5mm homopolymer polypropylene, the trim-lines were anterior to the malleoli and had a full-length footplate stiffened with carbon fibre. The medial and lateral flanges of the footplate were distal to the 1st and 5th MTPJ in an attempt to block the third ankle/foot rocker and reduce knee flexion in stance. The AFO had a loop through calf strap and a figure of 8 ankle strap. The optimum SVA for this participant was 10° with a point loading rocker. The leg length discrepancy was accommodated in the AFO-FC prescription.

8.15 Results

Kinematic and kinetic data points were compared between barefoot baseline non-tuned and tuned AFO-FC gait.

Temporal-spatial parameters

The mean (SD) of the temporal-spatial parameters for barefoot, tuned and non-tuned AFO-FCs are given in Table 8.11. The results indicate that the tuned condition increased the participant's right step length but reduced the left step length and increased the walking speed (52.39 m/min) and distance covered by 25m although cadence decreased over the five trials processed. The non-tuned condition decreased the participant's speed and distance covered, compared to the barefoot baseline.

Kinematics

Whilst wearing a non-tuned AFO-FC the participant demonstrated an increase in knee flexion at I.C to 23.01° (SD 3°) on the left and 23.85° (SD 1.91°) on the right. Peak knee flexion decreased bilaterally to 52.87° (SD 7.70°) on the left and 53.03° (SD 5.83°) on the right but increased in stance. Peak knee extension increased to 6.02° (1.76°) on the left and decreased to 11.16° (SD 1.63°) on the right. Overall knee ROM decreased compared to barefoot. At TMST the patient demonstrated knee flexion of 20° (SD 5.6°) on the left and 20.91° (SD 3.4°) on the right.

Peak hip flexion decreased bilaterally along with hip ROM, both values moving further away from the normal range. Anterior pelvic tilt decreased to 10.22° (SD 3.72) and peak posterior tilt increased to 5.31° (SD 1.8°).

Whilst wearing a tuned AFO-FC the participant demonstrated an increase in knee flexion at I.C to 26.8° (SD 2.66°) on the left and 30.6° (SD 3.17°) on the right, as expected. Peak knee flexion decreased bilaterally to 59.69° (SD 9.06°) on the left and 55.75° (SD 9.9°) on the right but increased in stance. Peak knee extension decreased to 10.66° (2.59°) on the left and 18.17° (SD 1.66°) on the right. Overall knee ROM decreased compared to barefoot. At TMST the patient demonstrated knee flexion of 19.99° (SD 5.62°) on the left and 22.2° (SD 6.5°) on the right.

Peak hip flexion and extension and hip ROM and pelvic tilt were within normal ranges with a tuned AFO-FC.

Case study 3: Descriptive analysis	**Barefoot (SD)**	**Non-Tuned (SD)**	**Tuned (SD)**	**Normal**
Item	**Average**	**Average**	**Average**	**Average**
Left Step Length (m)	0.48 (0.03)	0.46 (0.04)	0.46 (0.03)	0.57
Right Step Length (m)	0.45 (0.03)	0.45 (.03)	0.46 (0.03)	0.57
Steps / Minute (Cadence)	139.37 (9.36)	117.3 (10.95)	112.83 (11.29)	123.18
Metres per minute (Walking speed)	46.27	44.29	52.39	69.6
Distance covered (m)	185.1	177.2	210.2	

Table 8.11: Case study 3: Temporal-spatial parameters

Case study 3: Left	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal (SD)
Pelvic Kinematics				
Peak anterior pelvic tilt	12.5 (3.8)	10.22 (3.72)	12.45 (2.31)	12.9 (5.3)
Peak posterior pelvic tilt	8.16 (2.36)	5.31 (1.8)	8.16 (1.23)	10.9 (5.1)
Pelvic tilt ROM	4.34 (1.44)	4.91 (1.97)	4.29 (1.08)	2 (0.2)
Hip Kinematics				
Peak Hip flexion	38.06 (-0.99)	34.22 (-1.44)	37.79 (-1.86)	38.58 (-0.8)
Peak Hip extension	-11.76 (-3.98)	-12.84 (-6.5)	-6.35 (5.71)	-5.16 (-3.23)
Peak hip flexion (stance)	33.89 (3.98)	30.84 (-4.11)	37.47 (-5.71)	38.6 (-3.23)
Hip ROM	49.83 (2.98)	47.08 (5.05)	44.15 (3.85)	42.72 (1.29)
Knee Kinematics				
Knee flexion at IC	22.71 (2.24)	23.01 (3)	26.8 (2.66)	6.66 (5.24)
Peak knee flexion (stance)	29.24 (3.41)	32.28 (7.37)	37.02 (7.15)	19.52 (6.89)
Peak knee extension	7.30 (1.43)	6.02 (1.76)	10.66 (2.59)	3.7 (5.3)
Peak knee flexion	60.91 (4.15)	52.87 (7.70)	59.69 (9.06)	60.41 (3.69)
Knee ROM	53.54 (2.69)	46.68 (5.92)	48.91 (6.43)	56.72 (3.8)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.				

Table 8.12: Case study 3: Left hip and knee kinematic data

Case study 3: Right	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal (SD)
Pelvic Kinematics				
Peak anterior pelvic tilt	12.5 (3.8)	10.22 (3.72)	12.45 (2.31)	12.9 (5.3)
Peak posterior pelvic tilt	8.16 (2.36)	5.31 (1.8)	8.16 (1.23)	10.9 (5.1)
Pelvic tilt ROM	4.34 (1.44)	4.91 (1.97)	4.29 (1.08)	2 (0.2)
Hip Kinematics				
Peak Hip flexion	35.81 (-2.18)	30.86 (-1.7)	38.58 (-0.8)	38.58 (-0.8)
Peak Hip extension	-10.68 (-3.87)	-12.46 (-5.67)	-5.16 (-3.23)	-5.16 (-3.23)
Peak hip flexion (stance)	30.62 (-3.87)	30.7 (-5.65)	38.6 (-3.23)	38.6 (-3.23)
Hip ROM	46.44 (1.7)	43.27 (3.95)	43.7 (2.43)	42.72 (1.29)
Knee Kinematics				
Knee flexion at IC	20.49 (2.16)	23.85 (1.91)	30.06 (3.17)	6.66 (5.24)
Peak knee flexion (stance)	27.39 (4.89)	34.06 (5.82)	35.3 (6.58)	19.52 (6.89)
Peak knee extension	7.71 (1.83)	11.17 (1.64)	18.17 (1.66)	3.7 (5.3)
Peak knee flexion	64.5 (6.01)	53.02 (5.8)	55.75 (9.9)	60.41 (3.69)
Knee ROM	56.8 (4.25)	41.85 (4.16)	37.6 (8.21)	56.72 (3.8)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.				

Table 8.13: Case study 3: Right hip and knee kinematic data

Case study 3: Ankle Kinematics	Left Barefoot (SD)	Right Barefoot (SD)	Normal (SD)
Dorsi-flexion at I.C	-18.99 (-1.21)	-22.59 (-1.46)	-3.08° (5.12)
Peak Dorsi-flexion	-2.71 (0.1)	-6.34 (0.95)	11.4° (5.72)
Peak Plantar flexion	-28.22 (3.61)	-35.5 (-4.04)	-20.63° (8.62)

Ankle ROM	25.5 (2.61)	29.13 (3.1)	32° (7.33)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees,			

Table 8.14: Case study 3: Ankle kinematic data

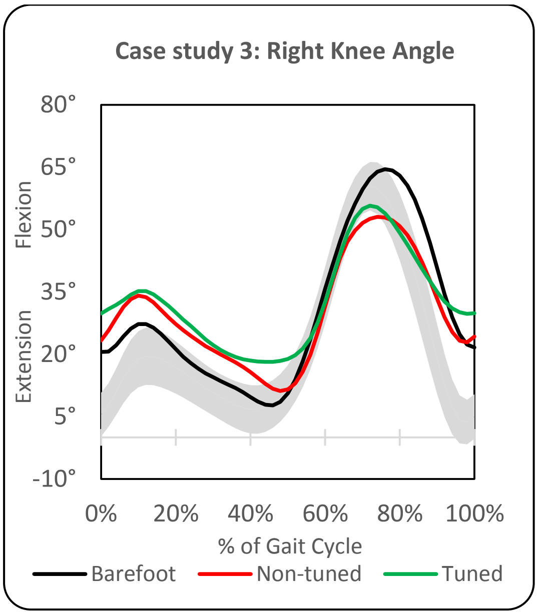


Figure 8.15.1: Graph showing right knee angle

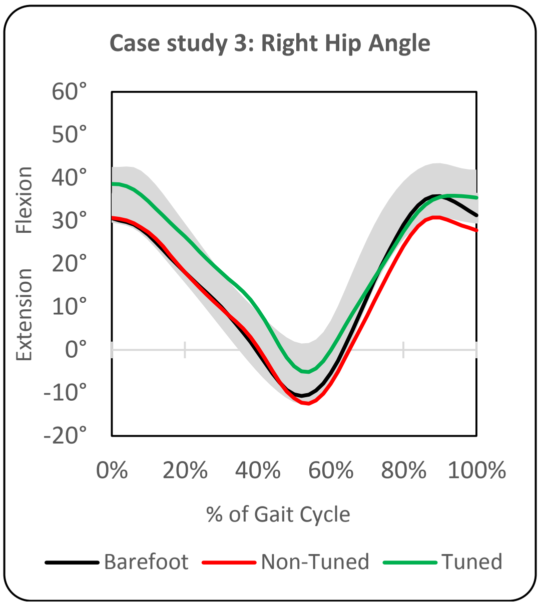


Figure 8.15.2: Graph showing right hip angle

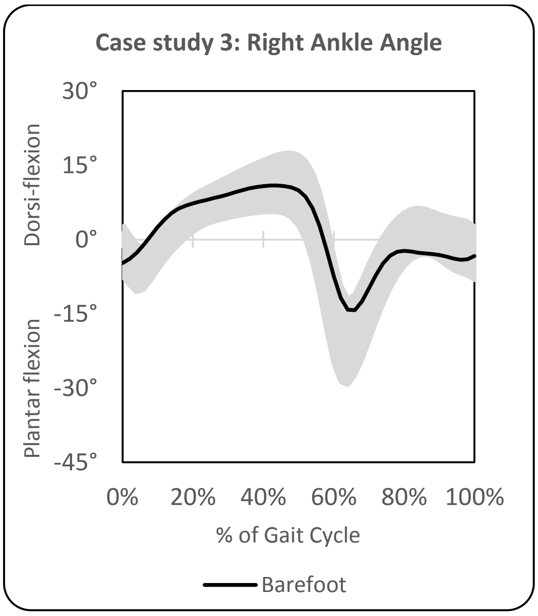


Figure 8.15.3: Graph showing right ankle angle

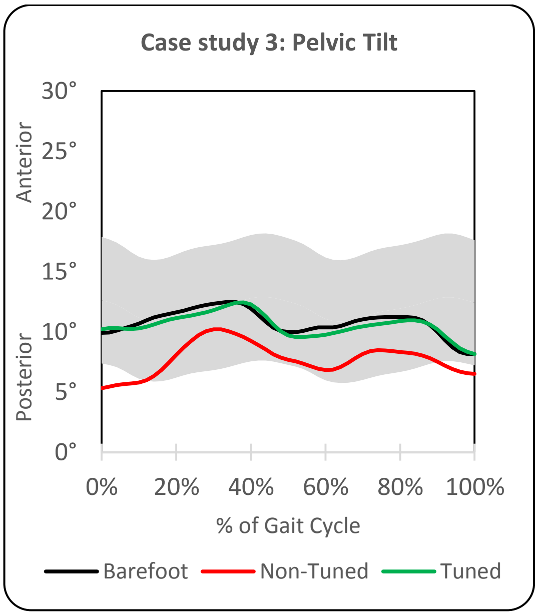


Figure 8.15.4: Graph showing pelvic tilt

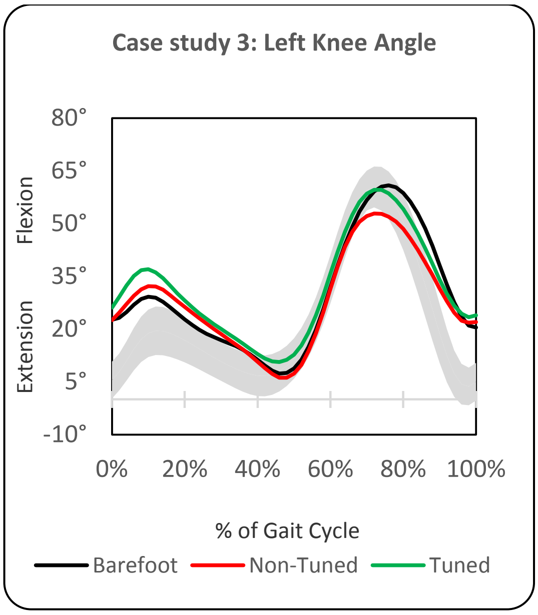


Figure 8.15.5: Graph showing left knee angle

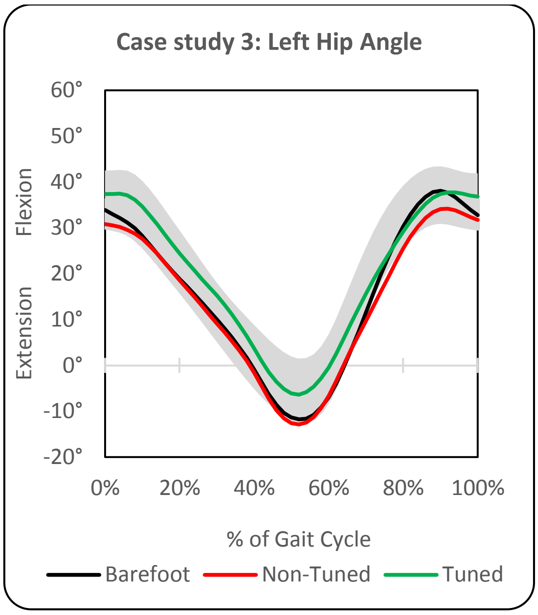


Figure 8.15.6: Graph showing left hip angle

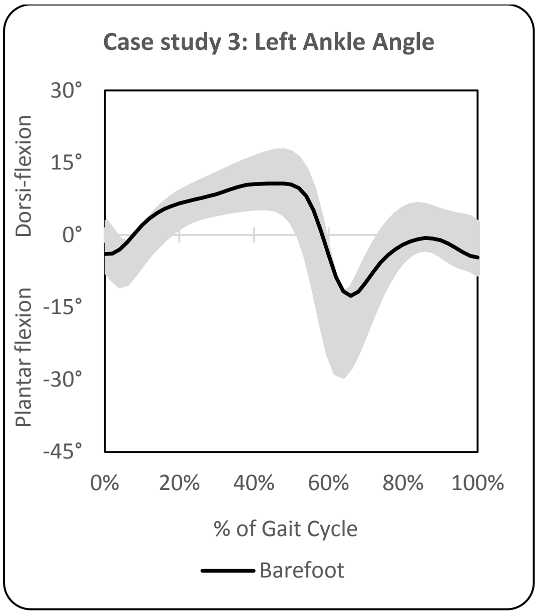


Figure 8.15.7: Graph showing left ankle angle

Kinetics

Case study 3: Left lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FZ_1 (Peak 1) N/Kg	10.93(0.99)	11.2(0.66)	12.24(1.83)
FZ_2 (Peak 2) N/Kg	9.84(0.6)	9.29(0.4)	9.7(0.39)
FZ_0 (Trough) N/Kg	8.88(1.1)	8.72(0.67)	8.75(1.17)
Vertical Ground Reaction Force data mean average: Key: SD- Standard deviation. The black horizontal line in all vertical force graphs demonstrates the bodyweight line at 9.81N/Kg.			

Table 8.15: Case study 3: Left vertical ground reaction force data

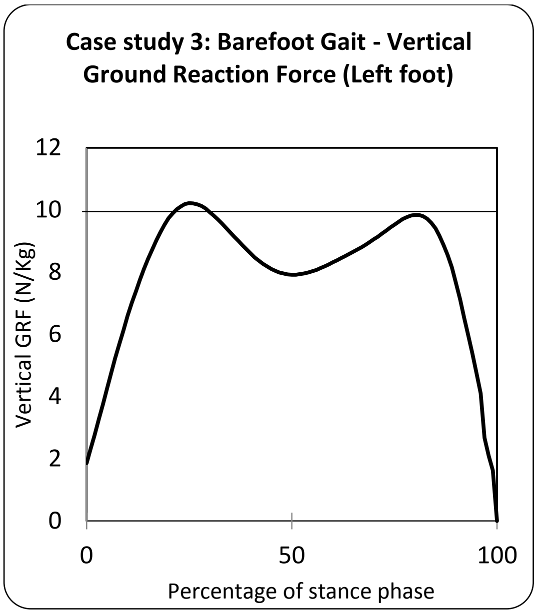


Figure 8.15.8: Graph showing barefoot vertical GRF (left)

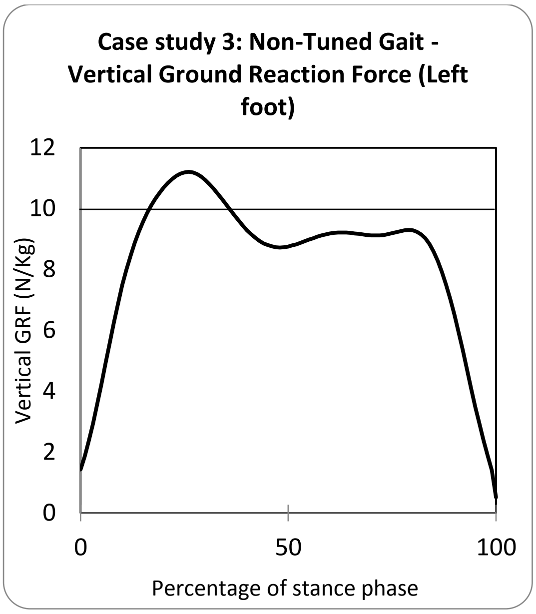


Figure 8.15 .9: Graph showing non-tuned vertical GRF (Left)

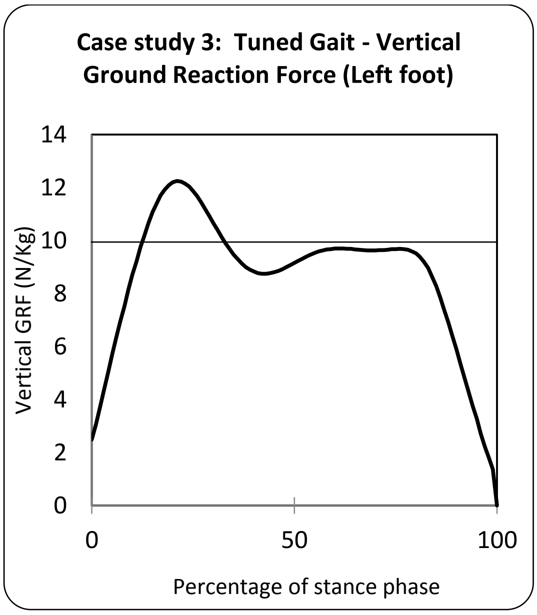


Figure 8.15.10: Graph showing tuned vertical GRF (left)

Case study 3: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FZ_1 (Peak 1) N/Kg	10.48(0.49)	10.93 (0.99)	11.32(0.99)
FZ_2 (Peak 2) N/Kg	9.11(0.72)	8.88(1.1)	10.13(0.48)
FZ_0 (Trough) N/Kg	8.12 (0.19)	9.8(0.55)	9.03(0.78)
Vertical Ground Reaction Force data mean average: Key: SD- Standard deviation. The black horizontal line in all vertical force graphs demonstrates the bodyweight line at 9.81N/Kg.			

