NATIONAL CENTRE FOR TRAINING AND EDUCATION IN ORTHOTICS AND PROSTHETICS.

UNIVERSITY OF STRATHCLYDE

‘SHANK ANGLE TO FLOOR’ MEASURES AND TUNING OF ‘ANKLE-FOOT ORTHOSIS FOOTWEAR COMBINATIONS’ FOR CHILDREN WITH CEREBRAL PALSY, SPINA BIFIDA AND OTHER CONDITIONS.

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Owen E (2002) Shank angle to floor measures of tuned ‘ankle-foot orthosis footwear combinations’ used with children with cerebral palsy, spina bifida and other conditions. Gait & Posture 16: Supp 1, S132-S133

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ABSTRACT

The purpose of this study is to report the Shank Angle to Floor (SAF) measures of the tuned Ankle-Foot Orthosis Footwear Combination (AFOFC) prescriptions for a population of children with CP, SB and other conditions in North West Wales. It also presents an unambiguous and clearly defined terminology to describe some of the key sagittal plane features of AFOFC prescriptions and methods of measuring them. The thesis includes an extensive literature review on AFOFCs and "tuning".

Seventy-four children (Cerebral Palsy n=50, Spina Bifida n=4, Other conditions n=20) who were independently ambulant without walking aids and using solid AFOFCs (n=112) had their prescriptions tuned on a Video Vector Generator Gait Laboratory. Children's gait was analysed while walking barefoot, in footwear and in AFOFCs until they were tuned. The results showed that whether the Angle of The Ankle in the AFO (AAAFO) was dorsiflexed, plantigrade or plantarflexed the SAFs of the tuned AFOFCs were all inclined. For all AFOFCs (n=112) mean SAF=11.36°, SD=2.08, range 7-15°. For AFOFCs used by children with CP (n=69), mean SAF=11.86°, SD=2.05, range 7-15°. For AFOFCs used by children with SB (n=8), mean = 7.75°, SD=0.46, range 7-8°. AFOFCs for other children (n=35), mean =11.2°, SD=1.41, range 8-14°.

The results suggest that when tuning AFOFCs a good starting point would be to set the SAF at 10-12° inclined and increase or decrease the SAF as required. The mean tuned SAFs approximate to the SAF of normal gait at midstance. A possible explanation for the 10-12° inclined SAF being central to the production of stability in stance in both normal and pathological gait with AFOFCs is that it is determined by anthropometric measures.10-12° inclined is the position which brings the centre of the knee joint directly over the middle of the foot. Other design features of the AFOFC to be considered, if it is to be tuned optimally for the whole of the gait cycle, are described. Knowledge of normal and abnormal shank kinematics, throughout the gait cycle is vital for a comprehensive understanding of AFOFC tuning. These are described and discussed.

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CONTENTS

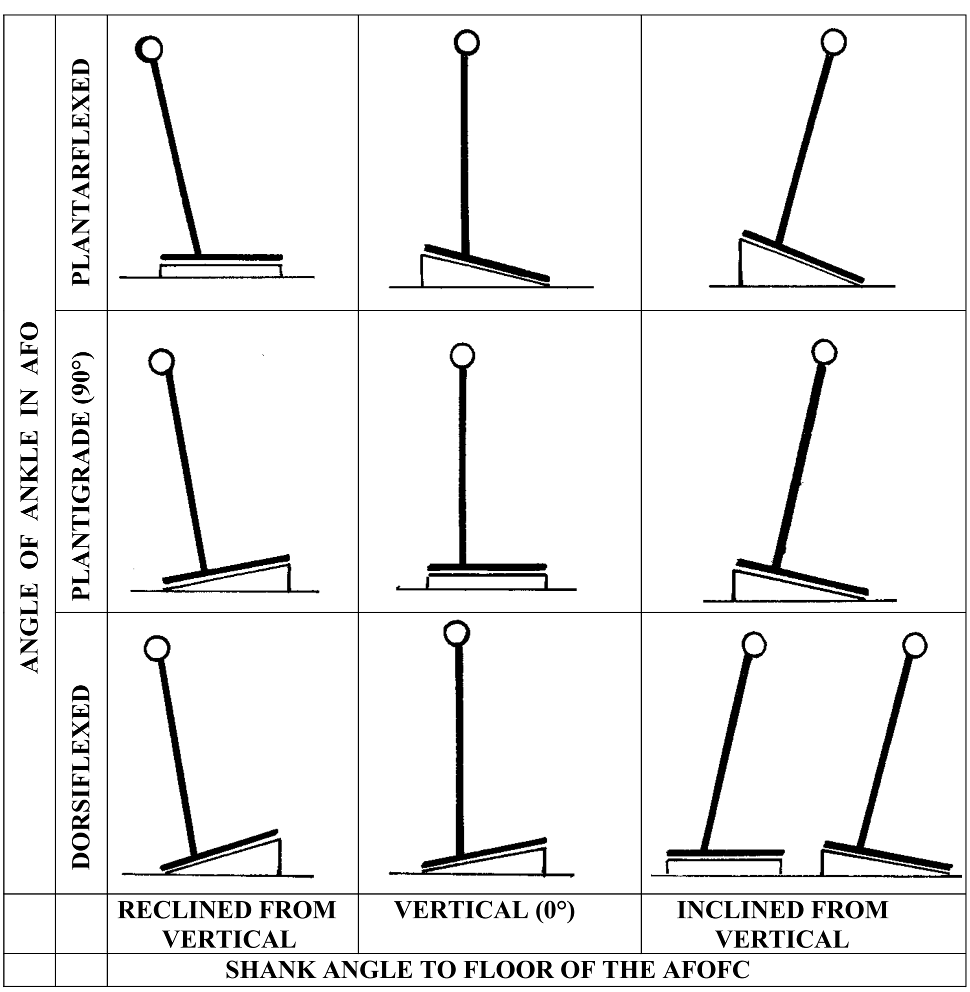
INTRODUCTION

DEFINITIONS AND TERMINOLOGY

An ankle-foot orthosis is one which encompasses the ankle joint and the foot (British Standards Institution 1990). The footwear worn with an AFO is integral in determining the overall biomechanical control provided so they have been described as an ‘AFO-footwear combination’ (Meadows 1984). In this paper the use of the words ankle-foot orthosis (AFO) will refer to the ankle foot orthosis itself. Use of the words ankle-foot orthosis footwear combination (AFOFC) will refer to the AFO together with the accompanying footwear.

The principal characteristics of an AFOFC are the angles at which the anatomical joints are set within the AFO, the stiffness of the AFO (Fillauer 1981, Lehmann et al 1983, Sumiya et al 1996, Nagaya 1997, McHugh 1999) the thickness of the sole and heel of the footwear, whether the sole is rigid or flexible, the profile of the heel and sole of the footwear particularly the type and position of rocker soles and whether the footwear has other features such as cushion heels (Lehmann et al 1970b, Weist et al 1979, Nuzzo 1980 and 1983, Meadows 1984, Hullin and Robb 1991, Hullin et al 1992, White 1992) and the angle which the shank makes with the vertical or the floor when standing in the AFOFC.

While descriptions in all 3 cardinal planes are important, (Condie and Meadows 1993) and recognition is given to the fact that all features are relevant, interactive and must be considered together, this paper concentrates on the sagittal plane and in particular on two of the principal sagittal characteristics. These are the Angle of the Ankle in the AFO (AAAFO) and the position of the lower leg relative to a vertical to the ground when standing in the AFOFC, which can be called the Shank Angle to Floor (SAF) of the AFOFC (Fig.1). To differentiate between the AAAFO and SAF is important not just for accuracy of description of the AFOFC but because while both are important determinants of gait, the SAF of the AFOFC is the major determinant



<u>FIGURE 1</u>

Nine configurations of the Angle of the Ankle in the Ankle-Foot Orthosis and the Shank Angle to floor of an Ankle-Foot Orthosis Footwear Combination of the kinematics and kinetics of gait and not, as is often assumed, the AAAFO (Nuzzo 1980).

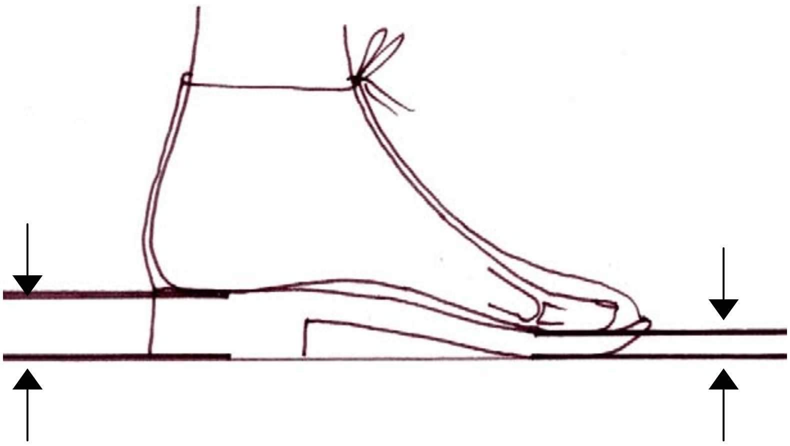
The Angle of the Ankle in the AFO (AAAFO) can be defined as the angle of the foot relative to the shank in the sagittal plane. It is described in degrees of dorsiflexion or plantarflexion with plantigrade or 90°. describing the neutral position.

The Shank Angle to Floor (SAF) of the AFOFC can be defined as the angle of the shank relative to a vertical to the horizontal surface when standing in the AFOFC with heels down and weight equally distributed between heel and toe. SAF is described as inclined if the shank is inclined forward from the vertical and reclined if the shank is reclined backward from the vertical. It is described in degrees from the vertical, vertical being 0 degrees.

Reclined, vertical and inclined are used to describe the SAF of AFOFCs whereas plantarflexion, plantigrade and dorsiflexion, are reserved to describe the AAAFO in AFOFCs. This eliminates confusion about use of the terms dorsiflexion and plantarflexion. The term SAF was devised for an orthotic recording system and was chosen to emphasise the fact that this angle must be measured with the patient standing in the AFOFC on the floor. Strictly speaking it could be described as shank angle to vertical.

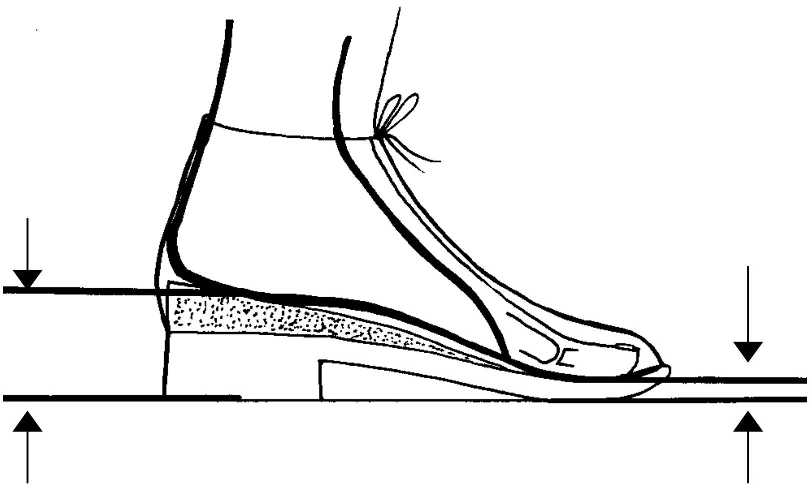
The two sagittal plane characteristics of the AFOFC which, when combined, will dictate the SAF can be called the internal and external characteristics (Meadows et al 1980, Sankey et al 1989). The internal characteristic is the AAAFO. Anything added to the AFO in the way of wedges attached to the AFO, footwear and adaptions to the footwear is the external characteristic. When using a solid AFO, because the ankle is fixed, the combination of the AAAFO and the 'pitch' of the external characteristic will determine the SAF of the AFOFC. Figure 1 shows how it is theoretically possible to achieve any position of SAF with any AAAFO by manipulation of the pitch of the external characteristic as long as a solid AFO is used.

<u>FIGURE 2</u>



2a. Heel Sole Differential of shoe/boot

The heel-sole differential is the measured difference between the thickness of the heel at mid-heel and the thickness of the sole at the metatarsal heads measured in millimetres.



2b. Heel Sole Differential if there are additions to heel

The heel-sole differential is the measured difference between the thickness of the heel of the shoe/boot and the additions at the heel at mid-heel and the thickness of the sole at the metatarsal heads measured in millimetres.

To replicate an AFOFC in the sagittal plane the minimum information required is either the AAAFO together with the SAF or the AAAFO together with the pitch of the external characteristic. The pitch can be measured in degrees (Meadows 1984, Hullin et al 1992) but for practical purposes the measured difference between the thickness of the heel and the thickness of the sole provides an adequate measure of pitch and is easier to obtain. It is not the same as a measurement of the heel height, which on its own will not reflect pitch. The term 'sole-to-heel height difference' has been used to describe this measure (Cook and Cozzens 1976) but to avoid any confusion with the heel height alone the term Heel Sole Differential (HSD) is used (Fig.2).

The AAAFO and SAF of an AFOFC have been described variously as 'ankle-foot attitude' and 'relative attitude of shank to ground' (Anderson and Meadows 1979); 'ankle angle' and 'relative angle of the tibia to the floor' (Gans et al 1979); 'anatomic dorsiflexion' and 'functional dorsiflexion, a measure of shoe sole to the tibia' or 'pseudo-dorsiflexion' (Nuzzo 1983); 'position of the foot relative to the leg' and 'position of the leg relative to the ground' (Sankey et al 1989); 'ankle angle' and 'the angle between the lower leg and the ground' (Butler and Nene 1991); 'foot-shank angle' and 'tibial floor angle' (Hullin et al 1992); 'floor/shank angle' (Major 1995); 'ankle angle' and 'shank line' (Miyamoto et al 1999).

While some of these authors describe both features most also describe a preference for a particular AAAFO. Anderson and Meadows (1979) and Sankey et al (1989) prefer the use of dorsiflexion. Gans et al (1979) used plantigrade only. Butler and Nene (1991) prefer plantigrade. Hullin et al (1992) used 10° dorsiflexion or plantigrade. Both dorsiflexed and plantigrade positions of the AAAFO have their place, but it is important to recognise that the choice of AAAFO is a complex clinical decision, based on a number of factors, and is individual for each leg of each child. The use of a plantarflexed position of the AAAFO is often essential and useful (Glancy and Lindseth 1972, Nuzzo 1983). In practice there is a place for use of a variety of plantarflexed, plantigrade and dorsiflexed AAAFO positions in AFOFCs.

THE EFFECT OF ORTHOSES ON PATHOLOGICAL GAIT

During normal gait there are typical kinematic (movement) and kinetic (force) features (Inman et al 1981, Sutherland et al 1988, Winter 1990, Gage 1991, Ounpuu et al 1991, Perry 1992). The ground reaction force (GRF) is aligned relative to the joints appropriately throughout the gait cycle in order to place minimal demand on the neuromuscular system and to produce a controlled low energy gait (Meadows 1984 and 1995, Winter 1990, Butler and Nene 1991, Perry 1992, Major 1995).

In pathological situations this may not be achieved (Simon et al 1978, Meadows 1984 and 1995, Lai et al 1988, Gage 1991, Butler and Nene 1991, Butler et al 1992, Perry 1992, Duffy et al 1996, Lin et al 2000).

Attempts have been made to categorise the gait pathologies seen in spina bifida (SB) and cerebral palsy (CP), (Winters et al 1987, Sutherland and Davids 1993, Vankoski et al 1995, Duffy et al 1996, Hullin et al 1996, O'Byrne et al 1998, Rodda and Graham 2001, Gutierrez et al 2003).

AFOFCs can be used to influence both the kinematic and kinetic features of gait (Condie and Meadows 1995, Morris 2002a, Mazur and Kyle 2004). During stance phase they act as manipulators of the GRF (Simon et al 1978, Meadows 1984 and 1995, Harrington et al 1984, Lehmann et al 1985, 1992, Lehmann 1993, Butler and Nene 1991, Hullin and Robb 1991, Butler et al 1992, Hullin et al 1992, Condie and Meadows 1993, Kerrigan et al 1996, Butler et al 1997, Freeman 1999, Thomson et al 1999). This is due to the influence of the AFOFC design on the kinematics of body segments relative to the vertical, particularly the shank, the kinematics of joints, the point of origin, magnitude and direction of the GRF, and consequently the relationship of the GRF to the ankle, knee and hip (Meadows 1984, 1986, and 1995). It has been emphasised that knowledge of the limb segment position relative to the GRF, rather than joint angles alone, is of fundamental importance when categorising gait (Hullin et al 1996). Knowledge of the limb segments relative to the vertical, and

FIGURE 3

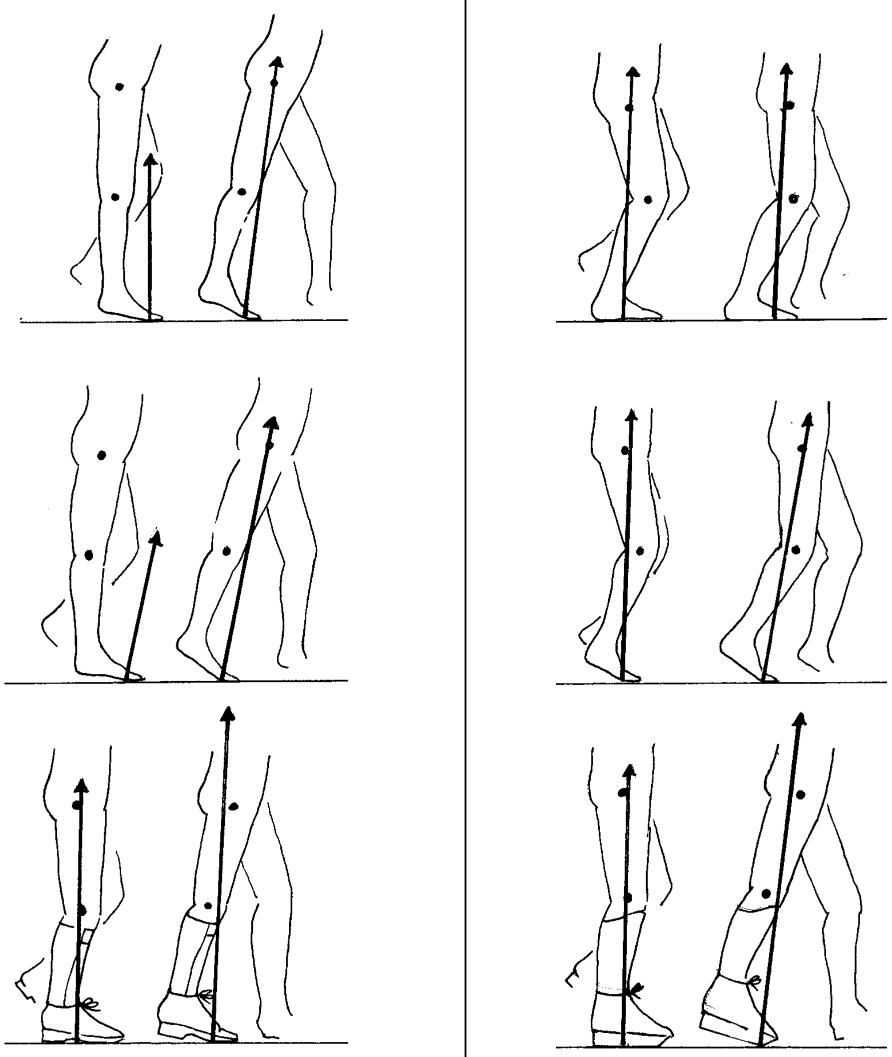
Common stance phase abnormalities seen at video vector gait analysis and their correction by Ankle-Foot Orthosis Footwear Combinations

MST TST | MST TST

3a | 3d

3b | 3e

3c | 3f



3a and 3b Shank insufficiently inclined in MST. Vector excessively anteriorly aligned at foot, knee and hip in MST. Vector vertical (1a) or forward leaning (1b).

3c AFOFC producing normal shank kinematics at MST and TST by increasing the inclination of the shank with resultant improvement of GRF alignment at foot, knee and hip.

3d and 3e Shank excessively inclined in MST. Vector aligned posterior to knee in MST and TST. Variable alignment at hip and foot.

3f AFOFC producing normal shank kinematics at MST and TST by reducing shank inclination with resultant improvement of GRF alignment at foot, knee and hip.

the GRF, are particularly important when using orthotic interventions, however, there are no publications which categorise gait deviations by the kinematic position of the segments relative to the vertical during the gait cycle.

Control of the kinematics of the shank, relative to the vertical, is essential to normal gait. Shank kinematics can be described by the Shank Angle to Floor (SAF), defined as the angle of the shank relative to a vertical to the horizontal surface, measured in the sagittal plane. The SAF is described as inclined if the shank is inclined forward from the vertical and reclined if the shank is reclined backward from the vertical. It is described in degrees from the vertical, vertical being 0 degrees. The SAF can be measured in standing or during a gait cycle when barefoot, in footwear or in AFOFCs. The SAF of normal stance phase of the gait cycle moves from a reclined position at initial contact (IC) to an inclined position at the end of pre-swing (PSW). The forward progression of the shank is produced by the three rockers (Perry 1992). It is in early MST that the SAF passes the vertical position. During MST there is a slowing of the angular velocity of the shank and that slowing occurs while the shank is at an inclined position (Perry 1974, Winter 1990).

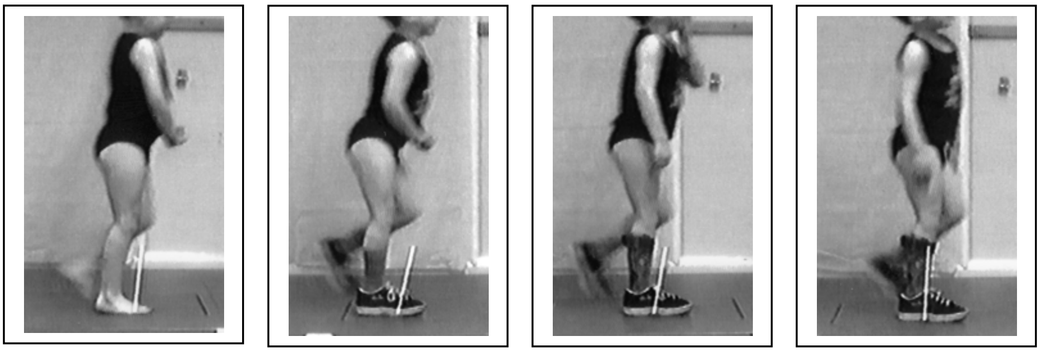
There are three stance phase gait abnormalities associated with CP, SB and other neurological conditions, which can be responsive to interventions with AFOFCs. These are excessive external knee extension moments usually coupled with an insufficiently inclined shank, excessive external knee flexion moments usually coupled with an excessively inclined shank and lack of appropriate external hip extension moments coupled with either of the first two scenarios (Fig.3: 3a 3b,3d,3e), (Fulford and Cairns 1978, Simon et al 1978, Meadows 1984, Butler and Nene 1991, Gage 1991, Hullin et al 1992, Perry 1992, Gage et al 1995, Hullin et al 1996, Connolly et al 1999, Rodda and Graham 2001). Some children may have a combination of excessively inclined and insufficiently inclined shanks in one gait cycle. Some may arrest the forward movement of the shank at an inappropriate position or demonstrate shank reversal (Simon et al 1978). Normalising shank kinematics produces the best chance of achieving optimum thigh and trunk kinematics and knee and hip kinetics.

In some CP gaits an increase in shank inclination, reduction of excessive external knee extension moments and the attainment of external hip extension moments in mid and late stance are essential goals of orthotic management (Fig.3: 3c). In other CP and SB gaits a reduction in shank inclination, reduction of external knee flexion moments and the production of external knee and hip extension moments are essential goals (Fig.3: 3f). If these goals are achieved then it may be possible to achieve another goal for successful gait, the production of second peak of the GRF (Meadows 1984, Lehmann et al 1985, Khodadadeh and Patrick 1988, Hullin et al 1992, Condie and Meadows 1993).

The selection of the design of both the AFO and the footwear and final tuning, the process whereby fine adjustments are made to the design of the AFOFC in order to optimise its performance, are crucial if these goals are to be achieved. Even small changes in the design of an AFOFC can make significant changes to the alignment of segments and the GRF to the joints in standing and walking (Rosenthal et al 1975, Stills 1975, Cook and Cozzens 1976, Meadows 1980,1984, 1986, 1995, Harrington et al 1984, Butler and Nene 1991, Nuzzo 1983 Part 1, Lehmann et al 1992, Lehmann 1993, Butler et al 1997, Schmaltz et al 2000, Stallard & Woollam 2003). Butler and Nene (1991) state that a considerable improvement in gait can be achieved with an increase of just 3mm in the HSD. Meadows (1984) showed that alterations of just 2-3°. in the SAF can produce changes in the kinematics and kinetics of the knee and hip.