Table 8.16: Case study 3: Right vertical ground reaction force data

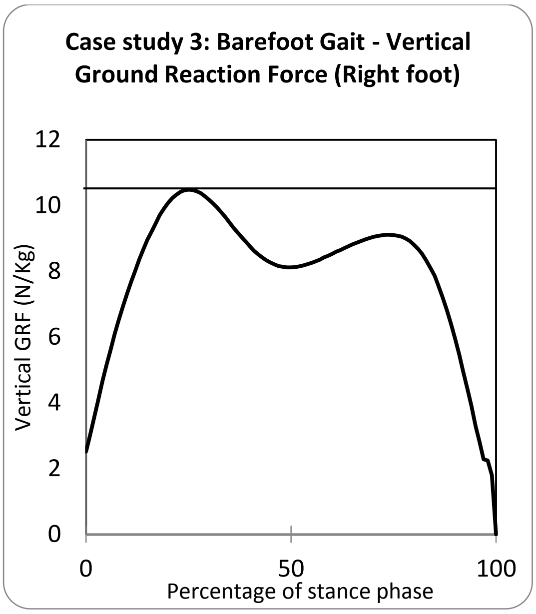


Figure 8.15.11 Graph showing barefoot vertical GRF (Right)

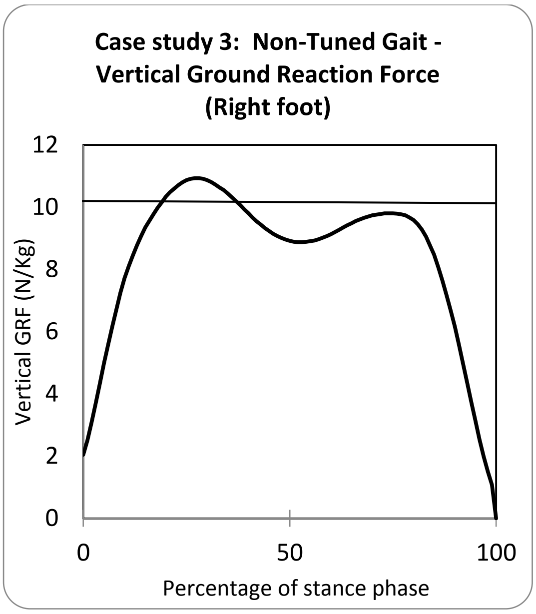


Figure 8.15.11: Graph showing tuned vertical GRF (Right)

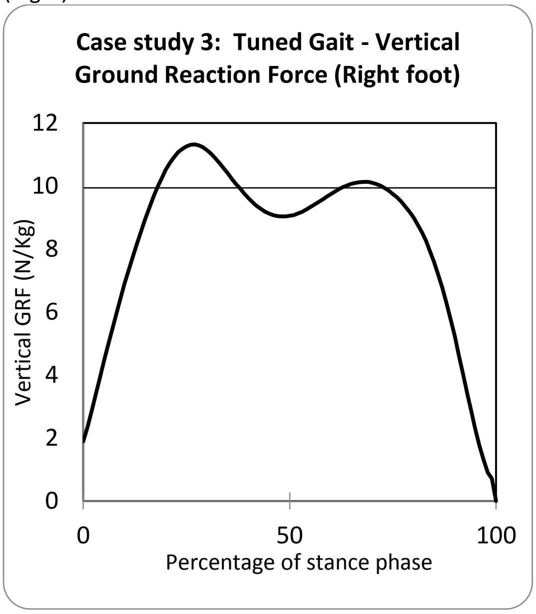


Figure 8.15.12: Graph showing tuned vertical GRF (right)

Case study 3: Left lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FX4 (Posterior) N/Kg	-1.48(0.39)	-1.48(0.18)	-1.488(0.4)
FX5 (Anterior) N/Kg	0.86(0.32)	1.37(0.09)	0.68(0.19)
Anterior-Posterior Ground Reaction Force data mean average: Key: SD- Standard deviation.			

Table 8.17: Case study 3: Left anterior-posterior ground reaction force data

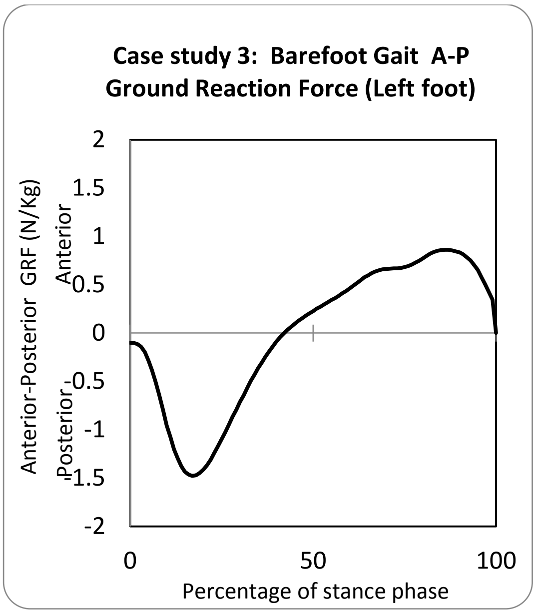


Figure 8.15.13 Graph showing barefoot anterior-posterior GRF (left)

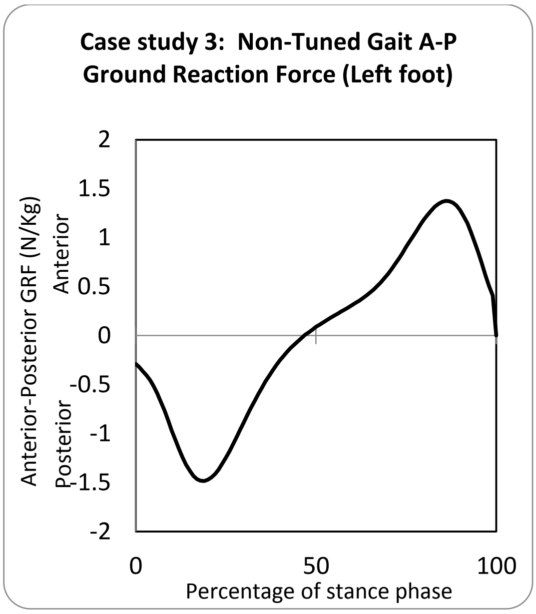


Figure 8.15.14 Graph showing non-tuned anterior-posterior GRF (left)

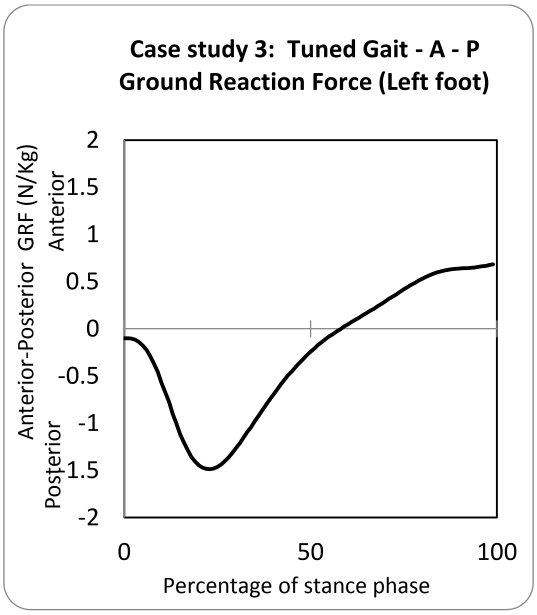


Figure 8.15.15: Graph showing tuned anterior-posterior GRF (left)

Case study 3: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FX_4 (Posterior) N/Kg	-1.32(0.15)	-1.57(0.4)	-1.13(0.16)
FX_5 (Anterior) N/Kg	1.36(0.08)	1.34(0.46)	0.96(0.8)
Anterior-Posterior Ground Reaction Force data mean average: Key: SD- Standard deviation.			

Table 8.18: Case study 3: Right anterior-posterior ground reaction force data

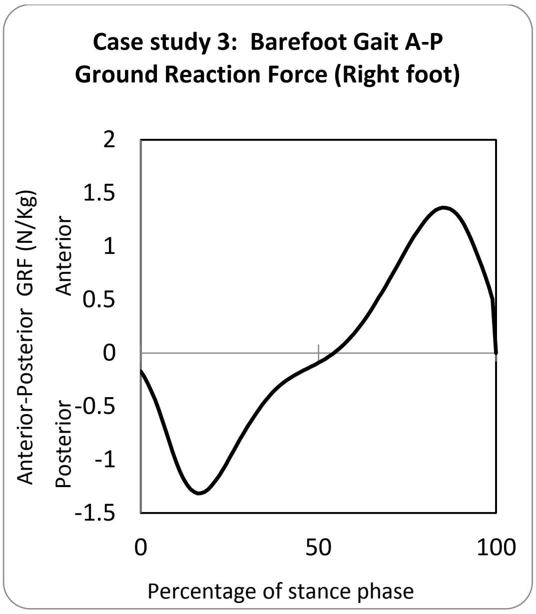


Figure 8.15.3.16: Graph showing barefoot anterior-posterior GRF (right).

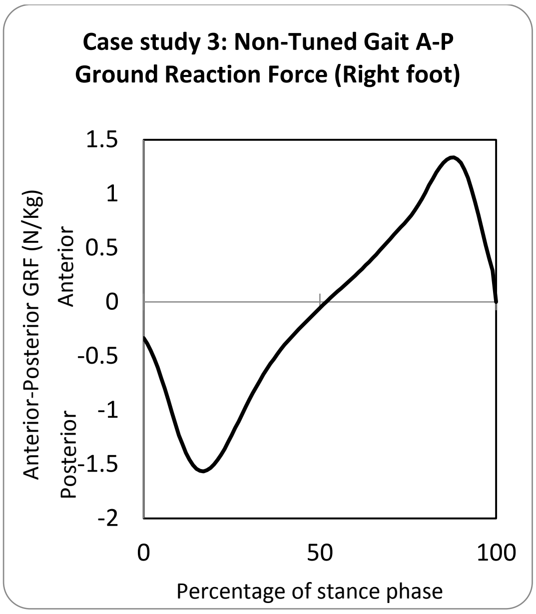


Figure 8.15.17: Graph showing non-tuned anterior-posterior GRF (right).

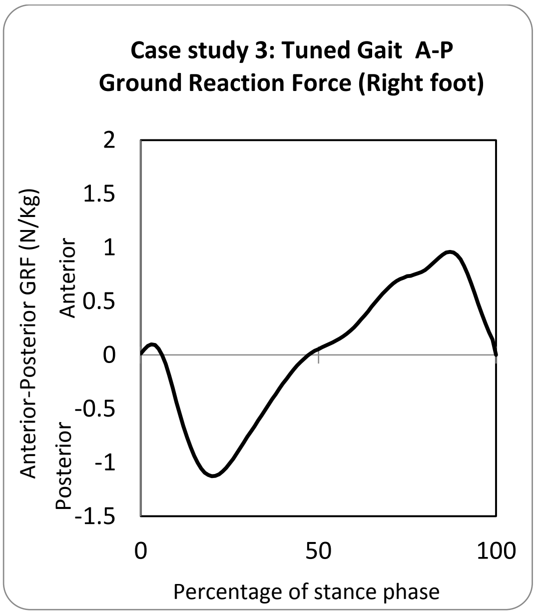


Figure 8.15.18: Graph showing tuned anterior-posterior GRF (right)

8.16 Discussion

With a tuned AFO-FC the participant's hip flexion and extension were within the range of normal. Conversely, the non-tuned AFO-FC decreased hip flexion and increased hip extension further away from the range of normal compared to the participant's barefoot gait. Anterior pelvic tilt was also within normal range in the tuned AFO-FC, whilst the non - tuned AFO-FC decreased the anterior tilt and increased posterior tilt compared to barefoot gait which is most often caused by hamstring contractures resulting in reduced hip extension or hip flexor contracture over activity(229). However, this was not displayed in the barefoot gait. Therefore this appears to be a compensation for the non -tuned AFO-FC.

The increase in knee flexion at I.C, in the tuned condition, is similar to the previous case study; higher than normal due to the adapted footwear inclining the shank and similar to findings by Jagadamma(37). Peak knee flexion remained within normal range bilaterally with the tuned AFO-FC but peak flexion during stance increased above the normal range in both conditions, which might be due to the hamstring contracture on the right and hip flexion returning to normal range in the tuned condition. Alternatively, the blocked ankle in the AFO may have contributed to increased knee flexion in stance, as a result the initial free fall of the foot during loading response carrying the tibia with it, as a result the knee flexes at the same rate as the foot falls(28). The non-tuned AFO also reduced peak knee flexion further away from normal and increased peak knee extension.

Similar to case study two, the hip and pelvic kinematics improved despite an increase in knee flexion further outside of normal. However, this could be in line with Perry's(28) claim regarding the relationship between knee flexion and hip flexion producing an improvement in pelvic and trunk kinematics.

The kinetic data showed that the participant was able to support their bodyweight in barefoot gait and tuned condition on the left side with the tuned condition demonstrating the highest vertical forces. In both the tuned and non-tuned conditions the second peak (FZ_2) was lower than the first peak, this is often termed "Ben Lomonding"(235) and is common in CP children. However, the force generated in the non-tuned condition was too low to support the patient's bodyweight which resulted in a premature switch of the bodyweight to the right lower limb in the non-tuned gait, most likely in an attempt to prevent the lower limb from collapsing into flexion. The force generated in the non-tuned condition during the second peak was furthest away from normal.

On the right lower limb the barefoot and the non-tuned conditions produced a reduced second peak (FZ_2) below bodyweight, this increased in the tuned condition to 10.13/Kg which is above bodyweight.

The A-P graphs indicate that the forces produced in all three conditions were below normal values, with the anterior force in the tuned condition being particularly low, demonstrating a reduced ability to propel the body forward.

8.17 Summary

The tuned condition offered the most improvement in 5 of the 12 kinematic parameters tested and the most deterioration in 3 of the 12 parameters. The non-tuned condition offered the most improvement in 1 of the 12 parameters and the most deterioration in 8 of the 12 parameters.

The tuned AFO-FC improved distance covered and speed of gait, peak posterior pelvic tilt (right limb), pelvic tilt ROM (right limb), peak hip flexion (right limb) peak hip extension (left and right limbs) peak hip extension during stance (left and right limbs), and hip ROM (left limb). Peak posterior tilt was unchanged and within normal range on the left limb. Knee flexion during stance was increased to above normal ranges bilaterally, and peak knee extension decreased further away from normal bilaterally. Vertical forces were also raised to above bodyweight in late stance phase.

The non-tuned AFO-FC resulted in several parameters moving further away from normal ranges, including; increased anterior and posterior pelvic tilt (bilaterally), increased pelvic ROM (bilaterally), decreased peak hip flexion (bilaterally) and increased hip extension (bilaterally) and decreased hip ROM (bilaterally).

Conclusion

Despite a popliteal angle greater than 45° and knee flexion greater than 15° at mid-stance, this participant demonstrated improvement in their hip and pelvic kinematics in the tuned condition; in contrast, the non-tuned condition caused deterioration in pelvic and hip kinematics.

8.18 Case study four

This participant was a ten year old male with spastic diplegia with the left side predominately affected. He weighed 31.6Kg and was 140cm in height. Open calf lengthening was carried out in 2011 on the left side, and botulinum injections into the left gastrocnemius was administered in 2010 and in the hamstrings in 2011. The participant started a daily physical therapy regime in 2005.

During the static physical examination, it was noted that the participant had a popliteal angle of 56° on the left which indicates an abnormal hamstring length on the left side(238) and is a poor prognostic sign for successful AFO-FC tuning (98), the right side measured 40°. He could achieve -8° at the foot/ankle with the knee extended on the left side, suggesting a loss of PROM in gastrocnemius of approximately 34°(239) and 90° with the knee flexed, suggesting a loss of PROM in soleus of approximately 42°. On The right side, he could achieve 10° dorsi-flexion with the knee extended indicating a reduction of 17° dorsi-flexion with the knee extended and 21° loss of PROM with the knee flexed to 90°. There was a reduction in subtalar inversion of 13° on the left. All other parameters were within normal range.

There was an actual leg length discrepancy of 15mm short on the left side and an apparent discrepancy of 4mm. He presented with a left foot position rated as eight on FPI(240) and seven on the right side. There was a spasticity rating on the left side of 2+/5 (0/5 on the right) in the hamstrings, 0/5 in quadriceps bilaterally and 2+/5 (0/5 on the right) in the plantar-flexors, using the modified Ashworth Scale(241). All other tests were within normal ranges.

The participant walked independently at a rate of 36.4 m/min barefoot, which is slower than normal paediatric walking speed(44,207). The barefoot step length measured 0.36m (0.03) on the left and 0.43m (SD 0.03) on the right which are shorter than normal. Cadence was 87.9 (SD 6.7) steps/min, which is lower than normal(209). (See table 8.19 for participant temporal-spatial parameters).

During barefoot gait, the participant presented with I.C at the forefoot on the left, with the foot plantarflexed at -9.47° (SD -2.91°), with minimal dorsi-flexion outside the range of normal throughout MSt, and plantarflexion throughout swing phase. There was increased flexion of the knee at I.C with the knee moving into extension during L.R. He demonstrated a reduced peak knee flexion during swing, and this was also delayed. There was reduced hip flexion during I.C, L.R and MSt. Pelvic tilt exhibited the single bump pattern, and there was excessive posterior pelvic tilt at TSt and PSw.

The barefoot gait pattern didn't fit into either Winter's(23) or Rodda's(24) classification completely. It was most similar to type IV of Winter's(23) classification for spastic hemiplegia, with I.C with the foot in an equinus position and lacking the first ankle rocker. However, there was minimal dors-flexion during Mst and TSt. There was increased knee flexion at I.C (22.19° SD 2.34) on the left which is approximately 15.5° higher than normal(209). Peak knee flexion was also delayed during swing. Peak knee extension was lower than normal (8.09° SD 1.11°). Peak hip flexion in stance was lower than normal (25.7 SD -2.4°). Peak posterior pelvic tilt was excessively high (2.8° SD 1.14°) and there was a double bump pattern which is often caused by reduced hip extension(229), which is not described by Winter's(23) for this group. See figures 8.19.1 – 8.19.4.

The participant wore a solid AFO on the left side, which was cast at an 8° angle and had a SAB build up to 90°. The AFO was made from 4.5mm homopolymer polypropylene, the trim-lines were anterior to the malleoli and had a full-length stiff footplate. The medial and lateral flanges of the footplate were distal to the 1st and 5th MTPJ in an attempt to block the third ankle/foot rocker and reduce knee flexion in stance. The AFO had a loop through calf strap and a figure of 8 ankle strap. The optimum SVA for this participant was 13° with a rounded forefoot rocker adaptation to the footwear. The leg length discrepancy was accommodated in the AFO-FC prescription.

8.19: Results

Kinematic and kinetic data points were compared between barefoot baseline non-tuned and tuned AFO-FC gait.

Temporal-spatial parameters

The mean (SD) of the temporal-spatial parameters for barefoot, tuned and non-tuned AFO-FCs are given in Table 8.19. The results indicate that the tuned condition increased the participant's left and right step length and increased the walking speed (49.91 m/min) and cadence (106.62 steps/min SD 7.1) and increased distance covered by 54.1m over the five trials processed. The non-tuned condition increased the same parameters, but they were lower than that achieved in the tuned condition.

Kinematics

Whilst wearing a non-tuned AFO-FC the participant demonstrated an increase in knee flexion at I.C to 25.5° (SD 4.11°) on the left. Peak knee flexion decreased to 43.15° (SD 5.5°) but increased in stance to 28.08° (SD 4.96°). Peak knee extension decreased to 14.82° (SD 1.38°). Overall knee ROM decreased compared to barefoot. At TMST the patient demonstrated knee flexion of 16.54° (SD 2.57°).

Peak hip flexion and peak hip flexion in stance decreased along with hip ROM, all values moving further away from the normal range. Anterior pelvic tilt increased to 14.4° (SD 2.42) and peak posterior tilt decreased to 5.53° (SD 0.7°).

Whilst wearing a tuned AFO-FC the participant demonstrated a decrease in knee flexion at I.C to 17.64° (SD 2.87°). Peak knee flexion decreased to 35.78° (SD 5.95°) but increased in stance. Peak knee extension was unchanged compared to barefoot gait. Overall knee ROM decreased compared to barefoot. At TMST the patient demonstrated knee flexion of 14.02° (SD 1.25°).

Peak hip flexion and extension and hip ROM and pelvic tilt were within normal ranges with a tuned AFO-FC.

Case study 4: Descriptive analysis	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal
Item	**Average**	**Average**	**Average**	**Average**
Left Step Length (m)	0.36 (0.03)	0.44 (0.05)	0.43 (0.03)	0.57
Right Step Length (m)	0.43 (0.03)	0.53 (0.05)	0.56 (0.03)	0.57
Steps / Minute (Cadence)	87.9 (6.7)	92.95 (9.81)	106.62 (7.1)	123.18
Metres per minute (Walking speed)	36.4	45.6	49.91	69.6
Distance covered (m)	145.6	182.7	199.7	

Table 8.19 Case study 4: Temporal-spatial parameters

Case study 4: Left Leg	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal (SD)
Pelvic Kinematics				
Peak anterior pelvic tilt	12.10 (2.99)	14.8 (2.42)	16.28 (1.9)	12.9 (5.3)
Peak posterior pelvic tilt	2.8 (1.14)	5.53 (0.7)	7.22 (0.93)	10.9 (5.1)
Pelvic tilt ROM	9.33 (1.84)	9.28 (1.73)	9.1 (0.94)	2 (0.2)
Hip Kinematics				
Peak Hip flexion	34.00 (-0.62)	28.28 (-1.73)	32.57 (0.75)	38.58 (-0.8)
Peak Hip extension	-2.67 (-3.74)	-5.81 (-4.15)	-4.15 (-2.63)	-5.16 (-3.23)
Peak hip flexion (stance)	25.7 (-2.4)	23.76 (-3.8)	32.57 (-2.6)	38.6 (-3.23)
Hip ROM	36.57 (3.12)	34.05 (2.4)	36.72 (1.87)	42.72 (1.29)
Knee Kinematics				
Knee flexion at IC	22.19 (2.34)	25.5 (4.11)	17.64 (2.87)	6.66 (5.24)
Peak knee flexion (stance)	22.42 (3.55)	28.08 (4.96)	24.01 (3.66)	19.52 (6.89)
Peak knee extension	8.09 (1.11)	14.82 (1.38)	8.16 (1.22)	3.7 (5.3)
Peak knee flexion	55.19 (7.86)	43.15 (5.5)	35.78 (5.95)	60.41 (3.69)
Knee ROM	47.03 (6.68)	28.3 (4.1)	27.56 (4.73)	56.72 (3.8)
Key: SD- Standard deviation I.C – initial contact, all values in degrees.				

Table 8.20: Case study 4: Left hip and knee kinematic data

Case study 4: Left Ankle Kinematics	Barefoot (SD)	Normal (SD)
Dorsi-flexion at I.C	-9.5 (-2.91)	-3.08° (5.12)
Peak Dorsi-flexion	4 (-0.9)	11.4° (5.72)
Peak Plantar flexion	-18.95 (6.44)	-20.63° (8.62)
Ankle ROM	22.96 (5.56)	32° (7.33)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees,.		

Table 8.21: Case study 4: Left ankle kinematic data

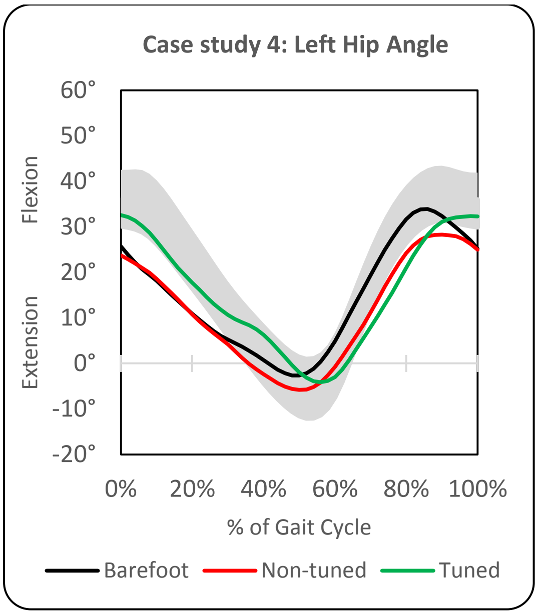


Figure 8.19.1: Graph showing left hip angle

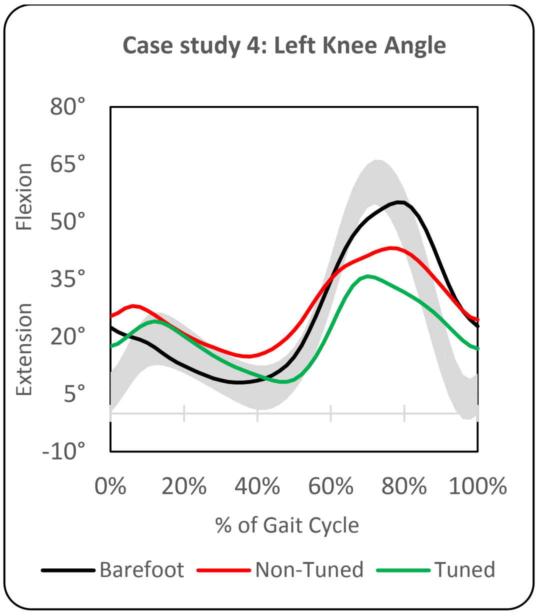


Figure 8.19.2: Graph showing left knee angle

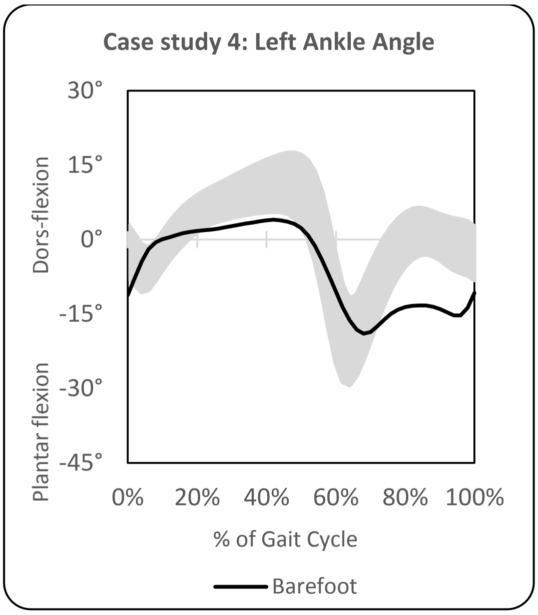


Figure 8.19.3: Graph showing left ankle angle

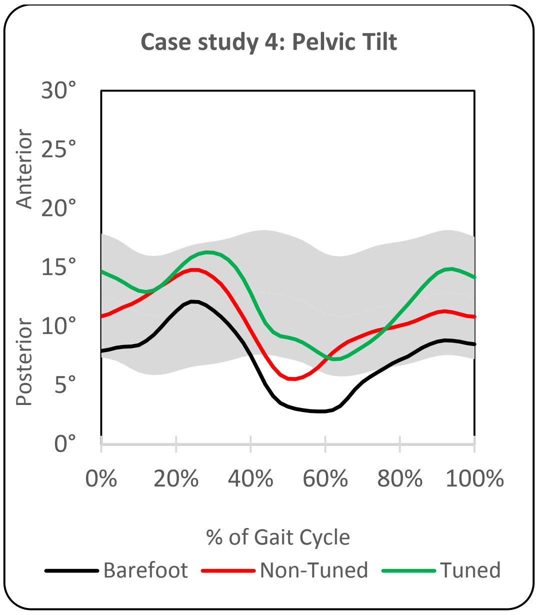


Figure 8.19.4: Graph showing pelvic tilt

Kinetics

Case study 4: Left lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FZ_1 (Peak 1) N/Kg	10.16(0.34)	10.56(0.37)	12.23(0.68)
FZ_2 (Peak 2) N/Kg	10.14(0.12)	10.28(0.2)	10.57(0.26)
FZ_0 (Trough) N/Kg	9.02(0.2)	8.69(0.32)	7.85(0.4)
Vertical Ground Reaction Force data mean average: Key: SD- Standard deviation. The black horizontal line in all vertical force graphs demonstrates the bodyweight line at 9.81N/Kg.			

Table 8.22: Case study 4: Left vertical ground reaction force data

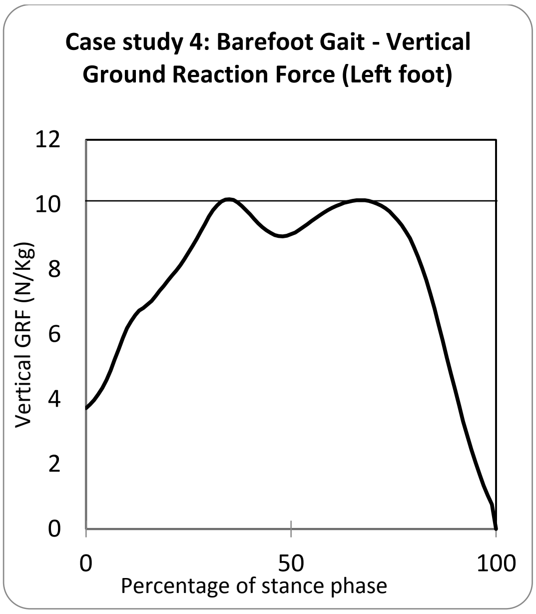


Figure 8.19.5: Graph showing barefoot vertical GRF

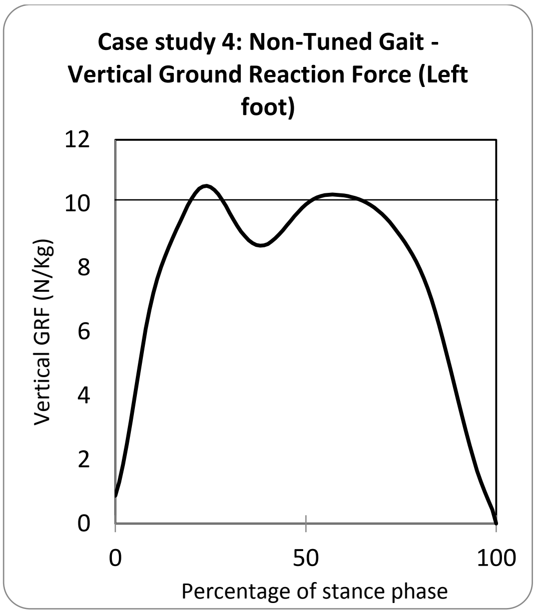


Figure 8.19.6: Graph showing non-tuned vertical GRF

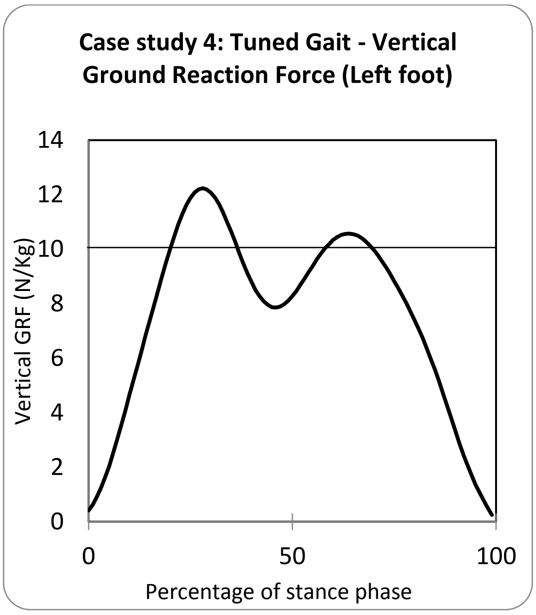


Figure 8.19.7: Graph showing tuned vertical GRF

Case study 4: Left lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FX_4 (Posterior) N/Kg	-0.48(0.22)	-1.36(0.33)	-0.98(0.19)
FX_5 (Anterior) N/Kg	0.85(0.14)	1.78(0.14)	1.17(0.14)
Anterior-Posterior Ground Reaction Force data mean average: Key: SD- Standard deviation,			

Table 8.23: Case study 4: Left anterior-posterior ground reaction force data

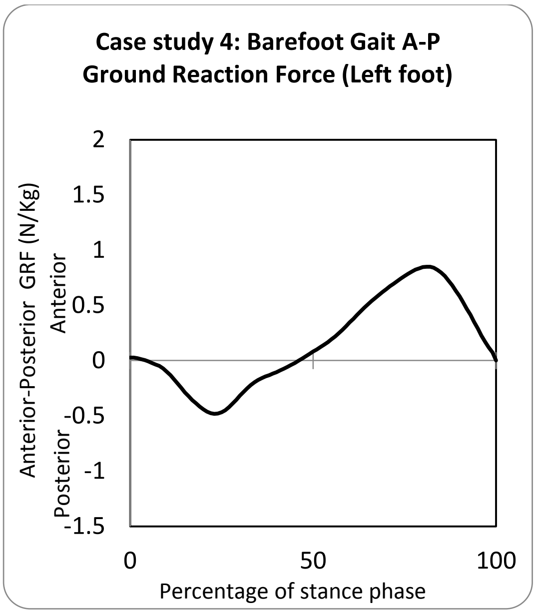


Figure 8.19.8: Graph showing barefoot anterior-posterior GRF

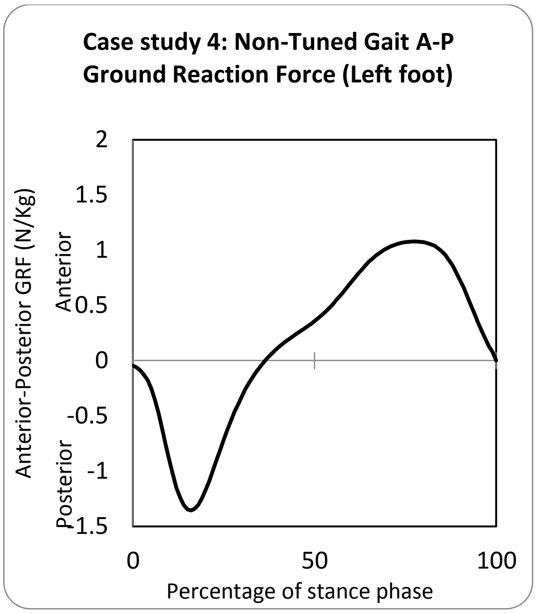


Figure 8.19.9: Graph showing non-tuned anterior-posterior GRF

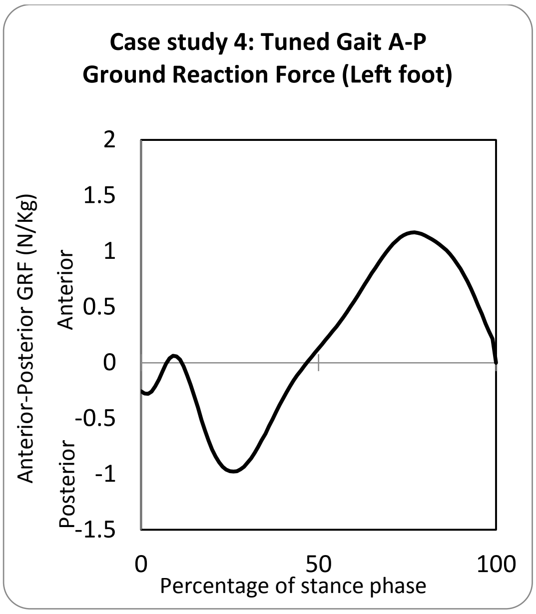


Figure 8.19.10: Graph showing tuned anterior-posterior GRF

8.20 Discussion

With a tuned AFO-FC the participant's hip flexion and extension were within the range of normal. Conversely, the non-tuned AFO-FC decreased hip flexion further away from the range of normal during swing and stance phase, compared to the participant's barefoot gait. I.C with reduced hip flexion reduces the demand on the hip extensors. To compensate for lack of hip flexion posterior tilt of the pelvis uses the abdominal muscles to advance the thigh. See figure 8.19.4 for this participant's excessive posterior tilt in the barefoot and non-tuned conditions. Advancing the limb in this manner utilises considerable energy as so much trunk mass must be moved(28), which might explain why the energy expenditure for this participant was lower in the tuned condition compared to the non-tuned condition even though the distance and speed increased. Initiation of voluntary excessive knee flexion can also be utilised as an indirect means of flexing the hip.

The decrease in knee flexion at I.C in the tuned condition is similar to case study one but contrary to the other case studies and findings in Jagadamma's(37) study. Peak knee extension was largely unchanged in the tuned condition compared (8.16° SD 1.22°) to the barefoot gait, but, decreased further away from normal in the non-tuned condition (14.82° SD1.38°).

Peak knee flexion in stance remained within normal range in the tuned AFO-FC but increased further away from normal in the non-tuned condition. Peak knee flexion in swing decreased further away from normal with the tuned AFO-FC, which results in a reduced push off during the third ankle rocker. This gait deviation can be caused by an overactive rectus femoris(229), which was not picked up during the physical examination. Another explanation might be due to the hamstring contracture on the left and the hip flexion returning to normal range. Alternatively, the blocked ankle in the AFO may have contributed to increased knee flexion in stance, as a result the initial free fall of the foot during loading response carrying the tibia with it, causing the knee to flex at the same rate as the foot falls(28). Alternatively, an increase in hip flexion may have resulted in a reduction in knee flexion during swing due to adequate clearance of the swing limb. Similarly, the increase in knee flexion in the barefoot and non-tuned conditions may be due to an inability to clear the floor due to reduced hip flexion.

It is important to not only focus on individual data points when analysing kinematics, in doing so one would miss the change in gait pattern in this participant's knee kinematics. It appears that there is little difference between the knee extension values during stance in the barefoot and tuned conditions, however, the introduction of an AFO produced a normal pattern with the knee moving from extension to flexion to extension during stance phase, whilst in the barefoot condition the knee moves immediately into extension, which reduces the ability of the shock absorption capability of the lower limb.

The kinetic data indicated that the vertical forces were not high enough to support the bodyweight in the barefoot condition. The trough (FZ_0) shows the patient was unable to move the body over the stance limb adequately, was also reduced, this ties in with the reduced step length and slow walking speed in this condition. The non-tuned condition improved the vertical forces to above bodyweight and indicated an improved movement of the body over the stance limb; this was further enhanced in the tuned condition. Similarly, the anterior-posterior forces in the barefoot condition indicated a reduction in posterior and anterior forces compared to the non-tuned and tuned AFO-FC conditions; with the non-tuned condition generating the highest forces.

8.21 Summary

The tuned condition offered the most improvement in 5 of the 12 kinematic parameters tested and the most deterioration in 2 of the 12 parameters. The non-tuned condition offered the most improvement in 1 of the 12 parameters and the most deterioration in 6 of the 12 parameters.

The tuned AFO-FC improved distance, cadence, step length and speed of gait, posterior pelvic tilt, peak hip flexion, peak hip extension, peak hip flexion during stance and knee flexion at I.C. The vertical GRF was also improved the most in this condition. However, there was deterioration in peak anterior tilt, peak knee flexion and knee ROM.

The non-tuned AFO-FC improved the same temporal-spatial parameters, but the improvement was not as high as the tuned condition. The non-tuned condition resulted in deterioration in hip flexion in stance and swing and hip ROM, an increase in knee flexion at I.C further from normal ranges, and an increase in peak knee flexion during stance further from normal ranges, a decrease in peak knee extension further away from normal ranges. An improvement in hip extension in addition, the A-P forces improved the most in this condition.

Conclusion

Despite a popliteal angle greater than 45° the hip and pelvic kinematics all improved in the tuned condition. Despite there appearing to be little difference between the knee extension data in barefoot and tuned conditions, critically, the introduction of an AFO changed the gait pattern of the knee during stance phase to allow shock absorption.