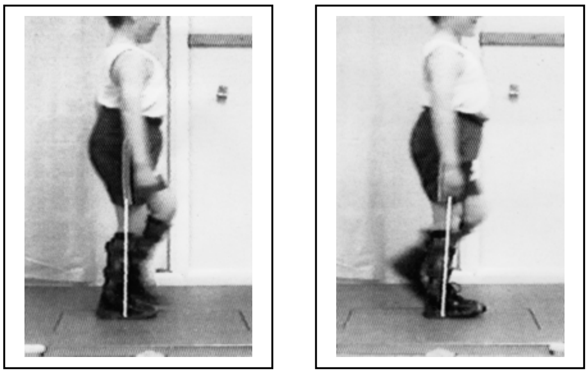
In addition it may be possible to make permanent changes in gait by using tuned AFOFCs (Rosenthal et al 1975, Simon et al 1978, Butler et al 1992, Butler et al 1997). Simon et al (1978) questioned whether the change was due to neuromuscular maturation, learning alterations in the recognition of the patterns of muscle activity or changes in anatomical structures with growth. Butler et al (1992) suggest that one explanation for the improvement is that a correction of the biomechanical environment allowed appropriate motor learning to occur. Butler et al (1997) concur with this. Meadows (1980, 1984, 1986 and 1995) describes how AFOFCs alter the

4a



Barefoot	Footwear only	AAAFO 5° dorsiflexed; SAF 10 ° inclined.	AAAFO 5° Dorsiflexed; SAF 15° inclined

4b



AAAFO 90°; SAF 15° inclined	AAAFO 90°; SAF 8° inclined

<u>FIGURE 4</u>

Examples of tuning the Shank Angle to Floor of
Ankle-Foot Orthosis Footwear Combinationss

<u>4a</u> Vector alignment in walking barefoot, in shoes, in untuned Ankle-Foot Orthosis Footwear Combination with Shank Angle to Floor 10° inclined, and in tuned Ankle-Foot Orthosis Footwear Combination with Shank Angle to Floor 15° inclined

<u>4b</u> Vector alignment when wearing an untuned Ankle-Foot Orthosis Footwear Combination with Shank Angle to Floor 15° inclined and tuned Ankle-Foot Orthosis Footwear Combination with Shank Angle to Floor 8° inclined

(Still photographs captured from ORLAU video vector generator) biomechanical environment within which the child has to function and the consequent influence on the nature of the demand on the neuromuscular system. The criticality of selecting the optimum prescription for each child is stressed. This is particularly so in neurological conditions where compensatory mechanisms, to adapt to a sub optimal SAF, are limited or abnormal.

Therefore, if an AFOFC is to assist the patient to ambulate with the optimum gait, and not introduce new problems, not only does the basic design of the AFO and the footwear have to be appropriate for the gait abnormality but final tuning has to be undertaken. One aspect of tuning is to finely adjust the SAF until optimal kinematic and kinetic gait is achieved in MST. Tuning for loading response (LR) and TST, the entrances and exits from MST, by choice of heel and sole design are of equal importance.

The development of kinetic systems of gait analysis has allowed researchers the opportunity to observe both the kinematic and kinetic changes which can occur when AFOFCs are worn and when the design of the AFOFC is adjusted (Simon et al 1978, Meadows 1984, Stallard 1987, Butler and Nene 1991, Hullin and Robb 1991, Hullin et al 1992, Lehmann et al 1992, Lehmann 1993, Butler et al 1997, Stallard and Woollam 2003). A combination of kinematic and kinetic analysis to tune an AFOFC is preferable as it allows greater accuracy and kinetic abnormalities which are not predictable from observation of kinematics alone are apparent in some cases (Meadows 1984, Kerrigan et al 1996). Tuning of the AFOFC is done individually for each limb of each child by observing or measuring the kinematics and kinetics throughout the gait cycle and adjusting the design of the AFOFC until the most normal or appropriate gait is achieved (Fig.4).

REVIEW OF LITERATURE

There have been three reviews concerning evidence of the efficacy of lower limb orthotic management of children with CP and SB (Condie and Meadows 1995, Morris 2002, Mazur and Kyle 2004). There are, however, two problems in assessing the evidence for the effects of AFOFCs in the ambulant child.

First, AFOFCs are rarely described as being tuned prior to evaluations of their efficacy and, therefore, they may not be producing optimum gait.
Second, the design characteristics of the AFOFC are often not reported and, when they are, the details are incomplete, inexact or ambiguous. Descriptions of the design of the footwear are ignored frequently. This seems to indicate an ignorance of the significant effects which footwear design can have on gait when combined with an AFO.

A review of 310 publications about AFOs and casts for children and adults, from 1959 to spring 2004, was undertaken. This was achieved by electronic searching and hand searching of reference lists of reviews and publications. The review reveals a paucity of full and precise information about the majority of AFOFCs described and only rare reports of the tuning of AFOFCs prior to evaluations of efficacy. Only 16 clinical studies recognise the importance of the combination of the footwear with AFOs or casts in influencing the SAF of the AFOFC or cast; only 15 recognise the importance of tuning the SAF of AFOFCs (Table I).

In all other reviewed clinical studies there is no evidence of recognition of the importance of tuning or of tuning having taken place nor is there recognition of the importance of the influence of footwear on the SAF, of the AFOFC, when combined with an AFO or cast. None of these contain descriptions of any two of the three minimum key AFOFC features needed to visualise or replicate a prescription. The AAAFO is given in some but as footwear details are either not given at all or are described in general terms such as 'trainers' 'standard' or 'sports' the SAF of the AFOFC cannot be deduced. The importance of the combination of the footwear with

the AFO or the importance of tuning an AFOFC is recognised in some descriptive publications but there are no details of successful SAFs.

Three authors have described a clear differentiation between the AAAFO and the SAF of the AFOFCs or casts they used and also specified the SAF used in degrees from the vertical (Corcoran et al 1970 and Jebsen et al 1970, Glancy and Lindseth 1972, Nuzzo 1986) (Table 1). Two authors have described a clear differentiation between the AAAFO and the SAF of the AFOFCs used and the SAFs in degrees from the vertical can be deduced from the stated AAAFOs and pitch, both described in degrees. (Meadows 1984, Hullin et al 1992)(Table1). Five papers clearly differentiate between the AAAFO and the SAF of the AFOFC but the SAF used is not given in degrees and cannot be accurately deduced (Cook and Cozzens 1976, Gans et al 1979, Nuzzo1983, Sankey et al 1989, Butler and Nene 1981)(Table I).

Table II provides detail about the sub-group of nine publications, which contain information about the position of the shank relative to the floor or vertical in the AFOFC or cast. They either describe an equivalent to the SAF in degrees or give sufficiently accurate information about the AAAFOs and footwear for deduction of an equivalent to SAF in degrees or give sufficiently accurate information about where they positioned the shank relative to the vertical when standing in the AFOFC or cast. Table II also indicates whether the AFOFCs or casts were tuned prior to evaluations or recommendations, and the method of tuning. Four publications recommend the use of particular SAF positions (Jebsen et al 1970, Glancy and Lindseth 1972, Nuzzo 1983, Hullin et al 1992). Three publications tune the SAF of the AFOFCs individually for each leg of each child (Simon et al 1978, Meadows 1984, Nuzzo 1986).

There are five publications, which include children with CP, which state broadly similar SAFs (Jebsen et al 1970, Glancy and Lindseth 1972, Fulford and Cairns 1987, Simon et al 1978, Nuzzo 1983, Nuzzo 1986). However, there are uncertainties in these: tuning was done for each individual leg but it is not clear whether the tuning was sufficient to achieve the optimum SAF for gait (Meadows 1984); tuning was

done to achieve optimal gait for each individual leg but it is unclear what exact SAFs were used because of the ambiguous use of language (Simon et al 1978); tuning of one patient is described but the recommended SAF for all patients comes from a theoretical kinematic justification and clinical experience (Nuzzo 1983,1986); no tuning was done but the recommended SAF for all patients also comes from a theoretical kinematic justification and clinical experience (Jebsen et al 1970).

There are four publications, which include children with SB. In two tuning was not done and the recommended SAF for all patients comes from a theoretical kinematic justification and clinical experience (Jebsen et al 1970, Glancy and Lindseth 1972); in one only two SAFs were compared, one of which had to have a specific footwear adaption to be recommended (Hullin et al 1992). In the other tuning was done in standing (Fulford and Cairns 1978).

Currently there are no publications that report the tuned SAFs of AFOFCs used for children with CP, SB and other conditions. The purpose of this paper is to report the SAF measures of the tuned AFOFC prescriptions, for each leg wearing an AFOFC, for a population of children with CP, SB and other conditions in North West Wales. It also presents an unambiguous and clearly defined terminology to describe some of the key sagittal plane features of AFOFC prescriptions and methods of measuring them.

ORTHOTIC PRESCRIPTION (SAGITTAL)		
DEGREE OF DORSI / PLANTA FLEXION OF ANKLE IN AFO O **PLANTARFLEXION** **NEUTRAL** **DORSIFLEXION**	**SHANK TO BENCH ANGLE OF FINISHED AFO** O **RECLINED** **VERTICAL** **INCLINED**	**HEEL SOLE DIFFERENTIAL OF FOOTWEAR** i.e. Height of footwear at heel minus height of footwear at metatarsal heads **mm**
ADDITIONAL WEDGES **AT HEEL** **mm** **AT MET. HEADS** **mm**	**FINAL "HEEL SOLE DIFFERENTIAL"** **mm**	**FINAL "SHANK ANGLE TO FLOOR"** O **RECLINED** **VERTICAL** **INCLINED**

FIGURE 5

Recording chart used for each Ankle-Foot Orthosis Footwear Combination trial

METHOD

During the period October 1997 to January 2002 151 children on the physiotherapy register with a walking disorder or disability were offered gait analysis as part of their routine clinical care. This represents the vast majority of children with these diagnoses and criterion living in North West Wales.

The ORLAU transportable Video Vector Generator Gait Laboratory was used for data collection. This system provides a video recording of gait, in the sagittal and coronal planes, together with simultaneous visualisation of the GRF, which is superimposed on the video image (Tait and Rose 1979, Stallard 1987, Stallard and Woollam 2003). It provides immediate playback, slow motion, freeze-frame and picture printing. This laboratory is used as a clinical tool for routine monitoring of gait, for tuning AFOFCs and for setting goals of physiotherapy interventions.

Children's gait was recorded and analysed whilst walking barefoot, in footwear and in AFOFCs if used. Children walked the length of the walkway until at least two strikes of the force plate were achieved with each leg whilst recording in the sagittal plane. The parents and physiotherapist determined whether the child was walking with a typical gait and only typical strikes were used for analysis. Coronal plane data was also collected.

AFOFC DATA COLLECTION

The following data was recorded for each AFOFC trial (Fig.5). The data was originally intended to be used as a clinical record and to enable prescription replication for any individual child.

Angle of the Ankle in the AFO (AAAFO)

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 base of heel) and the line of the shank. It is described in degrees of dorsiflexion or plantarflexion, with plantigrade describing the neutral position.

Shank Angle to Bench (SAB)of the AFO

The angle of the shank of the AFO relative to a vertical to the horizontal surface on which it is stood, in the sagittal plane. It is measured in degrees of incline and recline from the vertical, vertical being 0 degrees. Its value in degrees is the same as the AAAFO unless there is additional build-up fixed beneath the heel or sole of the AFO. For example, if the AAAFO is plantarflexed it is common to apply a build-up under the heel of the AFO to obtain a SAB of 0 degrees.

Heel Sole Differential (HSD) of the footwear.

The measured difference between the thickness of the heel at mid-heel and the thickness of the sole at the metatarsal heads, measured in millimetres, (Fig.2).

The thickness of any additions to the heel or sole of the footwear, added inside or outside the footwear, measured in millimetres.