8.22 Case study five

This participant was a nine year old male with spastic diplegia with the right side predominately affected. He weighed 25.8Kg and was 131cm in height. There was no history of any surgical intervention or botoxilium injections. The participant started a daily physical therapy regime in 2008.

During the static physical examination it was noted that the participant had a popliteal angle of 40° bilaterally, which indicates normal hamstring length(238). He could achieve 90° at the foot/ankle with the knee extended on the right side, suggesting a loss of PROM in gastrocnemius of approximately 24°(239) and 90° with the knee flexed, suggesting a loss of PROM in soleus of approximately 42°. On The left side, he could achieve 10° dorsi-flexion with the knee extended indicating a reduction of 17° dorsi-flexion with the knee extended and 23° loss of PROM with the knee flexed to 90°. All other parameters were within normal range.

There was an actual leg length discrepancy of 15mm short on the right side. He presented with a right foot position rated as eight on the FPI(240) and six on the left side. There was a spasticity rating on the right side of 1/5 (0/5 on the left) in the hamstrings, 1/5 in quadriceps bilaterally and 2/5 (1+/5 on the left) in the dorsi-flexors, 2/5 on the right (1/5 on the left) in the plantar-flexors, using the modified Ashworth Scale(241). There was a reduction in muscle power in the hamstrings of 4/5 on the right side (5/5 on the left) using the Oxford (205). All other tests were within normal ranges.

The participant walked independently at a rate of 56.66 m/min barefoot which is slower than normal paediatric walking speed(44,207). The barefoot step length measured 0.50m (0.03) on the left and 0.47m (SD 0.02) on the right which is shorter than normal. Cadence was 112.3 (SD 4.6) steps/min, which is lower than normal(209). (See table 8.24 for participant temporal-spatial parameters).

During barefoot gait, the participant presented with I.C at the forefoot on the left, with the foot plantarflexed at -6.1° (SD -1.48°) on the right, with minimal dorsi-flexion throughout MSt and plantarflexion throughout swing phase. The first ankle rocker was missing. There was increased flexion of the knee at I.C with the knee moving into hyperextension throughout MSt and TSt. There was reduced peak knee flexion during stance of 5.29° (SD 6.04°). There was also reduced hip flexion during I.C, L.R and MSt. accompanied by excessive posterior pelvic tilt at I.C and L.R.

The barefoot gait pattern didn't fit into either Winter's(23) or Rodda's(24) classification completely but was most similar to type II of Winter's(14) classification for spastic hemiplegia, with I.C with the foot in an equinus position and lacking the first ankle rocker, however, there was minimal dorsi-flexion during Mst and TSt. There was increased knee flexion at I.C (13.65° SD 4.04°) on the right which is approximately 6.94° (SD 5.24°) higher than normal(4), peak knee flexion during stance was lower than normal (5.29° SD 6.04°). Peak knee extension was higher than normal (-3.84° SD 1.61°). Peak hip flexion was lower than normal (31.74° SD -1.01°) as was peak hip flexion in stance (24.1° SD -2.85°). Peak hip extension was almost twice as high as normal (-10.6° SD -4.23°) as was peak posterior pelvic tilt (4.63° SD 1.73°), pelvic tilt ROM was higher than normal (8.38° SD 2.68°). See figures 8.23.1 – 8.23.4.

This participant wore a solid AFO on the left side, which was cast at a 90° angle. The AFO was made from 4.5mm homopolymer polypropylene; the trim-lines were anterior to the malleoli and had a full-length footplate. The medial and lateral flanges of the footplate were proximal to the 1st and 5th MTPJ, and the footplate was made flexible at the forefoot in an attempt to facilitate the third ankle/foot rocker and reduce knee hyperextension in stance. The AFO had a loop through calf strap and a figure of 8 ankle strap. The optimum SVA for this participant was 11°. The leg length discrepancy was accommodated in the AFO-FC prescription.

8.23: Results

Kinematic and kinetic data points were compared between barefoot baseline non-tuned and tuned AFO-F.

Temporal-spatial parameters

The mean (SD) of the temporal-spatial parameters for barefoot, tuned and non-tuned AFO-FCs are given in Table 8.24. The results indicate that the tuned condition increased the participant's left and right step length and increased walking speed (57.17 m/min) but reduced the cadence. The non-tuned condition increased the same parameters but decreased the speed and the distance covered compared to barefoot gait.

Kinematics

Whilst wearing a non-tuned AFO-FC the participant demonstrated an increase in knee flexion at I.C to 17.85° (SD 5.9°) on the right. Peak knee flexion remained the same at 57.77° (SD 12.52°) but increased in stance to 22.97° (SD 7.42°). Peak knee extension decreased to 1.6° (2.27°). Overall knee ROM decreased compared to barefoot. At TMST the patient demonstrated knee flexion of 4.14° (SD 6.18°).

In the non-tuned condition, peak hip flexion remained the same, but hip ROM reduced to 38.08° (SD 3.5°), moving further away from the normal range. Anterior pelvic tilt decreased to 11.35° (SD 1.57°) and peak posterior tilt increased to 2.5° (SD 0.52°).

Whilst wearing a tuned AFO-FC the participant demonstrated an increase in knee flexion at I.C to 26.2° (SD 1.6°). Peak knee flexion increased to 58.57° (SD 5.85°) moving closer to normal and increased in stance moving further away from normal. Peak knee extension decreased to 1.91° (SD 0.96°). Overall knee ROM reduced to within normal range, compared to barefoot. At TMST the patient demonstrated knee flexion of 16.86° (SD 1.59°).

Peak hip flexion and extension and hip ROM were all within normal range in the tuned condition. Peak anterior pelvic tilt remained unchanged and within normal range, but peak posterior pelvic tilt increased to 1.9° (SD 0.7°) occurring during I.C and L.R.

Case study 5: Descriptive analysis	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal
Item	**Average**	**Average**	**Average**	**Average**
Left Step Length (m)	0.50 (0.03)	0.55 (0.04)	0.51 (0.03)	0.57
Right Step Length (m)	0.47 (0.02)	0.49 (0.04)	0.48 (0.02)	0.57
Steps / Minute (Cadence)	112.31 (4.6)	109.84 (9.5)	103.54 (3.4)	123.18
Metres per minute (Walking speed)	56.66	56.13	57.17	69.6
Distance covered (m)	226.6	224.5	227.3	

Table 8.24 Case study 5: Temporal-spatial parameters

Case study 5: Right	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)	Normal (SD)
Pelvic Kinematics				
Peak anterior pelvic tilt	13 (4.11)	11.35 (1.57)	13.12 (2.4)	12.9 (5.3)
Peak posterior pelvic tilt	4.63 (1.43)	2.5 (0.52)	1.9 (0.7)	10.9 (5.1)
Pelvic tilt ROM	8.38 (2.68)	8.88 (1.04)	11.22 (1.73)	2 (0.2)
Hip Kinematics				
Peak Hip flexion	31.74 (-1.01)	31.92 (-2.31)	34.23 (-0.58)	38.58 (-0.8)
Peak Hip extension	-10.6 (-4.23)	-6.21 (-5.82)	-7.72 (-2.86)	-5.16 (-3.23)
Peak hip flexion (stance)	24.1 (-2.85)	29.7 (-5.81)	33.7 (-1.73)	38.6 (-3.23)
Hip ROM	42.3 (3.22)	38.08 (3.5)	41.92 (2.27)	42.72 (1.29)
Knee Kinematics				
Knee flexion at IC	13.65 (4.04)	17.85 (5.9)	26.2 (1.6)	6.66 (5.24)
Peak knee flexion (stance)	5.29 (6.04)	22.97 (7.42)	35.48 (3.8)	19.52 (6.89)
Peak knee extension	-3.84 (1.61)	1.6 (2.27)	1.91 (0.96)	3.7 (5.3)
Peak knee flexion	57.42 (7.06)	57.767 (12.52)	58.57 (5.85)	60.41 (3.69)
Knee ROM	61.23 (5.44)	56.13 (10.24)	56.66 (4.82)	56.72 (3.8)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.				

Table 8.25: Case study 5: Right hip and knee kinematic data

Case study : Right Ankle Kinematics	Barefoot (SD)	Normal (SD)
Dorsi-flexion at I.C	-6.06 (-1.48)	-3.08° (5.12)
Peak Dorsi-flexion	6.04 (5.13)	11.4° (5.72)
Peak Plantar flexion	-22.53 (1.35)	-20.63° (8.62)
Ankle ROM	28.57 (3.78)	32° (7.33)
Key: SD- Standard deviation, I.C – initial contact, all values in degrees.		

Table 8.26: Case study 5: Right ankle kinematic data

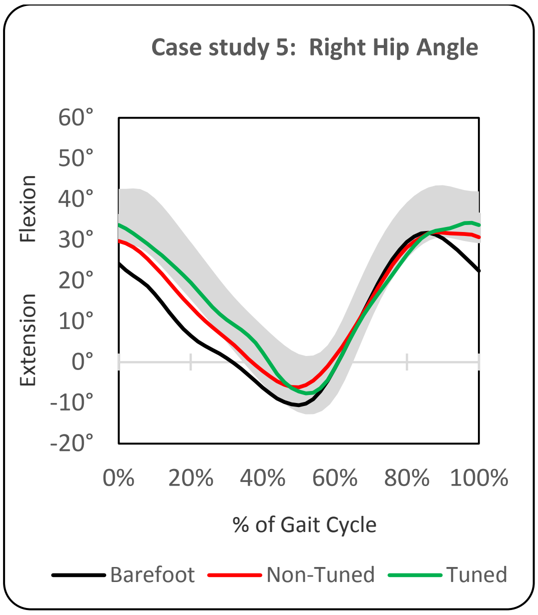


Figure 8.23.1: Graph showing right hip angle

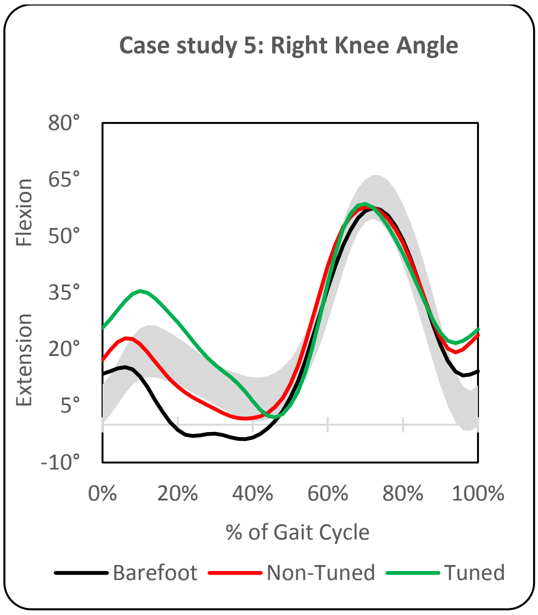


Figure 8.23.2: Graph showing right knee angle

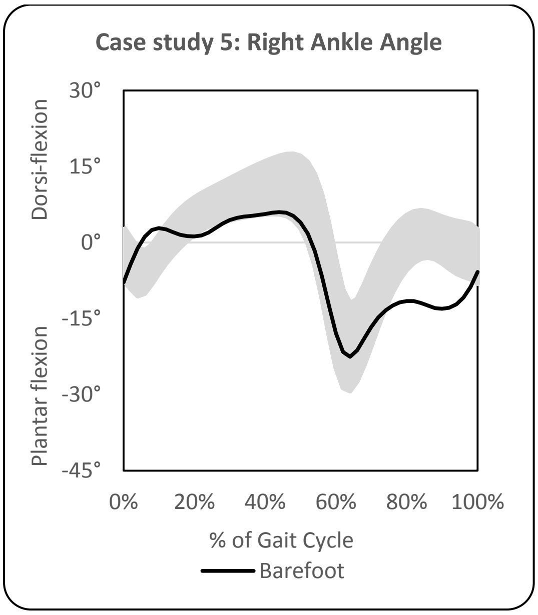


Figure 8.23.3: Graph showing right ankle angle

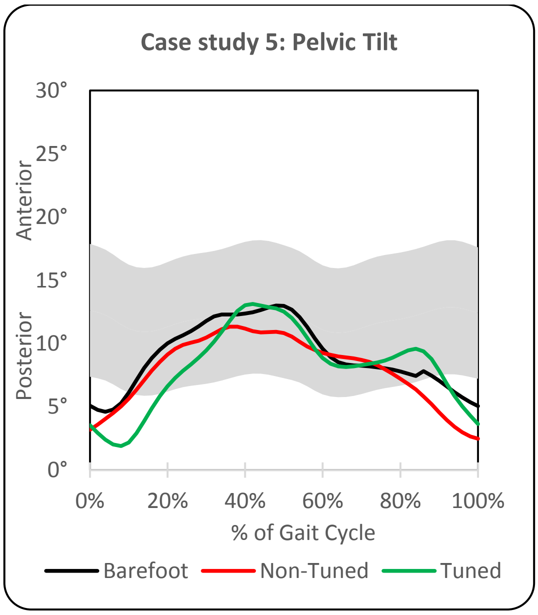


Figure 8.23.4: Graph showing pelvic tilt

Kinetics

Case study 5: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FZ_1 (Peak 1) N/Kg	9.9(1.62)	11.13(0.92)	12.8(1.15)
FZ_2 (Peak 2) N/Kg	9.96(0.49)	10.16(0.23)	9.99(0.35)
FZ_0 (Trough) N/Kg	8.01(1.28)	7.99(0.71)	7.21(0.37)
Vertical Ground Reaction Force data mean average: Key: SD- Standard deviation. The black horizontal line in all vertical force graphs demonstrates the bodyweight line at 9.81N/Kg.			

Table 8.27: Case study 5: Right vertical ground reaction force data

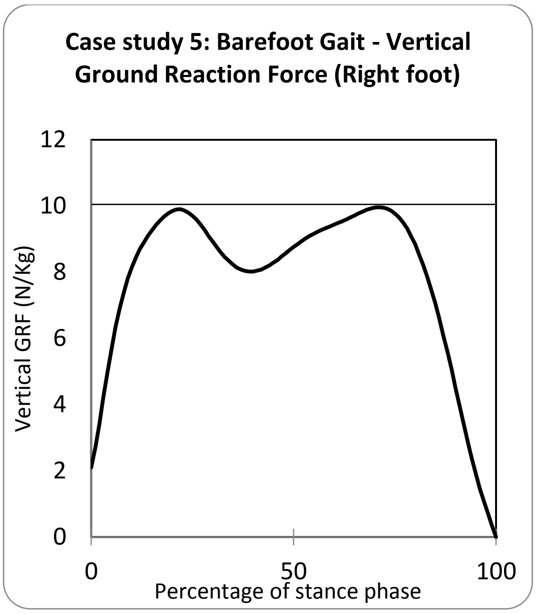


Figure 8.23.5: Graph showing barefoot vertical GRF

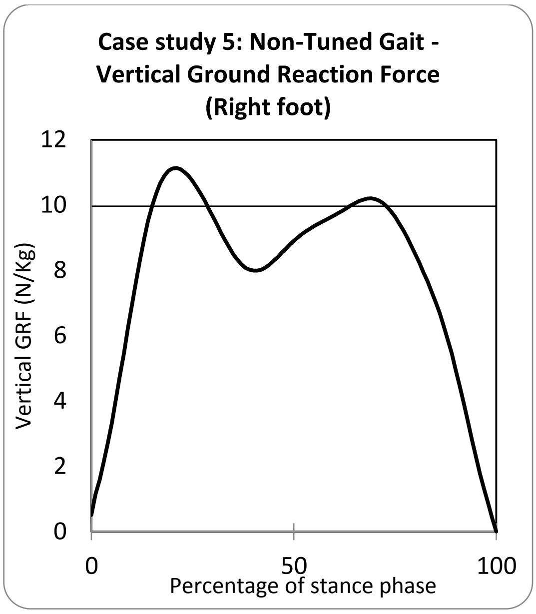


Figure 8.23.6: Graph showing non-tuned vertical GRF

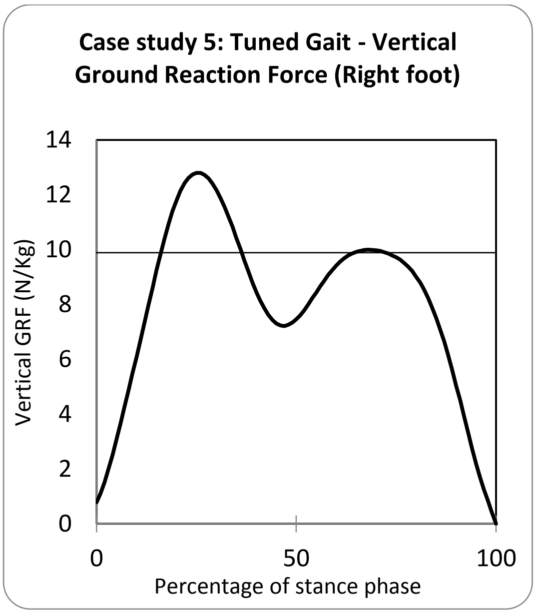


Figure 8.23.7: Graph showing tuned vertical GRF

Case study 5: Right lower limb	Barefoot (SD)	Non-Tuned (SD)	Tuned (SD)
Parameter			
FX_4 (Posterior) N/Kg	-2.22(0.48)	-2.18(0.46)	-2.12(0.22)
FX_5 (Anterior) N/Kg	1.06(0.22)	0.83(0.19)	0.96(0.24)
Anterior-Posterior Ground Reaction Force data mean average: Key: SD- Standard deviation.			

Table 8.28: Case study 5: Right anterior-posterior ground reaction force data

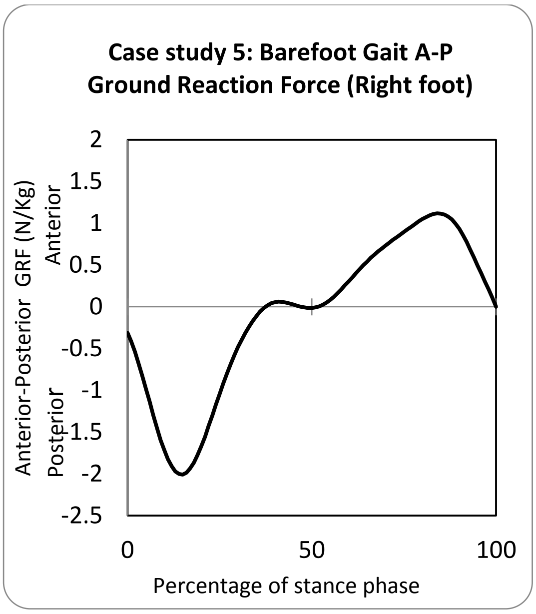


Figure 8.23.8: Graph showing barefoot anterior-posterior GRF

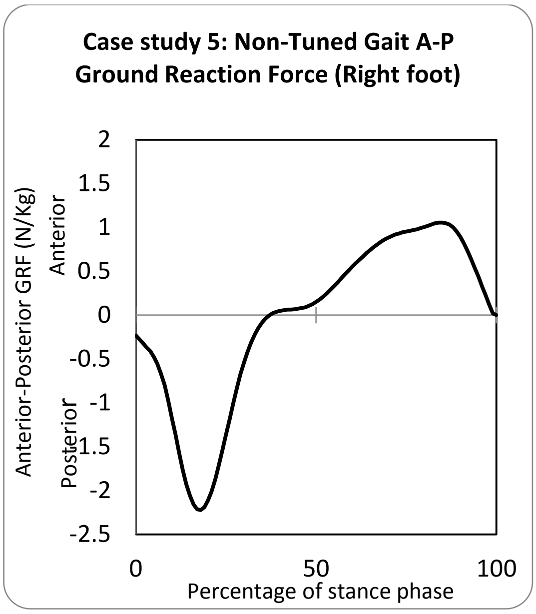


Figure 8.23.9: Graph showing non-tuned anterior-posterior GRF

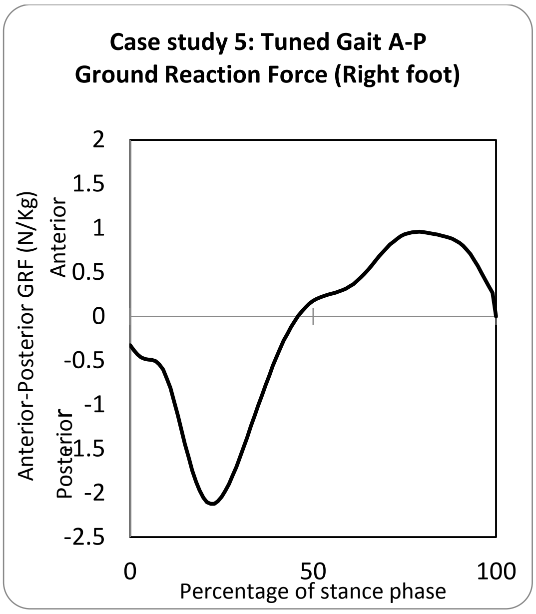


Figure 8.23.10: Graph showing tuned anterior-posterior GRF

8.24 Discussion

With a tuned AFO-FC the participant's hip flexion and extension were within the range of normal. Conversely, the non-tuned AFO-FC hip flexion was still low and outside the range of normal during I.C, L.R and MSt, which reduces the demand on the hip extensors. As explained in the previous case study, posterior pelvic tilt is a common compensation for inadequate hip flexion during stance. The posterior pelvic tilt did increase in the non-tuned condition by approximately 2° at I.C. However; posterior pelvic tilt also increased in the tuned condition by approximately 2.7° although hip flexion was within normal limits. See figure 8.23.4 for this participant's pelvic tilt graph.