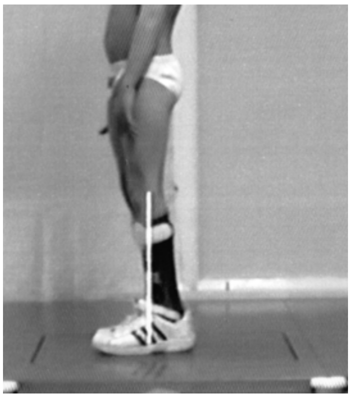
Final Heel Sole Differential (FHSD)

The sum of the HSD of the footwear and the thickness of any additions at heel or sole, measured in millimetres.

Shank Angle to Floor (SAF) of the AFOFC

The angle of the shank relative to a vertical to the horizontal surface when standing in the AFOFC with heel down and weight equally distributed between heel and toe, measured in the sagittal plane. The lower leg and foot were placed in the sagittal plane for the measure. SAF is described as inclined if the shank is inclined forward from the vertical and reclined if the shank is reclined backward from the vertical. It is described in degrees from the vertical, vertical being 0 degrees.

SAF was measured by one of two methods. The initial method was to stand the child, wearing the AFOFC, on a stool and measure the SAF by goniometer taking a line from knee joint centre to malleolus to represent the line of the shank. Another method, which was considered to be more accurate, was then developed. This was to stand the child on the force plate with the AFOFC truly sagittal to the camera and



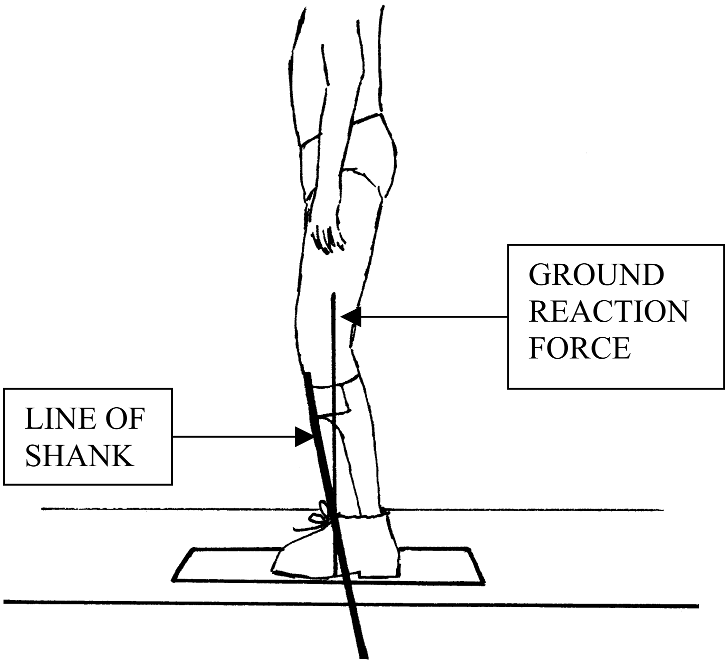


FIGURE 6

Measuring the Shank Angle to Floor of the Ankle-Foot Orthosis Footwear Combination ensuring that the GRF origin was in the middle of the foot. Measurement was then taken, with a goniometer, from a printed picture of the sagittal plane image (Fig.6). The line of the front of the tibia was used to represent the line of the shank as it was easier to identify this line than the line between the centre of knee and the malleollus and it appeared to be consistently parallel to it. This also eliminated problems, which could occur in measuring shank inclination in children where there was excessive torsion of the tibia. The SAFs were measured by one person. A confidence test was undertaken, by measuring a preset angle of 45°, to ensure that the pictures, from which the SAFs were measured, accurately represented the actual SAF angles.

For trials with footwear and no AFO the HSD and FHSD only were recorded.

Additional data, collected but not reported here, include design features of the AFO such as the position of trimlines, strap positions, addition of front plates and ribs or carbons and design features of the footwear such as type of heel, heel profile, sole stiffness, sole profile, type and position of rockers, the thickness of the heel and the sole and the thickness of any through raises.

The AAAFO of the AFOFCs had been determined prior to the manufacture of the AFOs. The AFOFCs had a variety of AAAFO in dorsiflexion, plantigrade and plantarflexion. The AAAFO for each leg of each child was chosen on the basis of a number of clinical considerations. These included the required positions of bones and joints, the length of calf muscle with the knee extended (with foot supinated and neutral), calf muscle tone and gait without AFOFCs.

Adjustments were made to a number of AFOFC characteristics in order to tune them; it is only the SAF results which are reported here. As the AAAFO had already been determined adjustment of the SAF of the AFOFC was achieved by altering the HSD of the footwear (Fig.7). Non-compressible material was used to change the HSD, either placed inside the footwear or attached externally to the footwear at the heel or sole.

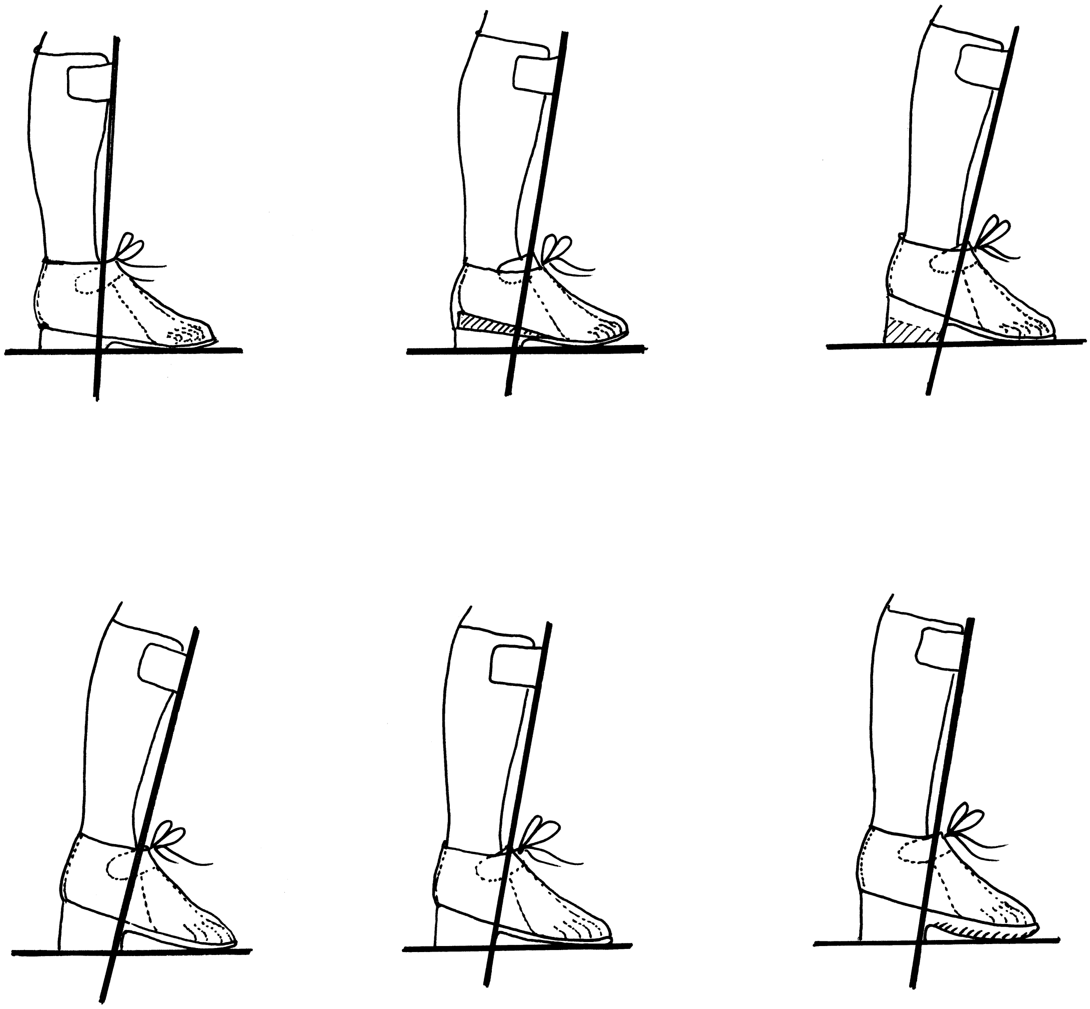


FIGURE 7

Altering the Shank Angle to Floor of the Ankle-Foot Orthosis Footwear Combination by increasing or decreasing heel or sole thickness in order to change the Final Heel Sole Differential of the Ankle-Foot Orthosis Footwear Combination

Alterations to the SAF of the AFOFC changed the kinematics of the shank and consequently the GRF alignment during the stance phase of the gait cycle towards or away from normal. The tuned AFOFC selected for each leg of each child was the prescription which produced the most normal gait cycle. Consideration was given to normalising both the kinematics and kinetics. Particular attention was paid to normalising the kinematics of the shank and the moments and moment arms of the GRF relative to the knee and hip during stance phase (Meadows 1984, Butler and Nene 1991, Butler et al 1992, Hullin et al 1992, Major 1995).

A retrospective data analysis was performed. Where children had more than one gait analysis session the data used was that from the latest tuned AFOFC prescription. Table III shows the reasons for exclusion from the retrospective data analysis of the SAFs of tuned AFOFCs. Of 151 children 74 children were eligible for inclusion. Thirty eight of the 74 children wore an AFOFC on each leg and 36 children wore an AFOFC on only one leg. Therefore, the data collected was from 112 legs wearing an AFOFC. Children who walked with walking aids were excluded because of the complexity of gait disorders and gait analysis in this group. Also excluded were those where a hinged AFO, which allowed free dorsiflexion but with a ‘stop’ to prevent plantarflexion beyond plantigrade, was used. This was because hinged AFOs in our population are only used where there is sufficient dorsiflexion range available, where there is a stable mid-foot and where there is a problem during the swing and initial contact phases of the gait cycle but no kinematic or kinetic problem during single stance which requires tuning of the SAF (Weber 1994,1995). Also, the measurement of the SAF as described is not appropriate, as the ankle is not fixed.

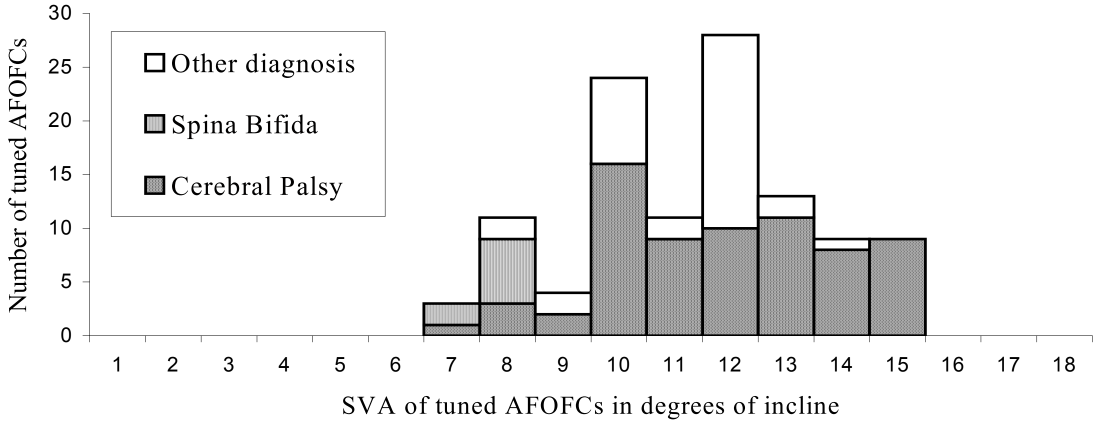


FIGURE 8

Frequency distribution of Shank Angle to Floor of tuned Ankle-Foot Orthosis Footwear Combinations by diagnosis

RESULTS

Figure 8 shows the SAFs of the latest tuned prescriptions for each of the 74 children (CP n=50, SB n=4 O n=20) using 112 solid AFOFCs.
For all AFOFCs (n=112) mean SAF = 11.36 °, SD 2.08, range 7-15 °.
For AFOFCs used by children with CP (n=69) mean SAF =11.86 °, SD 2.05, range 7-15 °.
For AFOFCs used by children with SB (n=8) mean =7.75, SD 0.46, range 7-8°.
AFOFCs for children with other conditions (n=35) mean=11.2, SD 1.41, range 8-14°.

Whether the AAAFO was dorsiflexed, plantigrade or plantarflexed, the SAFs of the tuned AFOFCs were all inclined and more than 5° inclined. Therefore all tuned AFOFCs are represented in boxes C, F, I in figure 1.

The AAAFOs used in the AFOFCs were as follows:-
Eighteen had an AAAFO in dorsiflexion (CP n=14, SB n=0, O n=4).
Sixty-four had an AAAFO in plantigrade (CP n= 43, SB n=4, O n=17). Thirty had an AAAFO in plantarflexion (CP n=12, SB n=4, O n=14).

The AAAFOs in the 69 AFOFCs of the children with CP were as follows:-
AAAFO 5°dorsiflexion, n= 14,
AAAFO plantigrade, n=43,
AAAFO 5° plantarflexion, n=9,
AAAFO 10° plantarflexion n=2,
AAAFO 18° plantarflexion n= 1.

The AAAFOs in the 8 AFOFCs of the children with SB were as follows:-
AAAFO plantigrade, n=4.
AAAFO 5° plantarflexed, n=4.

The AAAFOs in the 35 AFOFCs of the children with other conditions were as follows:-

AAAFO 5° dorsiflexed, n=4.

AAAFO plantigrade, n=17.

AAAFO 5° plantarflexion, n=8,

AAAFO 10° plantarflexion n=2,

AAAFO 15° plantarflexion n=4.

In this population it was found that only 2 of the 93 limbs requiring an AFOFC had sufficient control of shank kinematics and knee kinetics in stance phase to enable use of a hinged AFO, with a plantarflexion stop and dorsiflexion free (Table III).

DISCUSSION

There is likely to have been some error in the measurement of the SAFs of the AFOFCs but this has not been quantified. Error is likely to have been reduced by the use of one observer and the practical significance of error reduced by the measurement of a large number of AFOFCs. The results show a bias to recording in even numbers. Further research may be needed to quantify any measurement error in the technique used, especially if it is to be used by different observers. The current measurement technique, using a visual measure with goniometer, is simple to use in clinical environments and this is important. A more accurate measure may need to be developed for future research.

When reporting clinical trials, a statement of whether AFOFCs were tuned, or not, and documentation of the SAFs of AFOFCs used allows communication about successful and unsuccessful SAFs for diagnostic groups or categories of gait pathologies. It also allows a reader to decide whether any evaluation or comparative study is valid. Recording the SAF of an AFOFC is as important as recording the AAAFO. The use of inclined, vertical and reclined to describe the SAF of AFOFCs and reservation of dorsiflexion, plantigrade and plantarflexion to describe the anatomical angle of the AAAFO in AFOFCs eliminates confusion about use of the terms dorsiflexion and plantarflexion. Recording of, at least, these two key sagittal plane variables for each individually tuned AFOFC allows replication of these in any AFOFC provided for any individual. It also reduces the potential for misinterpretation of ambiguous descriptions that could lead to inappropriate orthotic prescriptions being applied to patients.

The significance of a precise choice of HSD of the footwear as part of the orthotic prescription needs to be better recognised and documented. Very small changes in the HSD/pitch will alter the SAF of the AFOFC and therefore the kinematics and kinetics of gait. This is particularly so in neurological conditions where compensatory mechanisms, to adapt to a sub optimal SAF, are limited or abnormal.

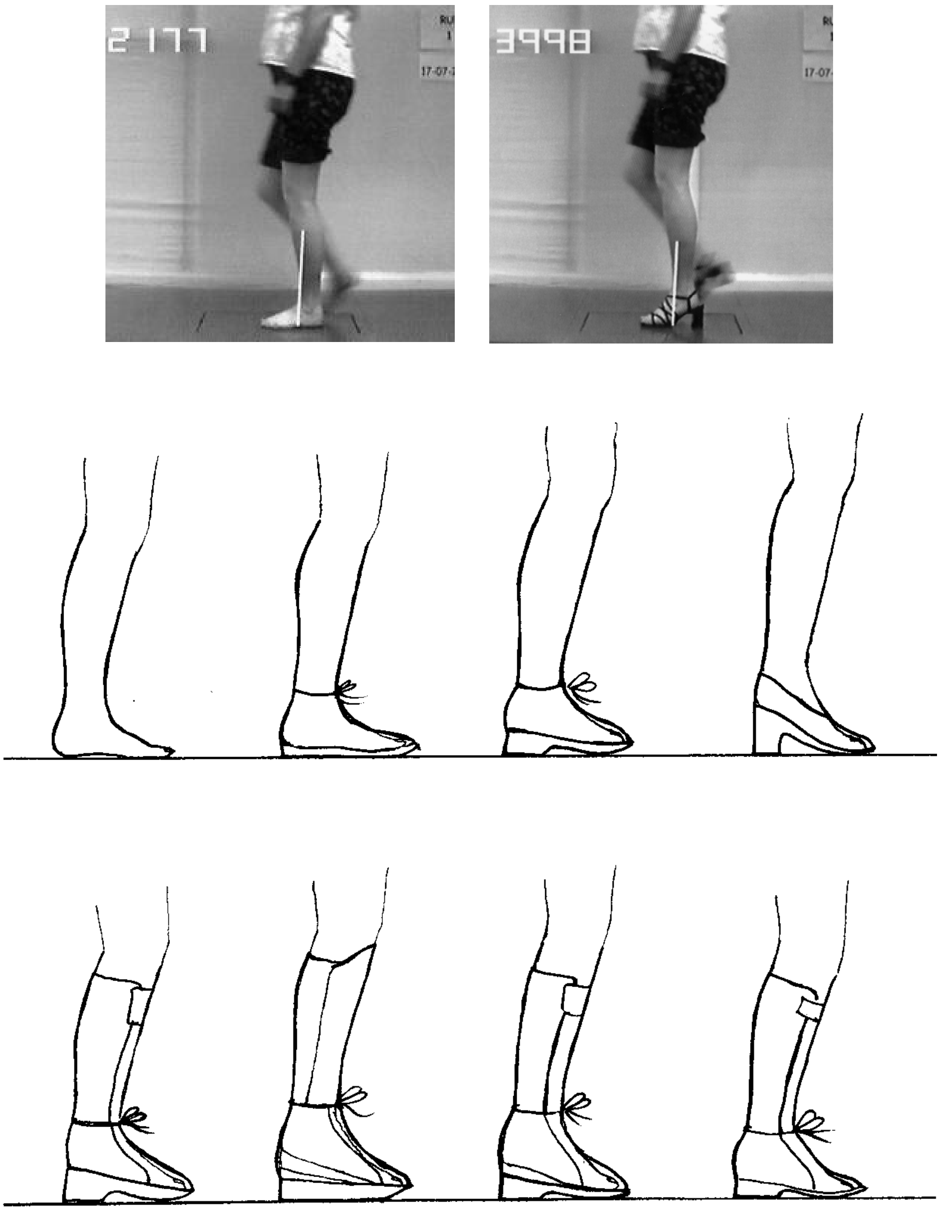


FIGURE 9

Shank Angles to Floor and ankle angles at midstance in barefoot gait, gait with footwear of various Heel Sole Differentials and in Ankle-Foot Orthosis Footwear Combinations with a variety of Angles of the Ankle in the Ankle-Foot Orthosis

The results show that the tuned SAFs in 74 independently ambulant children, with CP, SB and other conditions, using 112 AFOFCs, range from 7° incline to 15° incline with a mean of 11.36°. In comparison during midstance (MST) in normal barefoot gait prior to heel lift there is 10° of ankle dorsiflexion (Perry 1974, 1985), Gage 1991), and the SAF at this time would therefore be 10° inclined. There is therefore a match between the mean SAF of the tuned AFOFCs in this population, and the mean SAF of barefoot normal gait.

In normal barefoot gait the inclined SAF at MST is provided by ankle dorsiflexion. When walking in footwear which has heels, the amounts of dorsiflexion needed to achieve 10° inclined SAF at MST will reduce according to the HSD (Fig.9) (Murray 1967). In gait using solid AFOFCs the necessary incline of the SAF during MST can be achieved using any AAAFO (Fig.1 and Fig.9).

This inclined SAF angle in both normal barefoot, normal shod and tuned AFOFC gait is likely to be important for a variety of reasons.

First, an inclined shank in MST contributes to energy conservation by influencing the amount of vertical excursion of the knee which in turn contributes to minimising the vertical excursion of the body's centre of mass during gait (Saunders et al 1953, Nuzzo 1983).

Second, from the relative lengths of the shank and foot and the position of the ankle joint along the foot, 10° inclined is the position which brings the centre of the knee joint directly over the middle of the foot (Fig.10, anthropometric measures from Tilley 1993). A possible explanation for the 10° inclined SAF being central to the production of stability in stance in both normal and pathological gait is that it is determined by these anthropometric measures. In MST of normal gait the head, arms, trunk, swing limb and thigh of the stance limb have to travel over the shank and foot of the stance limb. The positioning of the knee joint centre over the centre of the foot would provide a very stable base for the stance limb as this occurs. In addition, in normal gait when the shank is inclined such that the knee is over the centre of the

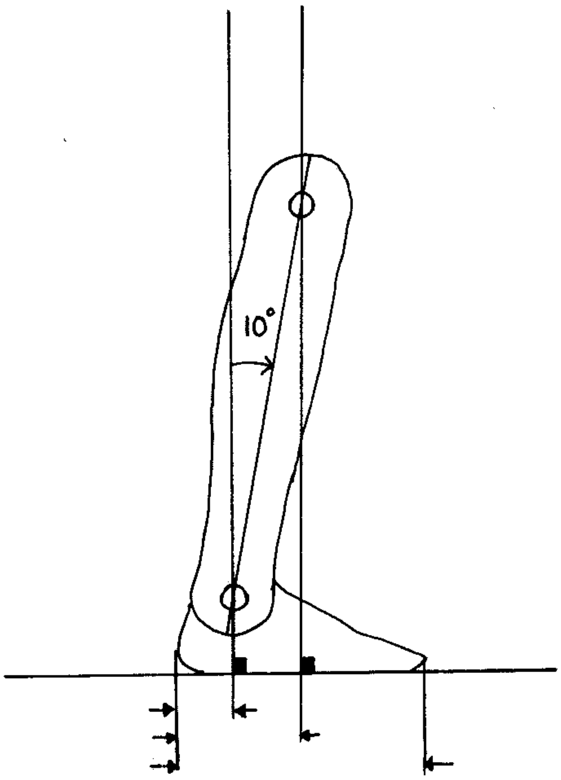


FIGURE 10

Anthropometric measures dictate that a Shank Angle to Floor of 10° inclined from the vertical brings the knee joint centre over the middle of the foot.

foot the angular velocity of the tibia slows (Perry 1974, Winter 1990, Connolly et al 1999). This slowing also contributes to distal stability at this point in the gait cycle and, as the forward progression of the thigh and trunk is maintained, knee and hip extension and consequent production of knee and hip extension are facilitated (Perry 1974). It is there fore important for children with poor balance to be able to achieve this lower leg stability. Tuned AFOFCs can place the SAF in the correct position in MST and also provide the slowing of the angular velocity of the shank, both of which are required to replicate the distal stability of normal shank kinematics.

Third, there is a narrow range of incline of the SAF in MST which will allow the necessary kinematic and kinetic changes which provide the stability of late MST and terminal stance (TST). In normal gait the calf muscles precisely control the rate of shank progression past the vertical and the position of the SAF during MST (Sutherland 1966, Inman et al 1981, Perry 1992). This is necessary for the production of appropriate external extension moments at both the knee and the hip (Perry 1974, Sutherland et al 1980, Gage 1991, Perry 1992). From anthropometric data it would seem that there is only a narrow range of the SAF where this can occur and the optimum SAF position is 10-12° inclined (Fig.11, Fig.12, anthropometric data from Tilley 1993). At this SAF the knee and hip joint centres are aligned sufficiently close to the GRF for there to be a switch of external moments, from a knee flexion moment to an extension moment and a hip flexion moment to an extension moment (Fig.12, Fig.13). If the shank is too vertical excessive knee extension moments are created and the production of hip extension moments is difficult (Fig.11, Fig.12). If the shank is too inclined knee extension moments cannot be created and maintained (Fig.11, Fig.12). While the optimum position of the SAF for these changes may be an SAF of 10-12° inclined there will be a larger limited range where these changes can occur. Perhaps the range of 7°-15° inclined of the tuned AFOFCs is that range. In normal barefoot gait the range of ankle dorsiflexion at end of MST is about 7°−15° (Gage 1991).