It is documented in the literature that this is an inefficient way to mobilise during gait(28); which could explain why the energy expenditure for this participant was higher in both the tuned and non-tuned conditions, compared to the barefoot condition, although the distance and speed was increased in the tuned condition indicating that this was a more efficient gait.

The increase in knee flexion at I.C in the tuned condition is in line with two of the four other case studies and the findings in Jagadamma's(37) study. Peak knee flexion in stance increased outside of the normal range in the tuned AFO-FC which may have enabled the participant to increase his hip flexion to within normal range. Peak knee flexion was within normal range with the non-tuned AFO-FC. Peak knee extension improved in the tuned condition to the lower end of the normal range but was delayed and occurred at 46% of the gait cycle rather than the normal 40%. In the non-tuned condition, knee extension was outside the range of normal during MSt.

The kinetic data show that in the barefoot condition the participant generated vertical forces slightly higher than his bodyweight and although he was able to move his body over the stance limb, the trough was shallower than normal. In the non-tuned condition, the first peak (FZ_1) increased to above bodyweight but the second peak remained unchanged, possibly indicating a poor push off. In the tuned condition the first peak increased to higher than the participant's bodyweight, the second peak was also above bodyweight but as in the non-tuned condition, the forces demonstrated the Ben Lomonding effect typical in CP children(235). The trough in the tuned condition was deeper than the other two conditions indicating an improved ability to move the body over the stance limb.

The A-P graphs show that the anterior forces were all below normal values, indicating difficulty in propelling he body forward, the lowest value being the non-tuned condition. The posterior force values were within normal ranges for all three conditions. The crossover of the A-P forces occurred prematurely in all three conditions but was improved closer to normal in the tuned condition

8.25 Summary

The tuned condition offered the most improvement in 5 of the 12 kinematic parameters tested and the most deterioration in 3 of the 12 parameters. The non-tuned condition offered the most improvement in 2 of the 12 parameters and the most deterioration in 2 of the 12 parameters.

The tuned AFO-FC improved distance, speed, anterior pelvic tilt, peak hip flexion, peak hip extension and peak hip flexion during stance, knee flexion-extension and knee ROM. However, peak knee flexion during stance was further away from normal and higher than the other two conditions, peak posterior pelvic tilt increased at I.C and L.R, and knee flexion increased at I.C further outside of normal. The vertical forces generated were highest in the tuned condition for the first peak and the trough was deeper, indicating an improved ability to advance over the stance limb.

The non-tuned AFO-FC resulted in a lower than normal peak hip flexion during stance, higher posterior pelvic tilt than normal, an increase in knee flexion at I.C, compared to barefoot, and a higher than normal knee extension during MSt. The vertical forces increased compared to barefoot gait but were not as high as the tuned condition for the first peak.

Conclusion

This participant's main gait deviation was hyperextension of the knee during stance. The introduction of a non-tuned AFO-FC reduced knee hyperextension but the introduction of a tuned AFO-FC reduced it further.

8.26 Summary of case studies

The results of this study show that all the participants improved their hip flexion and extension to within normal limits when wearing a tuned AFO-FC. Whilst in the non-tuned condition only case studies four and five improved their hip flexion and case studies one and three improved their hip extension, to within normal limits. All participants improved their anterior pelvic tilt to within normal limits in the tuned condition, with four out of five participants also improving in the non-tuned condition. Posterior pelvic tilt was improved to within normal limits in the tuned condition in three out of the five participants, with no participants showing an improvement to normal values in the non-tuned condition. Hip extension at TSt. is crucial in allowing knee extension and creating the "big V" (118,244) which offers a stretch to musculature of the lower limb.

An increase in knee flexion during stance, outside the range of normal, seemed to be common in both non-tuned and tuned conditions, with only case study one being within normal values, in both conditions. Jagadamma (245) found similar results in his research and hypothesised that the participants were using increased knee flexion to achieve an initial contact with a flatter foot when compared with barefoot where the ankle was mostly plantarflexed during I.C. Clinicians need to be mindful of the possible effects of increased knee flexion at I.C. as we do not know the long term effects. We do know that an extended knee at I.C has the advantage of being the most stable weight bearing position(28). Similarly, one needs to be mindful of children with reduced power in the quadriceps who may have difficult restraining a flexed knee and similarly those with weak hip extensors.

An improvement in peak knee flexion was observed in two out of five participants in the tuned condition and one out of five in the non-tuned condition.

Knee extension at MSt improved to within normal limits in case study four in the tuned condition, but improvements towards normal were also seen in case studies one and five. Conversely in the non-tuned condition participant one's knee extension increased further outside of normal, participant four's decreased outside of normal, but participants three and five improved towards normal but not within normal limits.

It has been hypothesised that knee flexion at I.C will increase in a tuned AFO-FC due to the enforced inclination of the shank, as demonstrated in a recent study(37). In contrast, knee flexion at I.C in the current study, was decreased in participants one and four but increased in three out of the five participants (two three and five). However, this was also the same in the non-tuned condition (participants three, four and five) thus it is unlikely to be the tuning wedge causing the increase in knee flexion at I.C.

Four out of five participants demonstrated the most improved first peak (FZ_1), in the vertical GRF, in the tuned condition (participants one, three, four and five). The second peak (FZ_2) was most improved following tuning, for two participants (three (right foot) and four). Whilst the values for A-P forces tended to be below normal, the tuned condition demonstrated an improvement in the posterior force in two participants (one and two) with the remaining participants showing little difference between the three conditions. However, the anterior force was lowest in four out of five participants in the tuned condition (participants one, two, three and five), indicating an increased difficulty with propelling the body forward.

Participants one and five showed the most improvement in all parameters tested, this may be due to both of these participants having full PROM in the hamstrings during the physical assessment and less than 20° knee flexion during the first third of stance phase(98), in addition both had similar gait patterns (Winter's group II(23)), as did the three participants who showed the least improvement (Winter's group IV(23)). This supports Jagadamma's(37) findings that the effects of tuning were different on the knee kinematics of participants with different gait patterns and Butler et al.'(98) findings that a popliteal angle greater than 45° is a poor prognostic sign for successful tuning of the knee in stance phase. However, although these participants didn't show an improvement in knee kinematics with a tuned AFO-FC they did show an improvement in hip and pelvic kinematics. Butler et al.(98)would not have known this as they only reported kinetics and kinematics of the knee joint and did not investigate the effect of AFO-FC tuning at the hip joint.

The results of his study indicate that improvements in kinematics can be made at the hip with CP children who have a hamstring contracture. Thus, supporting Owen's(149) view that the success of AFO-FC tuning may be limited by the inability to achieve full or nearly full extension at the knee and hip but that tuning can still produce positive results in such cases. Perry's(28)claim that when a subject's knee flexion matches their hip flexion there is an improvement in pelvic and trunk kinematics, might explain the improvements in these cases.

8.27 Conclusion

This research is the first to provide individual case-series analysis of the effects of AFO-FC tuning on the kinetics and kinematics of gait in children with CP. The results of previous studies provide group mean data only. The results indicate that tuning AFO-FCs can improve hip function, pelvic function, knee extension in stance phase and knee flexion during swing phase in children with CP and that a non-tuned AFO-FC can potentially decrease hip function, posterior pelvic tilt and increase knee extension. However, gait kinematics are not bijective and not all of the subjects tested responded in the same way to the tuned AFO-FC. Thus, it is still not fully understood which gait pathologies are most effectively improved with tuning, however, this study indicates that patients who demonstrate a gait pattern similar to Winter's(23) group II, demonstrate the most improvements. It is clear from the results of the study that accurate alignment of the lower limbs when issuing an AFO is an essential aspect of AFO treatment and prescription.

Although the data has not been subjected to any detailed statistical tests due to low participant numbers, the results pave the way to design further structured studies with accepted statistical power

8.28 Limitations of the study

The sample size for this study was small, thus, inferential statistics cannot be used as the sample size is less than ten. Therefore, descriptive statistics was used due to the heterogeneity of CP. A larger sample size is required to verify the results of this study.

All the participants had their initial gait assessed by the orthotist in clinic which determined the AFO prescription, without any kinetic or kinematic data available, as is common in clinical practice in the NHS. Thus, in one case (case study two), it is possible that a ground reaction force AFO (GRAFO) may have improved this participant's gait but unfortunately the extent of the knee flexion in stance was only picked up with the aid of the kinetic and kinematic data. Thus, supporting Owen's(36) that gait is too fast to pick up visually all the phases of the gait cycle and that what you see kinematically in the clinic is not necessarily what you get kinetically.

A further limitation is that no data was collected with footwear alone, to use as a comparison between barefoot and the AFO conditions. However, this study aimed to compare the effects of tuned and non-tuned conditions and the footwear during these conditions remained the same. The footwear used were over splint orthopaedic footwear which are designed to be worn with an AFO. Thus, another shoe would have had to be used, which would mean the results would not have been comparable to the AFO conditions, as it is widely documented that footwear is a crucial aspect of the AFO prescription.

Furthermore, it would have been impractical to collect a further trial of data on the same day by introducing another condition. To do this would have resulted in an additional day of data collection and this is unlikely to have been accepted by the participants who already had to travel a significant distance to the University gait laboratory to take part in the study.

The data from this research was processed using the Vicon Plug-in-Gait model. This model contains numerous simplifications, e.g. the hip joint centres are based on manufacturer specific anthropometric regression equations, rather than functional models(246). This can cause both random and systematic errors in the hip centre location(246,247). However, both the model and the inherent errors are commonly used in clinical gait analysis and are representative of most conventional gait analysis models(246).

The study did not look at the effects the tuned AFO-FC had on the contralateral limbs, only studying the limb on which the participant wore an AFO. Future research should study the effects of the contralateral limbs for these patients.

Finally, although the study aimed to compare the kinetics and kinematics of non-tuned versus tuned AFO-FCs in CP children, the non-tuned prescriptions had the correct AAAFO, which doesn't represent the full clinical picture. Eddison et al.'(212) study on common clinical practice in the UK, with regards to AFO-FC tuning, indicates that the AAAFO chosen in AFO prescriptions doesn’t necessarily represent the length of the gastrocnemius. Therefore, it is hypothesised that a non-tuned AFO with an AAAFO which doesn’t accommodate the length of the gastrocnemius would cause the kinetic and kinematics to deteriorate further. A study on the effects of incorrect AAAFOs is required to learn more about the potential effects of this crucial aspect of biomechanical optimisation of AFOs.

Chapter 9: Participant perception and compliance with tuned AFO-FC

9.1 Aim of the research

This study aimed to investigate the use and usability, acceptance and compliance of the adapted footwear the participants were asked to wear as part of their AFO-FC prescription. In particular, whether the modified footwear affected the amount of time the participant used the AFO-FC.

9.2 Clinical relevance

It is vital to understand whether orthotic prescriptions effect patient compliance. Orthotic prescriptions which are not utilised by the patient due to unacceptable cosmesis, result in a failed treatment intervention, regardless of the scientific application underpinning them.

9.3 Introduction

Biomechanically optimised AFO-FCs often have relatively large adaptations to the footwear which include the addition of wedges, flares and rockers (see figure 9.3.1 – 9.3.2). These modifications, along with the AFO itself, are often visible to others. It is quite common in clinical practice, especially as children get older, for compliance with orthotic intervention to become an issue. Often the child does not want to stand out amongst peers because they wear a splint or because their orthotic treatment is visible to others. Therefore, it is essential when discussing orthotic treatment plans, to take this issue seriously and discuss compliance with the patient and their family. The orthotic intervention must be acceptable to the patient for it to be useable and meet the aims of the treatment.

Figure 9.3.1 Example of a visibly tuned AFO-FC

Figure 9.3.2: Example of a visibly tuned AFO-FC

Usability is defined by report number 9241 of the International Organisation for Standardisation (ISO) as "the extent to which a product can be used by specific users to achieve goals with effectiveness, efficiency, and satisfaction in a specified context of use"(248). The concept of usability can be applied to people with special needs and disabilities(249).

A holistic approach to patient treatment is widely advocated; thus, It is essential to understand the psychosocial impact of orthotic intervention. Orthoses are often prescribed to fulfil several treatment goals, one of which is to improve activities of daily living and enable children to participate in activities by providing improved function. It is widely accepted that improved balance and stability can lead to an improvement in activities of daily living which are important for social development and self-confidence(250). In addition, participation in social activities in children is vital for optimal development and learning(251).

Appearance is a crucial aspect of self-image and of other people's perception of the person. Humans continually construct and interpret appearances as they define, shape, and organise their notions of everyday life. Thus, personal appearances are intertwined with human perceptions of the social order(252). Clothing and appearance are visible elements that we use to identify and differentiate ourselves and others(253). The clothing a person chooses to wear is intricately linked to aspects of their individual and social identity. Self-concept is one's self-perception which is related to attitudes, feelings, and knowledge about one's appearance or abilities(254). The concept of self-image and the need to fit in with peers are issues which may be affected by the provision of an orthotic, such as adapted footwear, which is visible to others.

Kaiser et al.(255) explored the clothing choice of disabled students. They concluded that disability was disruptive when social norms were breached, that is when people felt they looked different to everyone else. The study found that wearing special clothing was avoided because it reinforced differences between disabled and able-bodied persons.
Halsne and Hafne(256) state that compliance with an orthosis usually stems from satisfaction with the product and/or the service providing it. Satisfaction can be positively influenced by the design of the orthosis, its function and its cosmesis(257)

Studies which have investigated compliance with prescribed orthopaedic footwear, have reported that as little as 22–36% of patients use their footwear frequently(258–260). Jannick et al.(249) investigated the usability of orthopaedic footwear in adults with degenerative disorders of the foot. They reported a significant association was found between cosmetic appearance and actual use of orthopaedic shoes. Patients who considered their shoes to be cosmetic wore them more often. Another study reported that 50% of the patients they studied criticised the footwear they were prescribed on the basis of poor cosmetic acceptability, difficulty getting the shoes on, being too heavy and uncomfortable and in some cases not wearing the shoes at all(261).

Paton et al.(262) studied the patient's experience of therapeutic footwear and reported that when first issued with therapeutic footwear, all participants assessed the visual appearance to determine if the style of the shoe fitted with their perception of the accepted 'norm'. The patients were aware that the footwear was prescribed to prevent foot ulceration; however, the participants reported a conflict between achieving social inclusion and minimising risk of foot ulceration. The study reported that the participants' self-image had to be adapted to take account of the therapeutic footwear.

Further studies have also found a high level of non-compliance due to the weight and cosmesis of the footwear prescribed(258,259,263–267). It has also been reported that expected foot health improvements are negated by the fact that patients choose not to wear their prescribed footwear(268).

De Boer et al.(269) investigated compliance and usage of wrist supports in patients with rheumatoid arthritis and concluded that of 128 patients studied only 52% were using the wrist support prescribed to them. Satisfaction with comfort tended to be the driving force behind compliance. Other studies have looked at user satisfaction of reciprocating gait orthoses(270), knee ankle foot orthoses(271) and upper limb progressive resting splints(272).

There are three studies in the current literature which have investigated patient satisfaction and compliance with AFOs(257,273,274). Bulley et al.(273) reported non-compliance due to the function of the AFO including inflexibility, the AFO being cumbersome and difficulty finding footwear to accommodate the splint. Magnusson et al. (274) reported that pain was a significant factor in the use of an AFO along with difficulty walking on uneven surfaces. Both of these studies focussed on patients over the age of 16 years. Holtkamp et al.(257) investigated use and satisfaction with an AFO on patients over seven years of age with a mean age of 48.8 years. 210 patients in total responded to the questionnaire, 20% of whom were under the age of 18 years and were deemed the most dissatisfied group regarding the AFO as a whole. Design and use of the AFO scored high on the dissatisfaction rating. The authors concluded that in order to improve user satisfaction the AFO prescription and delivery process has to be identified as an important sub-process of orthopaedics including the tuning process.

The available literature on patient perception and compliance primarily focuses on orthopaedic footwear and is based on adults with foot health issues, with a small number of studies investigating AFO compliance and satisfaction, mostly on the adult population. There is currently no research available on the child's opinion and compliance of wearing an orthosis or adapted footwear as part of a tuned AFO-FC prescription. There are studies which have looked at the parents' perception of treatment methods for children with motor disabilities(275–278) and plagiocephaly(279) . Skar and Tamm(280) investigated how children perceive their technical aids, however, the children did not consider their orthoses technical aids. Naslund et al.'(281) qualitative interview study investigated how parents perceive the dynamic ankle-foot orthosis (DAFO) their child has been prescribed. All children were aged 4-18 years old and had a diagnosis of spastic CP. They concluded that the use of DAFOs may help children in their social interactions, giving them new functions and ability to participate in more activities, improving independence and play through increased stability, postural control and alignment.

To summarise there has been no study which has investigated the child's perception and compliance with orthotic intervention, in particular biomechanically optimised AFO-FCs. This is a shortcoming which is addressed by this study.

9.3 Method

A questionnaire was designed (see appendix 12.13) and issued by post, to all participants three months after they were issued with their permanently tuned AFO-FC. The participants were asked to complete the questionnaire and return it in the stamp addressed envelope supplied. The questionnaire was split into sections regarding the AFO/splint and a separate section regarding the adapted footwear, although they both form one prescription, the aim was to see if the introduction of the modified footwear had a particular effect on perception and compliance.

9.4 Results

See table 9.1 for the results of the questionnaire. The headline results show that all participants (n=5) reported they did not like wearing their splints and their adapted footwear and all participants said that the reason for this was because of the way they look and that other people notice them. All participants indicated that they walked better in their tuned AFO-FC with fewer falls (n=3) and improved balance (n=4).

	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5
Do you like wearing your splints?					
Yes					
No	✓	✓	✓	✓	✓
If you <u>don't</u> like wearing your splints, please tell us why					
I don't like the way they look	✓	✓	✓	✓	✓
I don't like the way they make me walk					
I don't like how they feel when I wear them		✓			
I walk better without them					
They hurt me when I wear them		✓		✓	✓
Because other people notice my splints	✓	✓	✓	✓	✓
My splints make me tired when I walk				✓	
Other:	Although I don't like wearing my splint I know that it helps me. I can run better without my splint; It's awkward to stand straight with it on			They make me tired and sweaty, and I don't like the style of the shoe	Because other people keep asking why I wear them

Please tell us what you <u>do</u> like about your splints					
They make me walk better	✓	✓	✓	✓	✓
I can walk further with my splints than I can without them	✓	✓			✓
I don't get any pain when I wear my splints					
My splints help me balance better	✓	✓	✓	✓	✓
I don't fall over as much when I wear my splints	✓	✓	✓		
I like the way my splints look					
My splints stop the muscles in my leg/s from feeling tight	✓				
I don't like anything about my splints					
I don't feel as tired when I walk with my splints on					
Other	I like to choose the pattern				
Do you like wearing the shoes, which we have adapted, with your splints?					

Yes					
No	✓	✓	✓	✓	✓
If you don't like wearing your adapted shoes, please tell us why					
I don't like the way they look	✓	✓	✓	✓	✓
I don't like the way they make me walk					
I don't like how they feel when I wear them					
I walk better without the adaptations on my shoes					
They hurt me when I wear them					
Because other people notice the adaptations on my shoes	✓	✓	✓	✓	✓
My balance is worse with my adapted shoes					
My adapted shoes prevent me from doing certain activities				✓	✓
My adapted shoes make me tired when I walk				✓	
Other	I don't have a choice of what style of shoes I can wear which makes me quite upset, it's annoying	Too small and uncomfortable, I felt no difference			

Please tell us what you <u>do</u> like about your adapted shoes *(compared to shoes and splints without adaptations)*					
They make me walk better	✓	✓	✓	✓	✓
I can do more activities with my adapted shoes and splints		✓	✓		✓
I don't have any pain when I wear my adapted shoes and splints	✓				
I can walk further with my adapted shoes and splints	✓		✓	✓	
I don't fall over as much when I wear my adapted shoes with my splints		✓	✓		✓
I like the way my adapted shoes look					
My adapted shoes improve my balance	✓	✓	✓		✓
I don't feel as tired when I walk in my adapted shoes					✓

I don't like anything about my adapted shoes				✓	
Other:					
Where do you wear your splints?					
I wear them whenever I go outside		✓	✓		✓
I wear them at home and when I go outside					✓
I wear them at school only	✓	✓	✓	✓	✓
I wear them at home only					
Other					
How long do you wear your splints for per day?					
I wear them for 2 - 3 hours per day					
I wear them for 4 - 5 hours per day					
I wear them for 6 - 8 hours per day	✓	✓	✓	✓	✓
I wear them for over 8 hours per day					
How many days per week do you wear your splints for?					
I wear them 7 days per week			✓		✓

I wear them Monday to Friday only	✓	✓			
I wear them at weekend only					
Other				Tuesday to Friday	
Since having adaptations added to your shoes do you wear your splints and shoes more or less often?					
I wear my splints and shoes *more* often now			✓	✓	✓
I wear my splints and shoes *less* often now					
There is no change in the amount of time I wear my shoes and splints for	✓	✓			
If you are wearing your splints and shoes more OR less often since having adaptations added to your shoes, please tell us why.				I only wear them at school to help my balance	Because they make walking easier
Is there anything else you would like to tell us about the way you feel about your splints and adapted shoes?					

No	✓	✓	✓		✓
Yes				✓	
Comments:				I don’t like the shoes the way they look; they're too big for me. They're too heavy. Also, I don’t like the way people look at me with the shoes.	

Table 9.1. Results of questionnaire on patient perception and compliance of their tuned AFO-FC.

9.5 Discussion

This study was the first to look at patient perception and compliance when wearing tuned AFO-FCs in children with CP. It is clear to see from the results, that the children who participated in this study did not like the cosmesis of the AFO-FC they were prescribed with and were very conscious of other people noticing the adaptations on their footwear. This was not unexpected, as self-image and the desire to fit into peer groups has already been described as a dominant driving force, especially in the disabled community(255), along with previous studies on adults which reported that cosmesis played a significant role in whether the patient chose to wear the footwear or not.

Although the participants unanimously agreed that they did not like the appearance of the adapted footwear, this did not result in them wearing them less often than when their footwear was un-adapted (non-tuned), with three of the five participants reporting that they now wear their AFO-FC more often than they did before. This is in line with results reported by Parton et al.'(262) study, which stated that the benefit of maintaining function, and being considered by others as functionally normal, often became more important than negative issues relating to self-image and that visual implications of the therapeutic footwear with regard to obvious disability were overridden by a desire to lead a functionally normal life.

The fact that wearing time didn't decrease and in three cases increased, despite the participants' dislike of the appearance of the footwear, may be due to the improvements the participants felt when wearing their tuned AFO-FCs. With the participants reporting that their balance had improved (n=4), they can walk further in their tuned AFO-FCs (n=3), they can do more activities in their tuned AFO-FCs (n=3) and they have less falls in their tuned AFO-FCs (n=3).

There were some contradictory answers in the questionnaire, i.e. participant two reported he "felt no difference" when walking with the adapted footwear, yet later in the questionnaire indicated that the modified footwear made him walk better, increased his activities, reduced his falls and improved his balance. Similarly, participant four reported he didn't like anything about the adapted footwear, yet later reported he could walk further in the modified footwear and walked better. These contradictions may be due to the participants trying to make their feelings known, that they emphatically do not like the look of the adapted footwear regardless of the improvements they achieved.

By exploring the understandings and experience of children with CP, issued with AFOs and adapted footwear, we begin to understand how a child's thoughts and feelings can influence their decision to comply with their orthotic treatment and better inform clinical practice.

9.6 Conclusion

It is clear that cosmesis is an important factor for children who wear adapted footwear, like all children they don't want to stand out as being different to their peers. The participants of this study were conscious that the modified footwear they were asked to wear was noticeable to other people, yet they continued to wear them and in some cases increased the wearing time. Thus, it can be concluded that impact of the AFO-FC on the participants' mobility outweighed their opinion on the cosmesis of the device.

9.7 Limitations of the study

The author recognises that there are two main limitations to this study; small sample size, as previously mentioned throughout this manuscript, the aim of the research project was to focus on the individual patient. Secondly, the questionnaire used has not been validated. However, and it was felt these questions were appropriate after initial discussions between the author and the extended research team.

Chapter 10: Summary and Conclusions

In the preceding chapters, each study has been primarily discussed independently of each other. The purpose of this section is to present the findings of the research in relation to each other and to offer clinically relevant conclusions regarding the effects of biomechanically optimised AFO-FCs on the gait of children with CP.

The original aims of the research are documented in table 10.1 along with a summary of findings.

Research aim:	Method of investigation	Main conclusions	Published research
Do research papers provide enough information on design and material used in Ankle-Foot Orthoses (AFO) for children with cerebral palsy (CP)? A systematic review	A systematic review of the current literature pertaining to AFOs and children with CP. See Chapter 3.	The current literature contains a dearth of detail regarding the AFO design and material used in studies involving children with CP. The lack of detail has the potential to misinform clinical practice and prevents meaningful meta-analysis from being performed.	Eddison N, Mulholland M, Chockalingam N. Do research papers provide enough information on design and material used in ankle-foot orthoses for children with cerebral palsy? A systematic review. 2017(185)
To explore current research on AFO-FC tuning in children with CP	Literature review. See chapter 5.	Although there is emerging evidence that AFO-FC tuning improves the gait of children with CP, the research is mostly theoretical with a paucity of research offering quantitative kinematic and kinetic data.	Eddison N and Chockalingam N. The effect of tuning ankle-foot orthoses-footwear combination on the gait parameters of children with cerebral palsy 2012(100)
To determine the prevalence of AFO-FC tuning in clinical practice and to identify issues preventing the use of AFO-FC tuning	A survey was issued to UK practising orthotists. See chapter 6.	AFO-FC tuning is not yet standard clinical practice in the UK. There is an evident lack of understanding regarding the key principles of AFO-FC tuning amongst UK orthotists.	Eddison N, Chockalingam N and Osborne S. Ankle-foot orthosis-footwear combination tuning: An investigation into common clinical practice in the United Kingdom. 2014. (212)
To determine the correlation between the SVA measured in stance and the SVA during gait.	The measurement of the SVA in standing was compared to the SVA during gait in a series of cases. See chapter 9.	The study indicated that measuring the SVA of the AFO-FC statically is an accurate way of determining the SVA at temporal mid-stance.	Eddison N, Healy A, Needham R and Chockalingam N. Shank – to – Vertical - Angle in AFOs: A comparison of static and dynamic assessment in a series of cases. Journal of Prosthetics and Orthotics 2017. (199)
To compare the energy expenditure during gait in non-tuned and tuned AFO-FCs .	Gross sub-maximal energy expenditure was measured during gait at self-selected walking	The results of this study indicate that a tuned AFO-FC can potentially reduce energy expenditure whilst increasing speed and distance during gait in children with CP. Whilst a non-	Eddison N, Healy A, Needham R, Chockalingam, N and Unnithan V. Exploratory investigation into energy expenditure using tuned versus non-

	speed, in barefoot, non-tuned and tuned AFO-FCs, in a series of cases. See chapter 10.	tuned AFO-FC has the potential to decrease energy expenditure often at the detriment of a reduction in speed and distance and can potentiality increase energy expenditure in some cases.	tuned ankle-foot orthoses-footwear combinations in children with cerebral palsy. Submitted July 2017.
To analyse and compare the kinetics and kinematics during gait in children with CP, using non-tuned and tuned AFO-FCs via 3D gait analysis.	Kinetics and kinematics of gait were measured and compared in a series of cases, in three conditions; barefoot, non-tuned AFO-FC and tuned AFO-FC. See chapter 11.	The results of this study indicate that tuning AFO-FCs has the potential to improve hip and pelvic function, knee extension in stance and knee flexion during swing phase in children with CP. A non-tuned AFO-FC can potentially decrease hip function, posterior pelvic tilt and increase knee extension.	Not yet submitted.
To determine the acceptance of tuned AFO-FCs from the view point of the patient to explore compliance.	A questionnaire was issued to the participants who took part in the AFO-FC tuning research to gather their feedback on their perception of the adapted footwear. See chapter 12.	The results of this study show that the participants did not like the cosmesis of the adapted footwear they were asked to wear as part of their tuned AFO-FC prescription. However, wear time was not affected as the participants reported improvements in their gait and function with the adapted footwear.	Not yet submitted.

Table 10.1: Research aims and summary of findings from the research project

This research aimed to explore the effects of biomechanically optimised AFO-FCs on the gait of children with CP, to inform clinical practice. Firstly, it was essential to examine the current literature involving AFOs and children with CP, to see what the current findings and the general consensus is, with regards to clinical practice, when prescribing AFOs for this patient group.

It was clear from the current literature that that are a number of studies investigating the efficacy of AFOs. However, the results of studies involving AFO interventions on this patient group are equivocal in their findings, with contrasting conclusions and recommendations. It was hypothesised that this may be due to several factors including;

- Lack of standardisation of study design.
- Poor quality studies.
- Grouping participants together and reporting mean results on a heterogeneous patient group.

- Comparing different AFOs against each other with no apparent clinical justification.
- A lack of standardised AFO prescriptions.
- A lack of biomechanically optimised AFOs in the studies reported.

A systematic review was required to study the hypothesised factors further. The systematic review on the detail of the design and material used in AFO studies(185) attempted to answer this question. The results show there is a definite lack of detail in almost all the studies involving an AFO intervention on children with CP. There was very little detail on the mechanical properties of the AFO intervention studied, the material used and its thickness, the terminology used to describe the AFO, the AAAFO, the clinical justification for the AFO prescription and the lack of consistency in outcome measures.

Thus, it is difficult to draw conclusions from studies lacking such detail on the primary intervention being studied and this has the potential to misinform clinical practice. Thus, this research concluded with several recommendations for future studies involving AFOs:

•The material of the AFO used as an intervention in a research study should be detailed, including type, thickness and any reinforcements.
•The full design of the AFO should be described, including trim-lines at the ankle, footplate design, length, medial and lateral flanges and flexibility, strapping arrangement and reinforcements.
•The stiffness of the AFO in stance phase should be described.
•The type of AFO used should be described, and a justification of the choice of design should be detailed.
•The AAAFO should be specified along with a rationale for the chosen AAAFO.

The next step was to investigate whether the biomechanical optimisation of AFOs might positively influence the results of the efficacy of AFOs in CP children. Firstly, a systematic review of the current literature(100) was required to ascertain the current evidence on AFO-FC tuning. The review identified that there was emerging evidence that biomechanically optimised AFO-FCs may positively influence the gait and function of children with CP. However, this evidence was mostly theoretical and lacked quantitative data.

Only two studies(37,90) provided quantitative data on biomechanically optimised AFO-FCs on this patient group. However, the studies failed to provide physical characteristics of the participants, a lack of information on the AAAFO and clinical justification for the AFO prescription. There was a lack of detail regarding the material used for the AFO, and crucially the footplate was made stiff at the MTPJs(37). When investigating the effects of tuned AFOs on hyperextension of the knee, it is imperative that the third rocker should not be blocked with anterior trim-limes past the 1st and 5th MTPJs which will, in fact, induce knee extension. In the other study(90) data was captured using temporary tuning wedges and there was no habituation period for the participants, with data being collected immediately after tuning and only 5 minutes after collecting data from the non-tuned condition.

Critically, these studies provided group mean data which does not tell us the effect on the individual patient and due to the heterogeneity of CP it is very difficult to deduce any meaningful conclusions from this data.

The literature review identified a need for further research on the kinetics and kinematics of gait with a biomechanically optimised AFO-FC to better inform clinical practice. Although firstly it was important to investigate current clinical practice with regards to AFO tuning in the UK., this was achieved by a questionnaire based study(212), issued to practicing UK orthotists.

The results of the questionnaire indicated that AFO-FC tuning is not yet standard clinical practice in the UK, with only 50% of participants reporting they routinely tune the AFOs they prescribe and only 2.4% able to accurately name the contraindications to successful AFO-FC tuning. The overall results identified an apparent lack of knowledge regarding AFO-FC tuning, amongst UK orthotists. It highlighted a clear need for further training and a simplification of the tuning process. This study was the first to investigate current UK practice regarding AFO-FC tuning.

The AFO-FC tuning process is based mainly on empirical data and theory. A crucial aspect of the tuning process is the alignment of the SVA. The method described by Owen(159) advocates measuring the SVA statically in relaxed stance on the assumption that this will be closely replicated dynamically during TMST, however, there has been no study which has verified this process.

The first part of this research set out to compare the static SVA with the SVA dynamically to see if there was indeed a correlation. The results show that the participants in this study all demonstrated an SVA in relaxed stance which correlated with their SVA in TMST, thus supporting Owen's(48) theory. This was the first study to verify the measurement of the SVA using Owen's(48) tuning process.

At this point, the project had identified a lack of consensus in the efficacy of AFOs in children with CP. Along with a lack of detail on the AFO intervention studied in research on CP children, a lack of research on the biomechanical optimisation of AFO-FCs, current clinical practice with regards to tuning AFOs in the UK and verification of Owen's(48) method for measuring the SVA during the tuning process.

The next part of the research involved measuring the effects of tuned and non-tuned AFO-FCs on the participants' gait. It is well documented that children with CP expend more energy walking than healthy counterparts. Thus, it was deemed important to investigate the effects of the AFO intervention on the energy expenditure of the participants. It is vitally important that any medical or therapeutic intervention improves the patient's quality of life and activities of daily living.

Throughout the project it was imperative to measure the effects of the non-tuned AFO-FC as this, as the aforementioned study identified, is current clinical practice in the UK. Therefore it is crucial to understand the effects of these commonly prescribed AFOs and compare them to those which have been biomechanically optimised, to better inform clinical practice.

Thus, three conditions were required:

I. Barefoot gait – to use as a baseline measurement of the participant's gait.
II. Non-tuned AFO-FC.

III. Tuned AFO-FC.

10.1 Implications for clinical practice

The results of the study show that tuned AFO-FCs have the potential to reduce EEI (O_2) and gross sub maximal energy expenditure of children with CP at self-selected walking speed, which was contrary to findings in the current literature(47,75,76), which are in-line with the conclusions in the non-tuned condition. Thus, indicating that the efficacy of the AFOs studied in the current research was potentially hampered by the lack of biomechanical optimisation.

The kinematics and kinetics indicated that tuned AFO-FCs have the potential to improve hip and pelvic function, knee extension in stance and knee flexion in swing, along with vertical and anterior GRFs in children with CP. A non-tuned AFO-FC has the potential to have a detrimental effect on hip function, posterior tilt and knee extension in children with type II gait described by Winters(23), where knee hyperextension is the predominant gait deviation.

Children with CP tend to present with excessive and abnormal timing of plantarflexion movement throughout the G.C, (as demonstrated in the case studies described in chapter eight), which is caused by contracted calf muscles, increased spasticity or impaired muscle activation(282). Often resulting in deterioration of the third foot rocker(28). A reduction at push off and inadequate clearance during swing results in excessive knee and hip flexion(28) and a lack of knee extension at the end of swing phase. The lack of knee extension and the plantarflexed position of the foot leads to I.C at the forefoot or the midfoot and consequently reduces step length. Such gait deviations are related to impaired muscle length which in turn may lead to the reduction in PROM in the adjacent muscles, which has been linked to the development of muscle contractures(283). Muscle contractures lead to further gait deviations, and thus the cycle of deterioration begins.

The primary purpose of an AFO intervention is to prevent this cycle of deterioration by improving the patient's gait pattern closer to that of a healthy individual. This study has indicated that a biomechanically optimised AFO-FC is likely to help achieve this aim and that the intervention of a non-tuned AFO-FC may actually lead to further deterioration for some patients.

Finally, the research focused on the participant's perception of the adapted footwear they had been prescribed. This was the first study to investigate patient perception and compliance in wearing tuned AFO-FCs. Research involving paediatric patient perception of orthotic intervention is scarce. The results indicated that, as expected, the participants did not like the cosmesis of the adapted footwear they were issued with but still complied with the treatment, and in three cases increased the wear time compared to their previous non-tuned prescription, citing improvements in function as crucial factors.

10.2 Limitations of the study

The studies outlined in this thesis have some limitations which should be acknowledged

The review of the design of AFO studies in the current literature (Objective 1) did not assign quality scores or rank studies, or look at the sample sizes or method outside of the materials and AFO design. One could argue that the scope of this study is limited. However, the reported results indicate that there is a substantial lack of structured information within the published research which needs to be addressed.

The investigation into common clinical practice of AFO-FC tuning amongst UK orthotists (Objective 3) represents only 9% of practising orthotists in the UK which could be attributed to the recruitment method. Although this does not appear to be a large number, this response rate exceeded most of previously published studies in the area of AFO-FC tuning. The results indicate that there is substantial need to conduct such an investigation in other countries and develop a consensus concerning processes and procedures related to AFO-FC tuning.

The investigator recognises that the sample size used in the main study is small and thus, the research would have benefited from a higher number of participants, however, this is not always possible due to various technical, human and financial difficulties. The investigation into the SVA as a valid measurement (objective 4) shows clinical applicability, the robustness of this validity has to be established with larger participant groups.

For the study on energy expenditure and kinetic and kinematic effects (objectives 5 and 6), the original aim was to recruit 15 participants in to detect significant differences at P=0.05 and power of 0.8 as recommended by Jagadamma(37). However, CP is an extremely heterogeneous disorder and as such, the investigator's aim was to look at the effects of the intervention on the individual participant as outlined in chapter seven.

The AFOs in the non-tuned condition had the correct AAAFO as dictated during the patient assessment; this is an essential aspect of AFO-FC tuning. It is hypothesised that setting the AFOs to an incorrect AAAFO would have further increased energy expenditure but this was deemed unethical. Thus, with the correct AAAFO we don't get the exact comparison between entirely biomechanically optimised AFO-FC and one which ignores the AAAFO required for the individual patient.

The AFO assessment was carried out without access to the kinetic and kinematic data, as stated in chapter eight. Thus, in one case (case study two), it is possible that a ground reaction force AFO (GRAFO) may have improved this participant's gait further, but the extent of the knee flexion in stance was only picked up with the aid of the kinetic and kinematic data.