Whilst a majority of children's AFOFCs are tuned at SAF 10-12° inclined some children need more or less incline. A clinical impression is that it is the pattern of

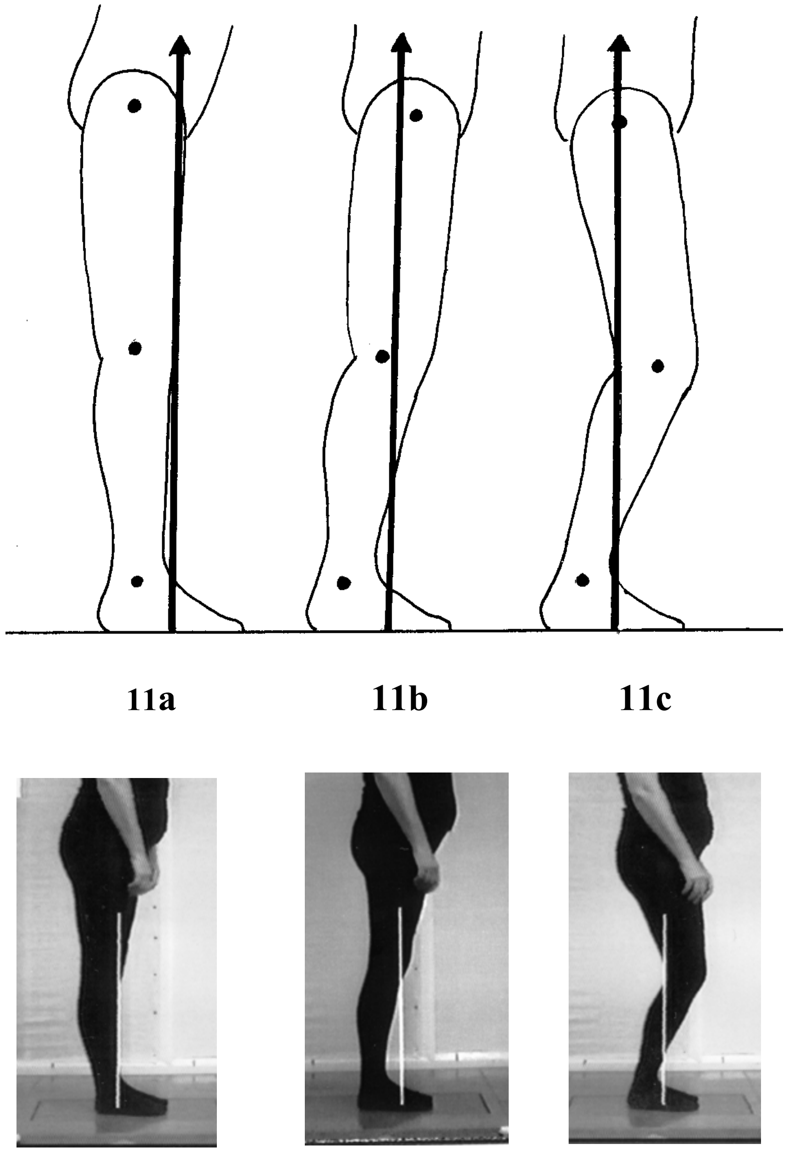


FIGURE 11

Positions of the shank and resultant Ground Reaction Forces in either walking or standing. Still images taken from ORLAU transportable video vector generator.

11a Shank Angle to Floor vertical/ 0°. Excessive knee extension moments and hip flexion moments

11b Shank Angle to Floor 10-12° inclined. Appropriate knee and hip extension moments

11c Shank Angle to Floor 20° inclined. Loss of knee and hip extension moment vector alignment at MST in barefoot gait, and the amount of musculotendinous and joint stiffness which the child has, which indicates the SAF required. Children who have vertical vectors with excessive knee extension moment arms (Fig.3, 3a) will need 10-12° incline. Children with forward leaning vectors and more excessive knee extension moment arms (Fig.3, 3b) will need 13°, 14° or 15° incline. Children who have excessive knee flexion moment arms and difficulty creating knee extension moments (Fig.3, 3d and 3e) need 10-12° or less incline if they do not have excessive stiffness at the hips, hamstrings and knees and may need more than 12° incline if they do. The latter vector pattern also needs complex design features in both the AFO and the footwear which strongly resist excessive shank incline in MST and TST (Owen 2004). Additional analysis of the data would be necessary to verify these impressions.

The results show that no child produced optimum gait with a vertical SAF in the AFOFC. In the vertical SAF position there are three possible mechanisms which bring the centre of mass over the middle of the supporting foot. These are knee hyperextension, hip flexion with excessive anterior pelvic tilt and forward lean of the trunk or changing the SAF to a more inclined position by heel rise to stand on the forefoot. None of these allow the normal kinematic and kinetic alignments of MST. Only appropriately inclined shanks allow this and the results suggest that the range of 7° to 15° inclined might be appropriate for independent walkers, with 10-12° inclined being appropriate for many but not all children.

Some recommendations about the use of casts (which are essentially AFOFCs) use vertical SAFs (Sussman 1983, Jordan 1984). Cusick 1990 recommends using an angle of 5° between the floor and shaft section of the cast. The results indicate that use of an SAF of 0° or 5° inclined in casts is unlikely to match the SAF requirements for this group of children, when they are being used for ambulation or gait training. It is also unlikely to be the optimal SAF for balanced standing or standing therapy, especially when facilitation of hip extension is required (Fig.11, Fig.12, Fig 13). Nuzzo (1983) recommends that in casts the knee be pitched forward until the skin of the kneecap is just above or slightly behind the metatarsal heads. This places the

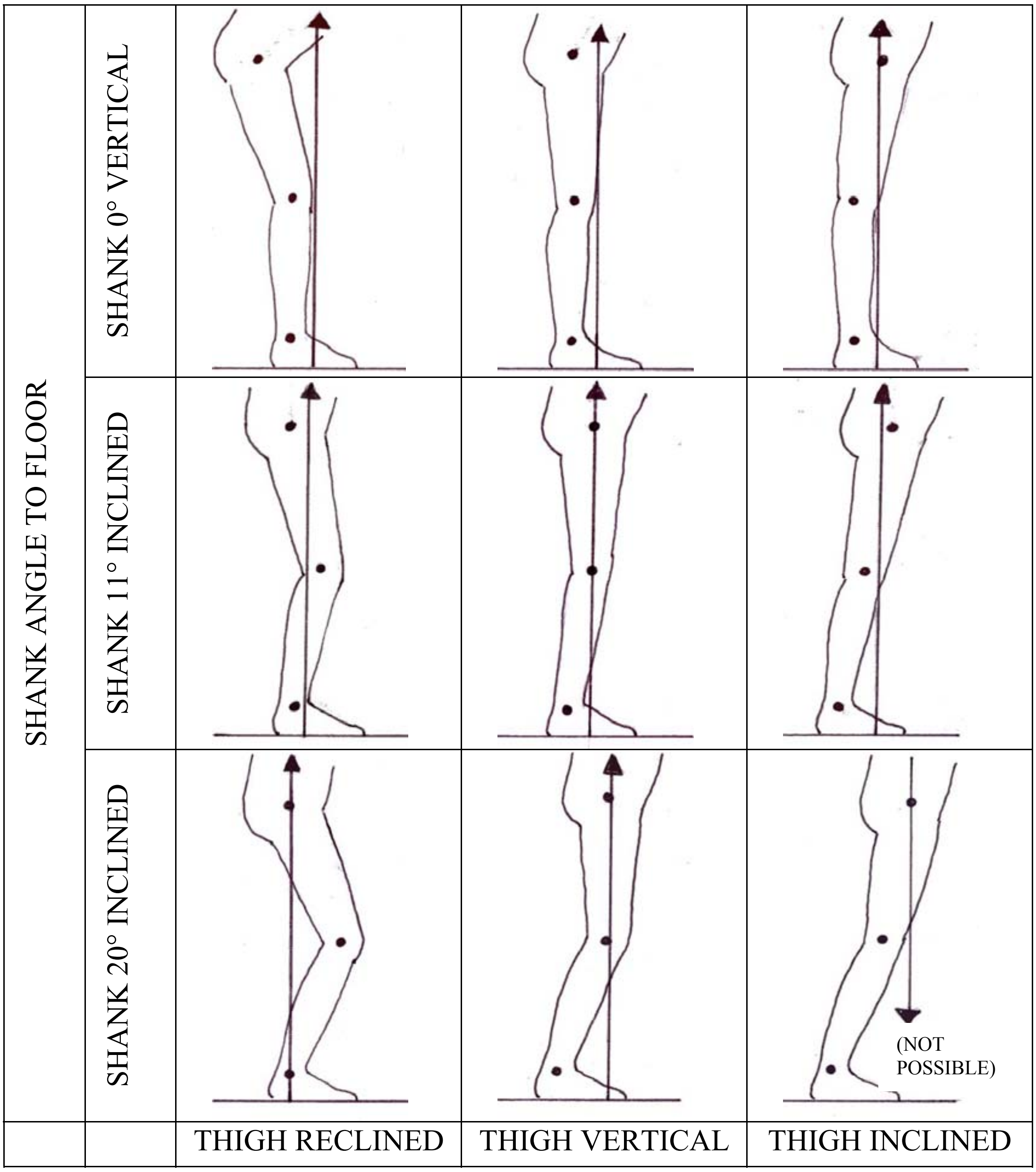


FIGURE 12

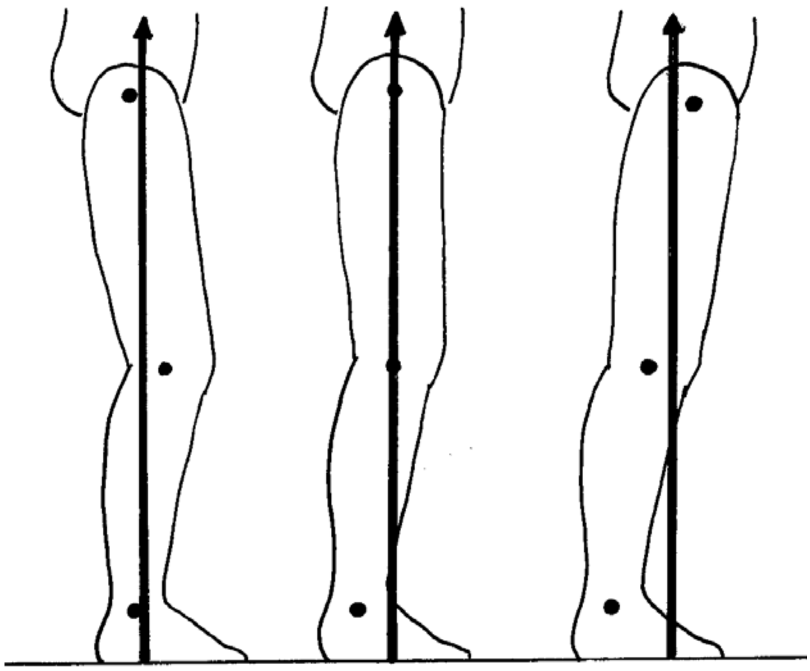
Joint, trunk and Ground Reaction Force alignment at a variety of shank and thigh positions

It is only possible to achieve appropriate hip and knee extension, appropriate hip and knee extension moments and a vertical trunk with appropriately inclined shanks.
The three positions with a Shank Angle to Floor of 11° inclined show that with this Shank Angle to Floor it is possible to translate a vertical trunk over a stable base and switch from knee and hip flexion moments to knee and hip extension moments as occurs during the normal gait cycle.

knee over the middle of the foot and the SAF at approximately 10° inclined. If the tuned SAF for the child is known then the SAF of casts can be set at that angle. If not, 10-12° inclined would probably be an appropriate SAF for casts, at least initially. The addition of plaster or wedges to the heel of the casts, where the angle of the ankle in the cast necessitates it, to create an appropriately inclined SAF in the cast, creates the same situation as an AFOFC with an inclined SAF.

The use of a vertical SAF in AFOFCs or casts may be because it is assumed to be the position that will facilitate knee extension in standing and in gait. However, maximum knee extension in the stance phase of the gait cycle occurs late in stance phase, at 40% of the gait cycle, in TST. At this point in the gait cycle the shank has become more than 10°-12° inclined reached at the end of MST, by the action of MTPJ extension raising the heel while the ankle remains relatively rigid (Perry 1992, Davis and DeLuca 1995). In standing it is only possible to achieve full knee extension with a vertical shank in an AFOFC or cast if there is hip flexion, excessive anterior pelvic tilt and forward trunk lean or excessive lumbar lordosis to produce a vertical trunk. In normal standing we align the GRF in front of the knee and behind the hip by using an appropriately inclined shank. This allows both knee and hip extension and consequently a stabilizing GRF alignment (Fig.14), (Blumentritt 1997).