A further possible limitation is that no data was collected with footwear alone, to use as a comparison between barefoot and the AFO conditions. However, this study aimed to compare the effects of tuned and non-tuned conditions and the footwear during these conditions remained the same. The footwear used were over splint orthopaedic footwear. Thus, another shoe would have had to be introduced, which would mean the results would not have been comparable to the AFO conditions, as it is widely documented that footwear is a crucial aspect of the AFO prescription.

10.4 Strengths of the research

This research provided individual case series analysis with detailed individual kinetic and kinematic data rather than meaningless group mean averages. Best practice guidelines(107,161)were followed, ensuring a full detailed description of the physical presentation of the participant and their gait pathology and a detailed description of the AFO-FC intervention used and the clinical justification for doing so.

Each participant was given three weeks to become accustomed to walking in their non-tuned AFO and subsequently their tuned AFO. On the day of testing each participant was given habitation time to become used to the gait laboratory and the testing equipment ensuring standardised adequate resting periods between conditions.

The study compared tuned versus non-tuned including barefoot gait as a baseline measurement, rather than testing tuned versus barefoot whereby the effects of the introduction of the AFO itself cannot be determined.

10.3 Conclusion

The primary objective of this research was to investigate the effects of a tuned AFO-FC compared to non-tuned on the gait and energy expenditure of children with CP. Further objectives were to examine the validity of the static SVA as a reliable measure of the dynamic SVA and to review the detail offered in current AFO research regarding the AFO intervention.

To the investigator's knowledge the investigation of the SVA, as outlined in this research, and the study of the effects of AFO-FC tuning on energy expenditure has never been carried out before.

Following the systematic review and various trials carried out during this project, it can be concluded that:

- There is a definite lack of detail regarding the AFO intervention studied in current research, a lack of standardised terminology to describe various AFO designs, a lack of clinical justification for the prescription of AFOs and a lack of consistency in outcome measures being studied in the available literature.

- AFO-FC tuning is not currently routine clinical practice amongst UK orthotists and there appears to be a lack of knowledge amongst this group of professionals regarding biomechanical optimisation of AFO-FCs.
- The SVA of the AFO-FC statically is an accurate way of determining the SVA at TMST during gait.
- Tuning an AFO-FC can potentially reduce the energy expenditure, the EEI (O_2) and increase speed and distance covered during gait, in children with spastic cerebral palsy.
- Biomechanically optimised AFO-FCs can improve hip function, pelvic function, knee extension in stance phase and knee flexion during swing phase, vertical and anterior GRF in children with CP, and that a non-tuned AFO-FC can potentially decrease hip function, posterior pelvic tilt and increase knee extension and as such, tuning should be common clinical practice, forming an essential part of the AFO prescription.
- Tuned AFO-FCs can have a negative impact on the posterior GRF during gait, reducing the participant's ability to propel the body forward.
- Children who demonstrate a gait pattern similar to that described by Winter's(23) group II, tend to demonstrate the most kinetic and kinetic improvements in a tuned AFO-FC.
- The impact of the AFO-FC on the participants' mobility outweighed their opinion on the cosmesis of the device and thus compliance was not affected.

10.4 Recommendations for future research

Further research is required to look at the effect of biomechanically optimised AFOs on upper limb and spinal movement during gait in children with CP. There is a need for a longitudinal study investigating the long term effects of biomechanically optimised AFOs including the effects on motor learning and muscle length in a plantarflexed AFO, which although counter-intuitive has been shown to increase musculotendinous unit length in below-knee casts(192,284).

It would also be interesting to investigate the effects of an AFO with an incorrect AAAFO to truly compare against a biomechanically optimised AFO-FC. In addition, a larger study is required to better understand how different gait pathologies in CP children respond to AFO-FC tuning.

Standardisation of terminology for AFOs needs to be devised along with standardisation for AFO prescriptions.

Research is required to determine the true accuracy of tuning AFO-FCs by eye compared to using 2D gait analysis. To ensure current practice utilises the best methods available for tuning AFO-FCs in the clinical setting.

Finally, whether one should align/tune/biomechanically optimise an AFO-FC is not the question, this by common sense should be mandatory. The definition of “tuning” in the wider sense is to optimise something’s performance. All clinicians must be aiming to optimise the performance of the AFO-FC they prescribe. The AFO treatment shouldn’t stop at the fitting stage; one must observe the patient’s gait and look to optimise the AFO-FC function in order to achieve the treatment goal. Which alignments suit which gait pathologies is what requires further investigation and clarification. A prosthetist would not provide prosthesis without correctly aligning it; similarly an orthotist should not provide an AFO without correctly aligning it.

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12.0 Appendices

12.1: A questionnaire on clinical practice amongst UK orthotists regarding AFO-FC tuning

12.2: P.I.G markers

12.3: Participant consent form

12.4: Parent/guardian consent form

12.5: Participant study information sheet

12.6: Parent/guardian study information sheet

12.7: Participant physical assessment form

12.8: Participant trial information sheet

12.9: Participant heart rate recording sheet

12.10: Study timing-gate recording sheets

12.11: Study force plate recording sheet

12.12: Study procedure flow chart

12.13: A questionnaire to measure participant perception and compliance with a tuned AFO-FC

12.1: A questionnaire on clinical practice amongst UK orthotists regarding AFO-FC tuning

STAFFORDSHIRE UNIVERSITY

A Questionnaire on tuning ankle foot orthoses and footwear combinations (AFO-FC).

Please delete answers as necessary leaving the answer which applies to you, visible.

1. Are you aware of AFO-FC tuning? Yes/No

2. Do you fully understand the process of tuning AFO-FC Yes/No

3. Do you use AFO-FC tuning as standard practice on all patients Who are prescribed with an AFO? Yes/No

4. If No, what is preventing you using AFO-FC tuning ?
    - I don't fully understand the process Agree/Disagree
    - I don't have access to 3D gait analysis Agree/Disagree
    - It is too time consuming Agree/Disagree
    - It is too costly Agree/Disagree
    - I am unaware of AFO-FC tuning Agree/Disagree
    - I don't feel there is any quality research highlighting the benefits of AFO-FC tuning Agree/Disagree
    - I have tried AFO-FC tuning and couldn't see any benefit Compared with an un-tuned AFO Agree/Disagree

5. If yes how do you decide which patients will benefit from AFO-FC tuning?
    - I have set criteria which patients must meet to ensure they will benefit from AFO-FC tuning. Yes/No

      Please indicate your criteria

      ____

    - I tune all patients who are prescribed an AFO Yes/No
    - It depends on whether I have enough time allocated at the appointment Yes/No

6. Do you use 3D gait analysis to tune AFO-FC? Yes/No

- If no, do you use video analysis Yes/No
  Or tune the AFO-FC by eye alone Yes/No

Please indicate any other method you use

____
____
____

1. Do you take AFO design into consideration when deciding whether
   to tune an AFO? Yes/No

   If yes, please state which design criteria would prevent tuning of an AFO

   ____
   ____
   ____
   ____
   ____

2. Do you take the physical ability (ROM, muscle tone, contractures,
   Stability etc.) of the patient into account when deciding whether their
   AFO should be tuned? Yes/No

3. If Yes, please state the criteria which would prevent you from tuning a patient's
   AFO

   ____
   ____
   ____

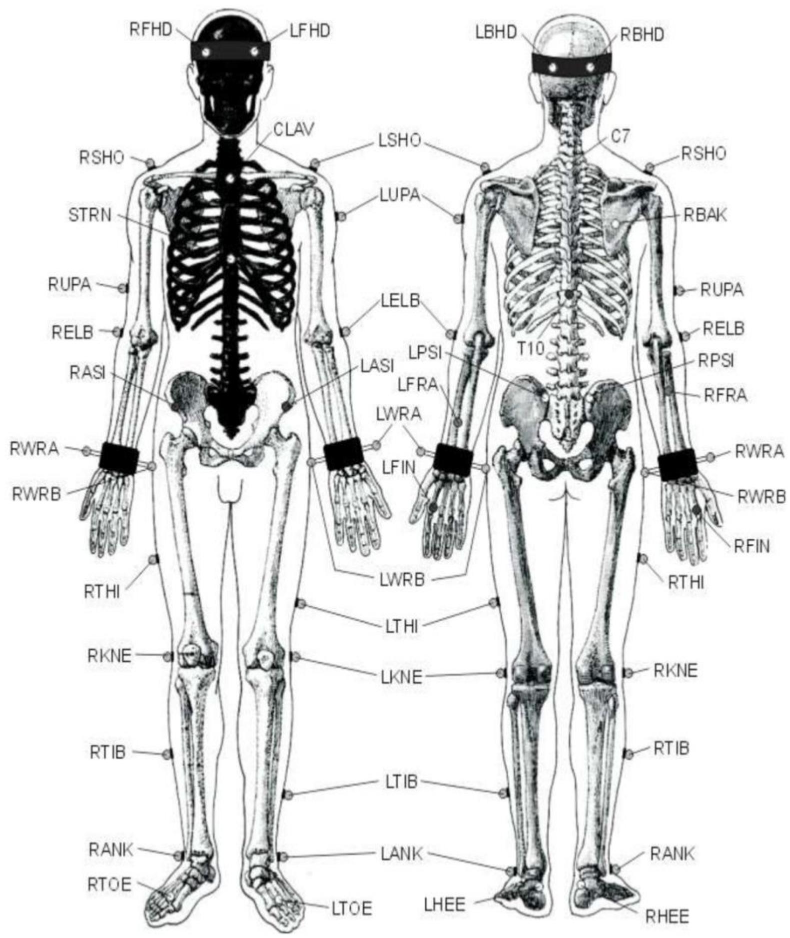
4. Are you a qualified Orthotist? Yes/No

5. How many years' experience do you have in orthotics? _______ ______________________

Thank you for taking the time to complete this questionnaire, please email it to:
N.Eddison@staffs.ac.uk
alternatively, post it to:
Nicola Eddison/ N Chockalingam, Faculty of Health, Staffordshire University, Leek Road,
Stoke on Trent ST4 2DF

12.2: P.I.G marker set up

Plug-in-Gait Marker Placement



The following describes in detail where the Plug-in-Gait markers should be placed on the subject. Where left side markers only are listed, the positioning is identical for the right side.

Upper Body

Head Markers

LFHD	Left front head	Located approximately over the left temple
RFHD	Right front head	Located approximately over the right temple
LBHD	Left back head	Placed on the back of the head, roughly in a horizontal plane of the front head markers
RBHD	Right back head	Placed on the back of the head, roughly in a horizontal plane of the front head markers

The markers over the temples define the origin, and the scale of the head. The rear markers define its orientation. If they cannot be placed level with the front markers, and the head is level in the static trial, tick the "Head Level" check box under options on "Run static model" in the pipeline when processing the static trial. Many users buy a headband and permanently attach markers to it.

Torso Markers

C7	7th Cervical Vertebrae	Spinous process of the 7th cervical vertebrae
T10	10th Thoracic Vertebrae	Spinous Process of the 10th thoracic vertebrae
CLAV	Clavicle	Jugular Notch where the clavicles meet the sternum
STRN	Sternum	Xiphoid process of the Sternum
RBAK	Right Back	Placed in the middle of the right scapula. This marker has no symmetrical marker on the left side. This asymmetry helps the auto-labeling routine determine right from left on the subject.

C7, T10, CLAV, STRN define a plane hence their lateral positioning is most important.

Arm Markers

LSHO	Left shoulder marker	Placed on the Acromio-clavicular joint
LUPA	Left upper arm marker	Placed on the upper arm between the elbow and shoulder markers. Should be placed asymmetrically with RUPA
LELB	Left elbow	Placed on lateral epicondyle approximating elbow joint axis
LFRA	Left forearm marker	Placed on the lower arm between the wrist and elbow markers. Should be placed asymmetrically with RFRA
LWRA	Left wrist marker A	Left wrist bar thumb side
LWRB	Left wrist marker B	Left wrist bar pinkie side

The wrist markers are placed at the ends of a bar attached symmetrically with a wristband on the posterior of the wrist, as close to the wrist joint center as possible.

LFIN	Left fingers	Actually placed on the dorsum of the hand just below the head of the second metacarpal

Lower Body

Pelvis

LASI	Left ASIS	Placed directly over the left anterior superior iliac spine
RASI	Right ASIS	Placed directly over the right anterior superior iliac spine

The above markers may need to be placed medially to the ASIS to get the marker to the correct position due to the curvature of the abdomen. In some patients, especially those who are obese, the markers either can't be placed exactly anterior to the ASIS, or are invisible in this position to cameras. In these cases, move each marker laterally by an equal amount, along the ASIS-ASIS axis. The true inter-ASIS Distance must then be recorded and entered on the subject parameters form. These markers, together with the sacral marker or LPSI and RPSI markers, define the pelvic axes.

LPSI	Left PSIS	Placed directly over the left posterior superior iliac spine
RPSI	Right PSIS	Placed directly over the right posterior superior iliac spine

LPSI and RPSI markers are placed on the slight bony prominences that can be felt immediately below the dimples (sacro-iliac joints), at the point where the spine joins the pelvis.

SACR	Sacral wand marker	Placed on the skin mid-way between the posterior superior iliac spines (PSIS). An alternative to LPSI and RPSI.

SACR may be used as an alternative to the LPSI and RPSI markers to overcome the problem of losing visibility of the sacral marker (if this occurs), the standard marker kit contains a base plate and selection of short "sticks" or "wands" to allow the marker to be extended away from the body, if necessary. In this case it must be positioned to lie in the plane formed by the ASIS and PSIS points.

Leg Markers

LKNE	Left knee	Placed on the lateral epicondyle of the left knee

To locate the "precise" point for the knee marker placement, passively flex and extend the knee a little while watching the skin surface on the lateral aspect of the knee joint. Identify where knee joint axis passes through the lateral side of the knee by finding the lateral skin surface that comes closest to remaining fixed in the thigh. This landmark should also be the point about which the lower leg appears to rotate. Mark this point with a pen. With an adult patient standing, this pen mark should be about 1.5 cm above the joint line, mid-way between the front and back of the joint. Attach the marker at this point.

LTHI	Left thigh	Place the marker over the lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical.

The thigh markers are used to calculate the knee flexion axis location and orientation. Place the marker over the lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical. The antero-posterior placement of the marker is critical for correct alignment of the knee flexion axis. Try to keep the thigh marker off the belly of the muscle, but place the thigh marker at least two marker diameters proximal of the knee marker. Adjust the position of the marker so that it is aligned in the plane that contains the hip and knee joint centers and the knee flexion/extension axis. There is also another method that uses a mirror to align this marker, allowing the operator to better judge the positioning.

LANK	Left ankle	Placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis
LTIB	Left tibial wand marker	Similar to the thigh markers, these are placed over the lower 1/3 of the shank to determine the alignment of the ankle flexion axis

The tibial marker should lie in the plane that contains the knee and ankle joint centers and the ankle flexion/extension axis. In a normal subject the ankle joint axis, between the medial and lateral malleoli, is externally rotated by between 5 and 15 degrees with respect to the knee flexion axis. The placements of the shank markers should reflect this.

Foot Markers

LTOE	Left toe	Placed over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
LHEE	Left heel	Placed on the calcaneous at the same height above the plantar surface of the foot as the toe marker

12.3: Participant consent form

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CONSENT FORM FOR CHILDREN
Patient and Subject study

Title: Modifying splints and shoes for children who find walking difficult

Child (or guardian on their behalf) to circle all they agree with please:

1. Somebody has explained this study to me **Yes -No**
2. I understand this study and I have asked all my questions **Yes -No**
3. I understand I don't have to do this study **Yes -No**
4. I understand I can stop doing this study at any time **Yes -No**
5. I am happy to take part in this study **Yes -No**

If you have answered YES to all these questions and would like to take part in this study please write your name and today's date. If you don't want to take part in this study then you don't need to write your name.

Your Name: ____________________________________

Date: ____________________________________

Your parent/guardian must also write their name here too if they are happy for you to take part in this study.

Parent/Guardian's Name: ____________________________

Signature: ____________________________

Date: ____________________________

The clinician who explained this study to you needs to sign too.

Print name: ______________________________________

Signature: ______________________________________

Date: ______________________________________

One consent form to be kept by the participant and one to be kept by the researcher

12.4: Parent/guardian consent form

CONSENT FORM

Patient and Subject Study

The effect of "tuning" ankle foot orthoses (AFOs) on the Gait parameters of children with cerebral palsy

Researchers

Nicola Eddison Bsc (Hons) PgCRM MBAPO
Prof. Nachiappan Chockalingam

Faculty of Health,
Staffordshire University
Stoke on Trent ST4 2DF

Telephone: 01902694082
Email: N.eddison@staffs.ac.uk or N.eddison@nhs.net
N.Chockalingam@staffs.ac.uk

NOTE : If the patient or sibling is under 16 years of age, the consent form is to be completed by a parent or guardian.

	Please initial box
1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.	
2. I understand that my participation or that of my child in this research is voluntary and that I/we are free to withdraw at any time, without giving a reason.	
3. I understand I need to be videoed/photographed: the photos/videos need to be kept for research purposes and I will not be identifiable in any of the photographs/videos	
4. I agree to take part in the above study*. I agree for my child to take part in the above study*. * delete not applicable.	

Name of Child ______ Date ______ Signature ______

Name of person giving consent ______ Date ______ Signature ______

One consent form to be kept by the participant and one to be kept by the researcher

Research ethics consent form (Last updated: November 2010) Ver: 1
Page 1

12.5: Participant study information sheet

Patient Group Studies
Information Sheet for children

STAFFORDSHIRE UNIVERSITY

Title: Modifying splints and shoes for children who find walking difficult

<u>What is research and why are we doing it?</u>

Research is when you look at something very carefully and try to work out why things happen and how. It helps us understand how things work and sometimes it can answer questions we didn't know the answer to before. This study is going to look at how children walk when we adapt their shoes and splints, to see if this helps them walk better.

We would like you to think about whether you would like to join in on this study?

<u>Why have I been asked to take part?</u>

You have been asked to take part because you wear special splints to help you walk better and you are under 16 years old.

<u>Who has checked if this study is ok to do?</u>

There is a group of people who have to check all research before it can be done, they have a special name, and they are called the **ethics committee**. They make sure the study is safe; the hospital has also checked this study to make sure it is safe to do.

<u>Can I say no if I don't want to take part?</u>

Yes! It is up to you whether you want to take part nobody will force you to do something you don't want to do.

<u>What will happen to me if I take part in this study?</u>

If you choose to take part in this study we will ask you to do the following things:

1. Let us check how much movement you have got in your legs and hips, this will be very similar to what your physiotherapist does when you see them.
2. Let us take a cast of your legs so we can make you some new splints. This will be the same as when you had the cast for the splints you have got now.

3. Come to the University so we can watch you walk with your new splints on in a special room. This will also mean we will need to ask you to wear shorts and we will put some special silver markers on your legs (have a look at the photo at the end of this page to see what they will look like).
4. We will need to record you walking with a video camera and we may also need take some photographs of you.
5. We may ask you to walk in the room up to 30 times, but you can have lots of rest in between.
6. Sometimes when you are walking we will ask you to wear a special mask which will fit over your mouth, this will tell us how tired you get when you walk
7. We will ask you to come back to the University a couple more times to watch you walk again.

Is there anything I need to be worried about?

No there is nothing you need to worry about, nothing we ask you to do will be painful or hurt you in anyway.

Who are the people I can speak to if I have any Questions?

You can speak to:

Nicola Eddison or Nachi Chockalingam

How can I contact them?

You can ask your parents to contact them for you in the following ways:

Name: Nicola Eddison
Address: Faculty of Health
Staffordshire University
Leek Road
Stoke on Trent ST4 2DF

Telephone: 01902694082
Email: N.eddison@staffs.ac.uk or N.eddison@nhs.net

12.6: Parent/guardian study information sheet

Patient Group Studies
Participation
Information Sheet

STAFFORDSHIRE UNIVERSITY

The effect of "tuning"ankle foot orthoses on the gait parameters of children with cerebral palsy

Contact for further information: -

Name: Nicola Eddison
Address: Faculty of Health
Staffordshire University
Leek Road
Stoke on Trent ST4 2DF

Telephone: 01902694082
Email: N.eddison@staffs.ac.uk or N.eddison@nhs.net

Name: Nachiappan Chockalingam
Address: Faculty of Health
Staffordshire University
Leek Road
Stoke on Trent ST4 2DF
Telephone:
Email: N.Chockalingam@staffs.ac.uk

'Your child is being invited to take part in a research study. Before you decide whether or not they can take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully'.