Unlike most of the joint movements associated with walking, hip extension appears to approach the limit of motion anatomically available (Murray et al 1964). Children with CP and SB have a tendency to have less hip extension in their gait (Lai et al 1988, Duffy et al 1996) and to develop hip flexion contractures (Bleck 1987,Gage 1991). This severely compromises their gait and increases the degree of disability. Tuned AFOFCs can normalise the alignment of the GRF with the knee and hip joints and they can introduce and effect the magnitude of external hip extension moments and the second peak of the GRF (Meadows 1984, Lehmann et al 1985, Khodadadeh and Patrick 1988, Hullin et al 1992). It may be that the use of tuned SAFs of AFOFCs, which facilitate improved hip extension and hip extension moments, would prevent or minimise the development of these hip contractures. The stability of



13a 13b 13c

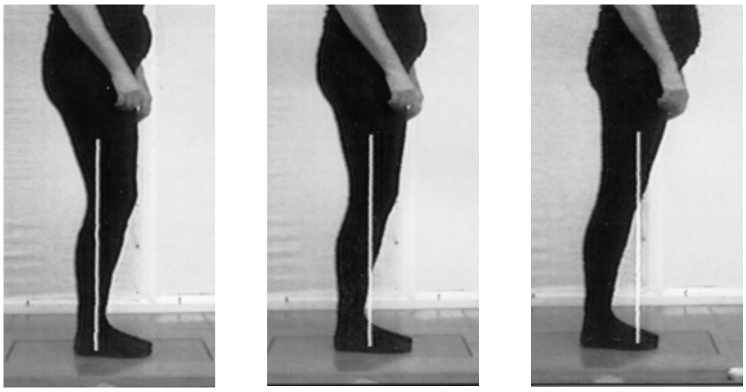


FIGURE 13

Shank Angle to Floor 12° inclined (13a, 13b, 13c) allowing posterior (13a) and anterior (13c) translation of a vertical trunk

13a Posterior translation of trunk. Reclined thigh. Knee flexion and hip flexion moments. Point of application of Ground Reaction Force aligned at posterior foot

13b Vertical thigh. Neutral knee and hip moments. Point of application of Ground Reaction Force aligned at centre of foot

13c Anterior translation of trunk. Inclined thigh. Knee extension and hip extension moments. Point of application of Ground Reaction Force aligned at anterior foot achieving hip and knee extension and appropriate GRF alignment in TST on the stance leg can facilitate the production of TSW in the swing leg. When TST and TSW are achieved the child is undertaking their own stretching therapy twice during each gait cycle. During TSW the knee, hamstrings and calf muscle are stretched (Thompson et al 2002) and in TST the hip, knee, hip flexors and calf muscles are stretched (Fig.15). In addition in late MST and in TST, with the ankle fixed in an AFO and the knee extending if the gastrocnemius muscle is active it will be actively lengthening and producing eccentric muscle activity. This could contribute to the strengthening of the calf muscle that children with disability require (Lieber 2002, Shortland et al 2002). Tuned AFOFCs can therefore be an adjunct to therapy or, in some cases, a replacement for stretching therapy. Research into the impact of tuned AFOFCs on the long-term outcomes of hip flexion, hamstring and calf muscle contractures in these children is recommended.

The range of SAFs of the tuned AFOFCs reported here was determined by the use of combined kinematic and kinetic tuning. Subtle abnormal shank kinematics are difficult to detect without slow motion and freeze-frame facilities and kinetic abnormalities, which cannot confidently be predicted from the kinematics, cannot be observed without kinetic analysis (Kerrigan et al 1996). Kinetic tuning allowed confident selection of the optimum SAF, and other features, of the AFOFC. Experience in North West Wales would support the view that as kinetic changes are only observable with kinetic analysis this is the preferred option for tuning (Stallard 1987). Additional research in this area is necessary to confirm that kinetic tuning is necessary to improve immediate and long-term outcomes for these children.

The review of the literature shows that there is an inconsistency between the evidence that tuning can have very significant effects on gait and the large number of publications that do not recognise the importance of tuning an AFOFC. The discovery of these effects has only become apparent since the development of kinetic gait analysis laboratories, which are not available to the vast majority of practioners. Currently the majority of research on the effects of AFOFCs on the gait of children is

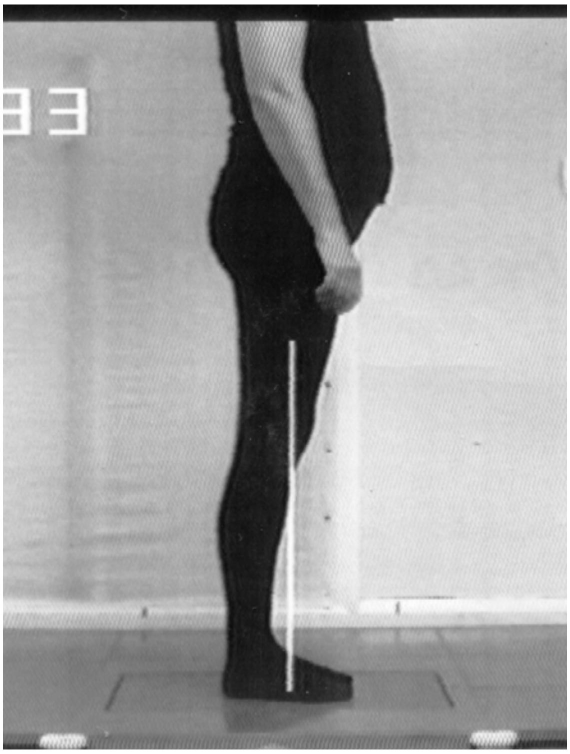


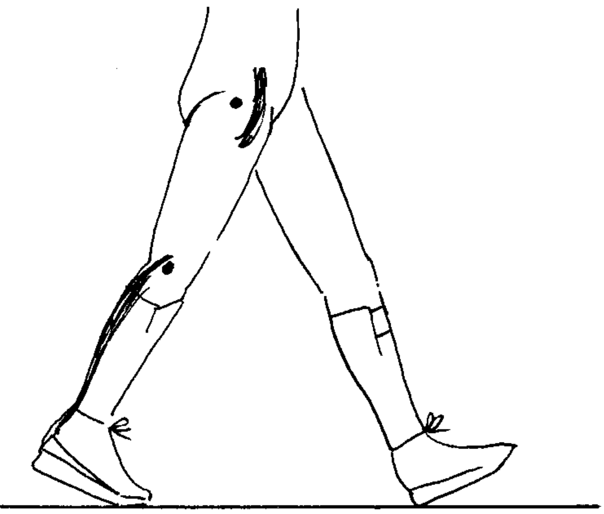
FIGURE 14

Ground Reaction Force alignment in relaxed standing undertaken in gait laboratories with facilities for kinetic analysis. However, the AFOFCs are not being tuned prior to evaluations, or not stated as being tuned. The reason for this is unclear. There may be an ignorance of the effects of tuning the AFOFC. For example, the researchers may not be aware that an alteration of the SAF of an AFOFC by 2 or 3° can alter gait kinematics and kinetics or that tuning for LR and TST can also have significant effects on gait. Alternatively, there may be a belief that there is not sufficient evidence of the effects of tuning the SAF of an AFOFC within 2-3° for this to become routine clinical practice or to be incorporated into research protocols. There is some evidence that tuning the SAF of an AFOFC can change the kinematics and kinetics of gait (Meadows 1984, Butler and Nene 1991, Butler et al 1992 and 1997, Hullin et al 1992). However, the degree of change in the SAF, from the untuned to the tuned condition, is either not stated (Butler and Nene 1991, Butler et al 1992 and 1997) or relatively large (Hullin et al 1992). One publication contains objective evidence which supports the view that changes of just 2-3° in the SAF of an AFOFC have a significant effect on the kinematics and kinetics of gait in children with cerebral palsy (Meadows 1984). The experience of using kinetic tuning in North West Wales would strongly support the view that tuning of the SAF by 2-3° steps is necessary to enable optimisation of the gait of each leg of each child.

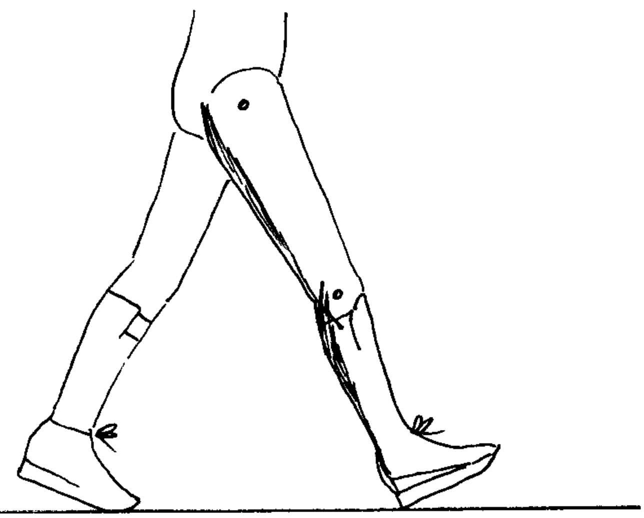
Another inconsistency apparent from the literature review is that there are a large number of publications that do not recognise the importance of tuning although there is some evidence that it may be possible to make permanent changes in gait by using tuned AFOFCs (Rosenthal et al 1975, Simon et al 1978, Butler et al 1992, Butler et al 1997).

The review of the literature also does not reveal a widespread use of a variety of AAAFOs despite the fact that the choice of the AAAFO is crucial to successful tuning and that any SAF of an AFOFC can be produced with any AAAFO (Fig.1). Glancy and Lindseth (1972) is unusual in being clear about this. Early literature describes a tendency to adjust the SAF of the AFOFC by adjusting the AAAFO rather than the HSD of the footwear (Stills 1975). While this may have been

15a



15b



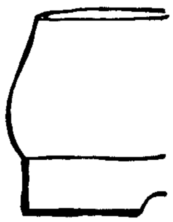
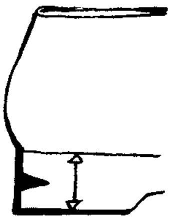
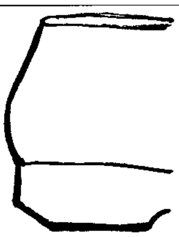
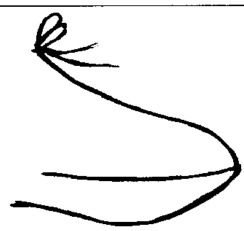
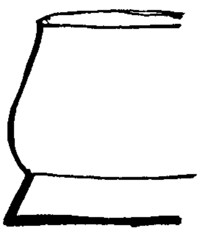
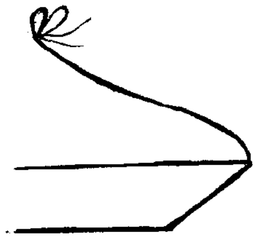
<u>FIGURE 15</u>

The “Big V” of terminal stance and terminal swing producing muscle stretches

<u>15a</u> Ankle-Foot Orthosis Footwear Combination worn on right leg facilitating Terminal Stance and stretching hip, knee, hip flexors and gastrocnemius.

<u>15b</u> Ankle-Foot Orthosis Footwear Combination worn on left leg facilitating Terminal Stance on left and consequently Terminal Swing on right and stretching knee, hamstrings and gastrocnemius appropriate for the diagnostic category of paralysis that was so prevalent in the past it is not appropriate for children with CP, SB and other neurological conditions. Children with these primary conditions have the complication of having secondary pathological effects in the musculotendinous units. This results in abnormalities of muscle length, muscle strength and muscle tone. There is also abnormal bony development. It is vital that the correct AAAFO is chosen to take into account the needs of the bony structures and the musculotendinous units during the gait cycle. Consideration of the gastrocnemius muscle as a tri-jointed muscle is vital if it is to have sufficient length at its proximal end for knee extension in TSW, MST and TST once fixed at its distal end in the AFO. Also vital is the need for consideration of the musculotendinous length of the calf muscles during the gait cycle if they are to produce muscle tension within the AFO. They cannot produce this if they are either excessively or insufficiently stretched at the phase in the gait cycle where they are required to produce tension (Lieber 2002). The AAAFO has been shown to influence the internal moment that the plantarflexors can generate (Miyazaki 1997). Therefore the decision about the AAAFO for each leg of each child is fundamental to the successful tuning of an AFOFC and to the effects of the AFOFC on the bones, joints and musculotendinous units contained within the AFO and more proximally.