<u>What are the purposes of the study?</u>

Ankle foot orthoses (AFO's) are commonly prescribed to treat various gait abnormalities in children with cerebral palsy. Research available on the effect of AFO's on gait is relatively poor in that it doesn't take into account the appropriate design of the AFO with regards to the assessment outcome of the patient. Furthermore, ankle foot orthosis and footwear combination (AFO-FC) tuning has been shown to improve gait parameters but once again the research available does take into account AFO design or the benefits of the AFO-FC tuning to the patient.

<u>Why have I been invited to participate?</u>

Your child has been asked to participate as part of this very important study to help us understand how we can improve the way children, who wear AFO's, walk.

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Do I have to let my child take part?

No! It is up to you to decide whether or not to allow your child to take part. If you do decide to allow them to take part you will be given this information sheet to keep and you will be asked to sign a consent form. If you decide to allow your child to take part you are still free to withdraw them at any time and without giving a reason.

What will happen to my child if I take part?
(See the images at the bottom of the sheet)

- You will be required to have a physical assessment of your lower limbs where the researcher will check the movement you have in your legs and hips.

- You will be required to have a cast taken of the leg/s you currently wear your AFO on, so the researcher can make a new AFO/s (See photos 1-5)

- You will be invited to Staffordshire University's Biomechanical facility on up to 5 separate occasions to have the way you walk observed and recorded. The full procedure will be as follows:

    1. A set of markers will be placed on certain bones of your lower limbs and hips (image 6)
    2. You will be asked to walk bare foot along a walkway within the laboratory (you may be required to do this several times) – your walking will be video recorded.
    3. You will then be asked to walk along the same walkway whilst wearing your AFOs and footwear (you may be required to do this several times).
    4. You will be invited back to the laboratory again on another day at which time you will be asked to walk in your AFOs and footwear which the researcher will have adapted (adapted by making the shoes stiffer or more flexible or adding wedges inside the shoe), you may be required to do this several times.
    5. You will be fitted with a portable gas analyser (see image 7) this will measure how much oxygen you use when walking. You will be asked to walk along the walk way several times whilst wearing this equipment.

- You will be required to continue wearing the AFO-FC for a 12 month period; these will be replaced if they are outgrown. After which you will be asked to undergo another physical assessment of your lower limbs and hips, a repeat of the assessment you will undergo in the first stage of this study.

- You will be asked to complete a questionnaire regarding your opinion on the cosmesis of your new AFO-FC and your thoughts about continuing to wear the AFO-FC.

What are the possible benefits of taking part?

A better understanding of the effects of tuned AFO-FC's on the gait of children with cerebral palsy and the effects on the muscles of the lower limbs, which will improve clinical decisions taken in prescribing AFO's.

What should I do If I want my child to take part?

Should you agree to allow your child to take part you will be asked to sign a Consent Form and the researcher will arrange a time at your convenience to be fully briefed on the apparatus and for a data acquisition session. **You may withdraw at any time.**

Will data acquired be kept confidential?

There will be no correlation between any volunteer's identity and any data that are acquired, stored and published will be kept strictly confidential (subject to legal limitations). The Researcher will only use a common file identification numbers to tie data sets together to ensure full confidentiality, privacy and anonymity .Data generated by the study must be retained in accordance with the University's policy on Academic Integrity. The data generated in the course of the research will be kept securely in paper or electronic form for a period of five years after the completion of a research project.

What will happen to the results of the research study?

The results of the research will be used in research publications with an emphasis on biomechanics and pediatric gait. The researcher will be able to advise you on how you can obtain a copy of any published research.

Who is organising the research?

The research is being conducted by researchers at the Faculty of Health, Staffordshire University.

Who has reviewed the study?

The research has been approved by the University Research Ethics Committee of Staffordshire University and the Royal Wolverhampton NHS Trust research committee.

Contact if you have any concerns

If you have any concerns about the way in which the study has been conducted, you should contact the Chair of the University Research Ethics Committee.

Many thanks for taking the time to read this information sheet.

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Images 1-5: Casting technique to manufacturer AFO's

Image 1

Image 2

Image 3

Image 4


Image 5

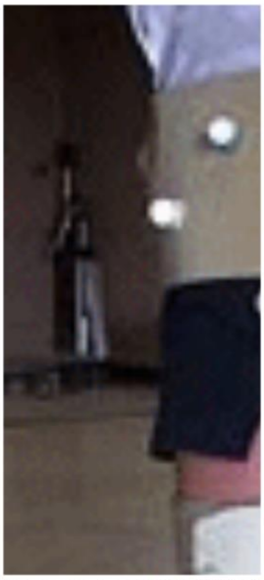
Image 6: Anatomical Markers


Image 7: Gas analyser

5

12.7: Participant physical assessment form

Orthotic Physical Assessment form

ID

Name:	
D.O.B:	
Hospital No:	

Date:	
Orthotist:	
Physio:	

Height:		**Cerebral Palsy Classification:**	
Weight:		**Hemiplegic / diplegic / Quad / Triplegic**	**Left/right**
GMFCS Level:		**Spastic / Ataxic / Dyskinetic**	

Detailed Description of CP presentation:
Any other medical conditions?
Previous surgery/botox? **Is future surgery/botox planned? Is there any change in treatment planned?** **Current treatment regime? Include date treatment started**

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PROM	RIGHT PASSIVE	LEFT PASSIVE	Comments
Hip ABD			
Hip ADD			
Hip Flexion			
Hip Extension			
External (Med) Rotation			
Internal (Lat) Rotation			
Anteversion Ryder's test			
Thomas Test			

Knee Extension			
Knee Flexion			
Popliteal Angle			
Varus Angle			
Valgus Angle			

Ankle Dorsiflexion Knee extended				
Ankle Dorsiflexion Knee flexed				
Ankle plantar flexion				
Subtalar inversion				
Subtalar eversion				
Position of foot in STJN	LEFT RIGHT			
Tibial Torsion				
Foot progression angle (Thigh foot angle)				
Actual Leg length I.C to Med. Malleous			LLD = SHORT: LEFT / RIGHT	
Apparent Leg Length Umbilicus to Med malleolus			LLD = SHORT: LEFT / RIGHT	
Spasticity score (Modified Ashworth Scale) HAMSTRINGS QUADS DORSFLEXORS PLANTARFLEXORS			Angle of spastic catch	If muscle is an extensor start in max extension then move briskly to full flexion
Is Clonus present?				SCALE 0-3
Muscle Power (Oxford Scale}				SCALE 0/5 -5/5

HIP EXT **HIP FLEX** **HIP ABD** **HIP ADD** **KNEE EXT** **KNEE FLEX** **DORSIFLEX** **PLANTAR FLEX** **INVERSION** **EVERSION**				
Description of Tone				

	Static Spinal assessment
Is there a scoliosis?	**Yes/No** **Fixed/Correctable**
Is there a Lordosis?	**Yes/No** **Fixed/Correctable**
Is there a Kyphosis	**Yes/No**

	Fixed/Correctable
Any other comments on spinal alignment?	

Eligibility to take part in the proposed research

Inclusion/Exclusion Criteria	**Comments**
Is the patient an independent ambulator?	
Does the patient wear AFO/S?	
Is the patient GMFCS level 1 or 2?	
Is the patient aged between 5-10 years old?	
Does the patient have contractures of the hips and or knees?	
Does the patient have an exaggerated stretch reflex?	
Does the patient have an excessive foot progression angle?	
Does the patient have any surgery or change of treatment planned?	

Is this patient eligible to take part in the study? **YES / NO**

If No, Give Reason:

____

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____

____

Researcher's Signature______________________________ **Date:** ___________

Researcher's Name__________________________________

Description of Gait: Bare Foot

12.8: Participant trial information sheet

Participant information and measurements

Testing date: ________ Room Temperature___________________________

Tester(s): ____

Name:	
Date of Birth:	
Height (mm):	
Weight (kg):	
Shoe size:	

Food intake today and time when eaten:	
Food intake in lab:	

		Left	Right
Leg length (mm):	Full leg length, measured between the ASIS marker and the medial malleolus, via the knee joint. Measure with patient standing, if possible.		
Knee width (mm):	The medio-lateral width of the knee across the line of the knee axis. Measure with patient standing, if possible.		
Ankle width (mm):	The medio-lateral distance across the malleoli. Measure with patient standing, if possible.		
Shoulder offset (mm):	Vertical offset from the base of the acromion marker to shoulder joint centre		
Elbow width (mm):	Width of elbow along flexion axis (roughly between the medial and lateral epicondyles of the humerus)		
Wrist width (mm):	Anterior/Posterior thickness of wrist at position where wrist marker bar is attached		
Hand thickness (mm):	Width thickness between the styloid processes of the wrist		

Notes:	

12.9: Participant heart rate recording sheet

Heart rate monitoring

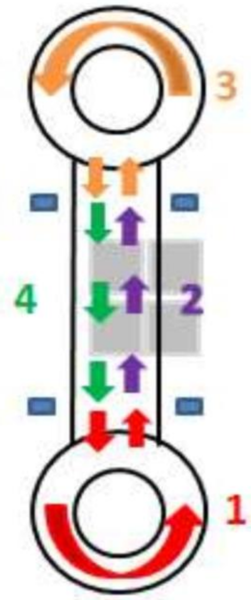
Participant: ______________________ **Testing date:** ______________________

Vicon subject name:______________________ **Tester(s):** ___________________________

Condition	Trial	Standing			Walking				Rest											
		0min	1min	2min	1min	2min	3min	4min	1min	2min	3min	4min	5min	6min	7min	8min	9min	10min	11min	12min
Barefoot	**1**																			
	2																			
	3																			
AFO	**1**																			
	2																			
	3																			

Notes:

12.10: Study timing-gate recording sheets



Date:	
Participant:	
Trial name:	
Tester(s):	

Condition:	

Loop 1	1		Loop 7	1	
	2			2	
	3			3	
	4			4	
Loop 2	1		Loop 8	1	
	2			2	
	3			3	
	4			4	
Loop 3	1		Loop 9	1	
	2			2	
	3			3	
	4			4	
Loop 4	1		Loop 10	1	
	2			2	
	3			3	
	4			4	
Loop 5	1		Loop 11	1	
	2			2	
	3			3	
	4			4	
Loop 6	1		Loop 12	1	
	2			2	
	3			3	
	4			4	

Notes:

1

12.11: Study force plate recording sheet

Participant: ____________________ **Testing date:** ____________________

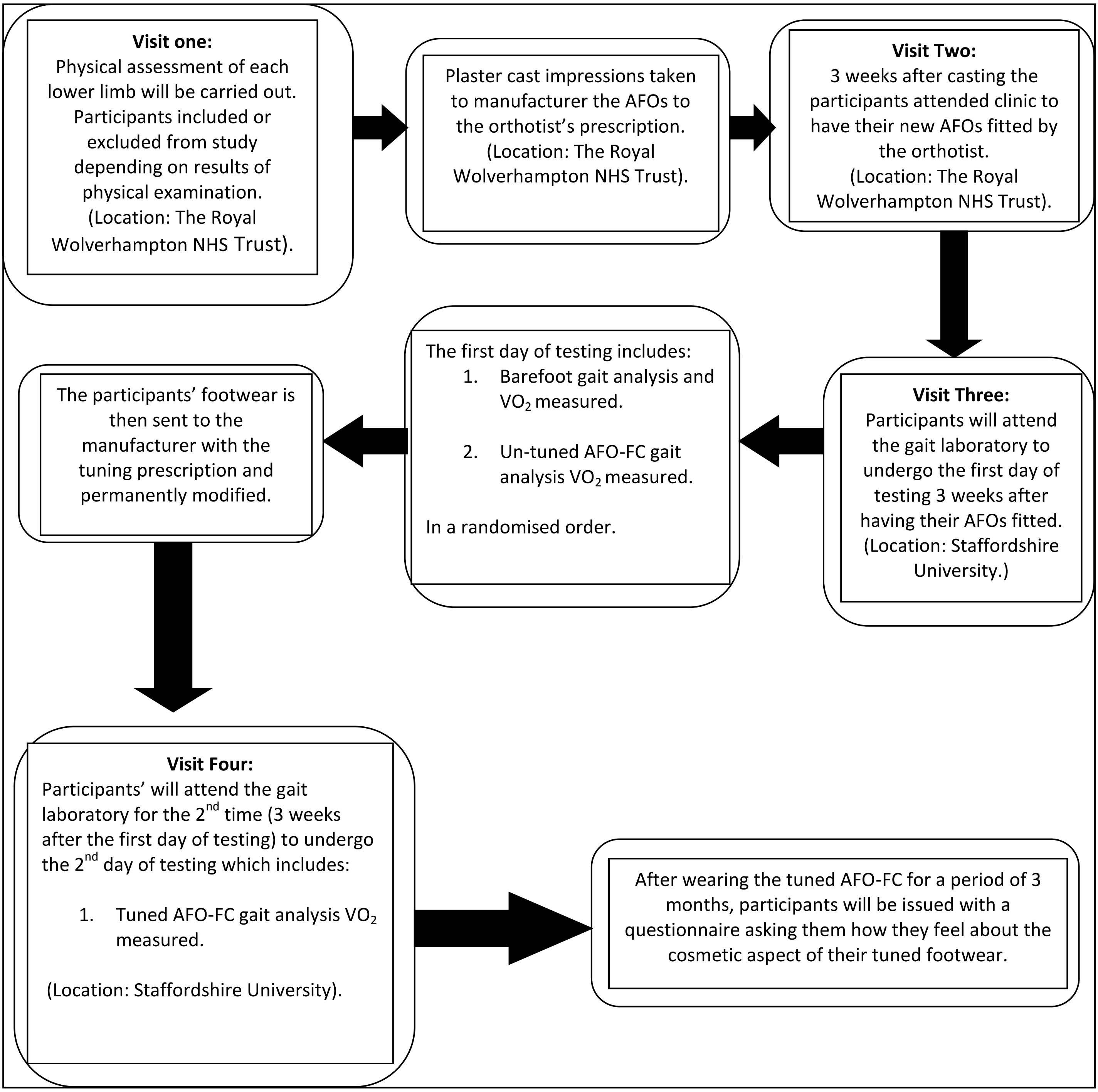
Vicon subject name:____________________ **Tester(s):** ________________________

Vicon configuration name: _____________________________________

Trail Name			Contacted force plate?	Notes
	Loop 1	2 ↑		
		4 ↓		
	Loop 2	2 ↑		
		4 ↓		
	Loop 3	2 ↑		
		4 ↓		
	Loop 4	2 ↑		
		4 ↓		
	Loop 5	2 ↑		
		4 ↓		
	Loop 6	2 ↑		
		4 ↓		
	Loop 7	2 ↑		
		4 ↓		
	Loop 8	2 ↑		
		4 ↓		
	Loop 9	2 ↑		
		4 ↓		
	Loop 10	2 ↑		
		4 ↓		
	Loop 11	2 ↑		
		4 ↓		
	Loop 12	2 ↑		
		4 ↓		

12.12: Study procedure flow chart

Diagram to show the sequence of events undertaken by each participant



12.13: A questionnaire to measure participant perception and compliance with tuned AFO-FC

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Questionnaire:

Thank you for taking part in our research which looked at how children walk with their splints. As part of the study, we would like to ask you some questions on how you feel about your splints and the footwear we have adapted for you. If you would like to answer our questions, please ask your parent/guardian to help you fill out this form. **You don't have to answer the questions if you don't want to.**

Who are the people I can speak to if I have any questions about this questionnaire?

You can speak to:

Nicola Eddison or Prof. Nachi Chockalingam

How can I contact them?

You can ask your parents to contact them for you in the following ways:

Name: Nicola Eddison

Address: Faculty of Health
Staffordshire University
Leek Road
Stoke on Trent ST4 2DF

Telephone: 01902 694082

Email: N.eddison@staffs.ac.uk or N.eddison@nhs.net

Name: Prof. Nachiappan Chockalingam

Address: Faculty of Health
Staffordshire University
Leek Road
Stoke on Trent ST4 2DF

Telephone: 01782 295853

Email: N.Chockalingam@staffs.ac.uk

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Child's name: ____

Today's Date: ____________________

Parent/Guardian Name: ____

Parent/Guardian signature ____

Questions ***(Please tick the answer which applies to you)***

1) Do you like wearing your splints?

Yes ☐

No ☐

1A) If you <u>don't</u> like wearing your splints please tell us why ***(Please tick all answers which apply to you)***

I don't like the way they look ☐

I don't like the way they make me walk ☐

I don't like how they feel when I wear them ☐

I walk better without them ☐

They hurt me when I wear them ☐

Because other people notice my splints ☐

My splints make me tired when I walk ☐

Other:

____

____

____

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1B) **Please tell us what you <u>do</u> like about your splints** ***(Tick all which apply to you)***

They make me walk better ☐

I can walk further with my splints than I can without them ☐

I don't get any pain when I wear my splints ☐

My splints help me balance better ☐

I don't fall over as much when I wear my splints ☐

I like the way my splints look ☐

My splints stop the muscles in my leg/s from feeling tight ☐

I don't like anything about my splints ☐

I don't feel as tired when I walk with my splints on ☐

Other ____

____

____

2) **Do you like wearing the shoes which we have adapted, with your splints?**

Yes ☐

No ☐

3A) **If you <u>don't</u> like wearing your adapted shoes please tell us why** ***(compared to shoes and splints without adaptations)***

I don't like the way they look ☐

I don't like the way they make me walk ☐

I don't like how they feel when I wear them ☐

I walk better without the adaptations on my shoes ☐

They hurt me when I wear them ☐

Because other people notice the adaptations on my shoes ☐

My balance is worse with my adapted shoes ☐

My adapted shoes prevent me from doing certain activities ☐

My adapted shoes make me tired when I walk ☐

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Other:

____

____

____

3B) **Please tell us what you <u>do</u> like about your adapted shoes** ***(compared to shoes and splints without adaptations)***

They make me walk better ☐

I can do more activities with my adapted shoes and splints ☐

I don't have any pain when I wear my adapted shoes and splints ☐

I can walk further with my adapted shoes and splints ☐

I don't fall over as much when I wear my adapted shoes with my splints ☐

I like the way my adapted shoes look ☐

My adapted shoes improve my balance ☐

I don't feel as tired when I walk in my adapted shoes ☐

I don't like anything about my adapted shoes ☐

Other:

____

____

____

4) **Where do you wear your splints?**

I wear them whenever I go outside ☐

I wear them at home and when I go outside ☐

I wear them at school only ☐

I wear them at home only ☐

Other:

____

5) **How long do you wear your splints for per day?**

I wear them for 2 - 3 hours per day ☐

I wear them for 4 - 5 hours per day ☐

I wear them for 6 - 8 hours per day ☐

I wear them for over 8 hours per day ☐

6) **How many days per week do you wear your splints for?**

I wear them 7 days per week ☐

I wear them Monday to Friday only ☐

I wear them at weekend only ☐

Other ☐

7) **Since having adaptations added to your shoes do you wear your splints and shoes more or less often?**

I wear my splints and shoes *more* often now ☐

I wear my splints and shoes *less* often now ☐

There is no change in the amount of time I wear my shoes and splints for ☐

7A) **If you are wearing your splints and shoes more OR less often since having adaptations added to your shoes, please tell us why.**

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8) **Is there anything else you would like to tell us about the way you feel about your splints and adapted shoes?**

No ☐

Yes ☐

____

____

____

____

Thank you for completing this questionnaire and helping us with our study. Please return this form in the envelope provided.