When the principles of kinetic gait analysis were applied to the gait pathology of this population of children with CP it was found that only a few children requiring an AFOFC had sufficient control of shank kinematics and knee kinetics in stance phase to enable use of a hinged AFO with a plantarflexion stop. The stance phase abnormalities of gait included excessive shank incline in stance with abnormal kinetics, so contraindicating the use of a hinged AFO, or insufficient incline with abnormal kinetics necessitating the SAF of a corrective AFOFC to be inclined to 10-15° incline which negates the purpose of the hinge in an AFO. If the latter gait abnormality was subtle the use of kinetic analysis allowed it to be detected.

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 PROFILE

<u>FIGURE 16</u>

Heel and sole design options for tuning Loading Response and Terminal Stance phases of the gait cycle.

Tuning the SAF of an AFOFC, which will place the shank in the optimal position during MST, is not the only tuning which is essential and which benefits from kinetic analysis.

The SAF throughout normal stance is controlled by the action of the three rockers, which require ankle and MTPJ movement (Perry 1992). Control of the shank kinematics by the rockers facilitates GRF alignment to the knee.

When using AFOFCs it is important to replicate normal shank kinematics throughout stance. When using a fixed ankle or fixed MTPJ in an AFOFC the design of the AFO and footwear are used to produce the required shank kinematics. The AFO design, the tuned SAF of the AFOFC and the design of the heel and sole of the footwear significantly influence the kinematics of the shank as it enters and exits from its MST position and, consequently, the kinetics of gait (Hullin and Robb 1991). Kinetic tuning can assist in deciding on the optimum design of the heel and sole profile of the footwear and whether a flexible or stiff sole is required (Fig.16).

Experience in kinetic tuning for TST in North West Wales has found that the use of point-loading rockers is useful when the gait pathology which is being corrected is one of an excessively inclined shank in MST and TST combined with absent or inadequate knee and hip external extension moments. Inappropriate footwear combined with an AFO which prevents ankle dorsiflexion and MTPJ extension does not prevent the shank inclining excessively. A stiff sole and a sole profile that will not allow the heel to lift until the point of application of the GRF reaches the point of the rocker, together with an appropriate toe spring angle allows the footwear to control the shank kinematics in MST and TST and consequently the kinetics (Owen 2004). In addition, the point of the rocker arrests the forward movement of the point of application of the GRF which facilitates alignment of the GRF behind the hip joint (Meadows 1984). The optimal position of the rocker and toe spring angle can be assessed most accurately with kinetic analysis.

It has been traditional for a solid AFO to be accompanied by a cushion or negative heel (Fig.13) to facilitate LR by simulating plantarflexion (McIllmurray and Greenbaum 1959). Experience in kinetic tuning in North West Wales has, however, shown that children with motor control problems frequently are unable to accommodate to these adaptions. With them they have a prolonged LR with abnormal kinetics. This is especially the case when the tuned SAF of the AFOFC is highly inclined and they have good knee extension in TSW. The use of plain heels usually prevents this but when this is insufficient a positive heel is used (Fig.16). The majority of the AFOFCs in North West Wales have plain heels with some children requiring positive heels. Kinetic tuning is preferable to kinematic tuning to be confident about the optimum heel and sole design of the footwear for any individual leg.

There is a widely accepted concept that an AFOFC should be worn throughout the waking day (Davey et al 2003). This may be the case when there are bony considerations or when the child cannot function without the AFOFC. The choice of the percentage of the 'walking waking week' is the final consideration in the prescription of an AFOFC and this will vary between children and for any individual child it will be different from month to month and year to year. It depends on the aims of the prescription of the AFOFC which may be related to bony, musculotendinous, motor control or functional considerations. Achieving compliance with the recommended percentage of the walking waking week can sometimes be difficult. The use of the VVG, in demonstrating to parents and children the importance of the HSD of the footwear and the influence that the footwear design has on the child's gait has, in our experience, not only facilitated compliance with the wearing of the AFOFCs but also the compliance with keeping to the recommended final HSD and SAF prescription for the child's AFOFC.

When tuning AFOFCs the effect of alterations in the design of the AFOFC alter shank kinematics with consequent changes in the kinematics of the more proximal joints and segments, the kinetics of gait and muscle activity. Knowledge of normal

and abnormal shank kinematics, throughout the gait cycle, is vital for a comprehensive understanding of AFOFC tuning.

CONCLUSION

A review of the literature revealed that the combination of the footwear with AFOs or casts, SAF measurements and tuning of AFOFCs for an individual are not generally recognised as being of importance. However, there is some evidence that these are crucial to the normalising of gait and that a tuned AFOFC can be a powerful tool as simple adjustments of the distal AFOFC can modify both the distal and proximal gait abnormalities.

The literature review also showed that there is ambiguity in the terms used to describe AFO and AFOFC prescriptions. This can only be remedied by use of standard terms with clear definitions. In this paper the use of inclined, vertical and reclined to describe the SAF of AFOFCS and reservation of dorsiflexion, plantarflexion and plantigrade to describe the anatomical angle of the AAAFO in AFOFCs eliminates confusion about use of the terms dorsiflexion and plantarflexion.

In a clinical setting it is possible to measure and record in a simple manner the minimum set of sagittal plane data which are required for replication of some key features of an AFOFC. These are the AAAFO, the SAF and the HSD/ pitch of the footwear. Once there is agreed understanding of the definitions of terms used the information can be imparted to others in an unambiguous way.

In this population of children whether the AAAFO was dorsiflexed, plantigrade or plantarflexed the SAFs of the tuned AFOFCs were all inclined and there is a match between the mean SAF of the tuned AFOFCs and the SAF of barefoot normal gait. When tuning AFOFCs for children with CP and other conditions it is recommended that a useful starting point would be 10-12° inclined SAF. For children with SB an SAF of 8° inclined would be a good starting point. If necessary the SAF can then be increased or decreased.

A possible explanation for the 10-12° inclined SAF being central to the production of stability in stance in both normal and pathological gait with AFOFCs is that it is

determined by anthropometric measures. A 10-12° incline is the position which brings the centre of the knee joint directly over the middle of the foot.

Tuning the SAF of an AFOFC, which will place the shank in the optimal position during MST, is not the only tuning which is essential and which benefits from kinetic analysis. When using AFOFCs it is important to replicate normal, or near normal, shank kinematics throughout stance. The AFO design, the tuned SAF of the AFOFC and the design of the heel and sole of the footwear significantly influence the kinematics of the shank both in MST and in LR and TST, as the shank enters and exits its MST position, with consequent effects on the kinetics of gait.

Knowledge of normal and abnormal shank kinematics, throughout the gait cycle, is vital for a comprehensive understanding of AFOFC tuning.

DEFINITIONS

Ankle-foot orthosis (AFO)

An orthosis which encompasses the ankle joint and the foot (British Standards Institution 1990).

Ankle-foot orthosis footwear combination (AFOFC).

The AFO together with the accompanying footwear.

Angle of the Ankle in the AFO (AAAFO)

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 base of heel) and the line of the shank. It is described in degrees of dorsiflexion or plantarflexion, with plantigrade describing the neutral position.

Shank Angle to Bench (SAB) of the AFO

The angle of the shank of the AFO relative to a vertical to the horizontal surface on which it is stood, in the sagittal plane. It is measured in degrees of incline and recline from the vertical, vertical being 0 degrees. Its value in degrees is the same as the AAAFO unless there is additional build-up fixed beneath the heel or sole of the AFO. For example, if the AAAFO is plantarflexed it is common to apply a build-up under the heel of the AFO to obtain a SAB of 0 degrees.

Heel Sole Differential (HSD) of the footwear.

The measured difference between the thickness of the heel at mid-heel and the thickness of the sole at the metatarsal heads, measured in millimetres, (Fig.2).

Final Heel Sole Differential (FHSD)

The sum of the HSD of the footwear and the thickness of any additions at heel or sole, measured in millimetres.

Shank Angle to Floor (SAF) of the AFOFC

The angle of the shank relative to a vertical to the horizontal surface when standing in the AFOFC with heel down and weight equally distributed between heel and toe, measured in the sagittal plane. The SAF is described as inclined if the shank is inclined forward from the vertical and reclined if the shank is reclined backward from the vertical. It is described in degrees from the vertical, vertical being 0 degrees.

Shank Angle to Floor (SAF)
The angle of the shank relative to a vertical to the horizontal surface, measured in the sagittal plane. The SAF is described as inclined if the shank is inclined forward from the vertical and reclined if the shank is reclined backward from the vertical. It is described in degrees from the vertical, vertical being 0 degrees.
The SAF can be measured in standing or during a gait cycle when barefoot, in footwear or in AFOFCs.

Table I: Clinical studies that recognise importance of the SAF of an AFOFC and/or importance of tuning the SAF of an AFOFC

Author	*Subject Age*	*Subject diagnosis*	*Description of AAAFO and SAF where clear differentiation is made*		*Information about AFOFCs used*		
			AAAFO Equivalent	*SAF Equivalent*	*AAAFO*	*SAF*	*HSD or Pitch*
Corcoran et al 1970	C A	CVA		Distal tibial shaft inclined forward with respect to perpendicular to floor.		10° inclined	7/8" for males 5/8" for females
Jebsen Corcoran and Simons 1970		CP SB		Distal tibial shaft inclined forward with respect to perpendicular to floor		10° inclined	
Glancy and Lindseth 1972	C A	SB Others	Sole of foot relative to tibia	Angle of edge of anterior panel relative to perpendicular to level surface	Dorsiflexion, Plantigrade Plantarflexion	3-5° inclined	
Rosenthal et al 1975	C	CP			Variety of dorsiflexion		'Regular laced Oxford shoe'
Rubin and Danisi 1975	A	Paralysis of quadriceps			Plantarflexion		
Cook and Cozzens 1976	A	Normal	Position of foot with respect to the shank	Pictures of resulting SAFs	15° dorsiflexion Plantigrade, 15° plantarflexion	Measurable from pictures	0.9 cms 2.5 cms 5.7 cms
Fulford and Cairns 1978	C	SB				Uprights adjusted slightly forward of the vertical	
Simon et al 1978	C	CP			7-10° dorsiflexion	Deducible as approximately 10-15° inclined	As Rosenthal et al 1975 'Regular laced Oxford shoe'
Gans Erickson and Simons 1979	C A	CP SB	Ankle angle	Relative angle of tibia to floor	Plantigrade		
Nuzzo 1980	C	CP MD SB				Position the knee just in front of the ankle when the patient is standing in the shoe	
Harrington Lin and Gage 1983	C	CP			5° dorsiflexion 5° plantarflexion 10° plantarflexion		
Nuzzo 1983	C A	CP Others	Anatomic dorsiflexion	Functional dorsiflexion, a measure of shoe sole to tibia	Dorsiflexion Plantigrade Plantarflexion	Pitch knee forward until the skin of kneecap is just above or slightly behind metatarsal heads	Wedge adjustable sandal

C, Children ; A, Adults

Recommends same SAF angle for all legs	*Recommends tuning of SAF for individual leg*	*Recognition of importance of AFOFC for determining SAF*	*Recognition of importance of tuning SAF*			*SAF Tuning Method*
			By description of a process of tuning AFOFCs	*By tuning AFOFCs prior to an evaluation of effects on gait*	*By using a variety of SAFs to evaluate effect on gait or standing*	
Yes		Yes				
Yes		Yes				
Yes		Yes				
	Yes			Yes		Use of inclined walkway
		Yes	Yes			Weight line in standing
		Yes			Yes (Standing)	
	Yes	Yes	Yes			Standing balance
	Yes			Yes		As Rosenthal 1975
		Yes				
Yes		Yes				
	Yes		Yes	Yes		Kinematic and kinetic gait parameters
Yes		Yes	Yes			

Table I (continued): Clinical studies that recognise importance of the SAF of an AFOFC and/or importance of tuning the SAF of an AFOFC

Author	*Subject Age*	*Subject diagnosis*	*Description of AAAFO and SAF where clear differentiation is made*		*Information about AFOFCs used*		
			AAAFO Equivalent	*SAF Equivalent*	*AAAFO*	*SAF*	*HSD or Pitch*
Meadows 1984	C	CP	Ankle floor attitude	Attitude of the shank with respect to the ground	1-8° dorsiflexion	Deducible as 1-17° inclined	0-10°
Nuzzo 1986	C	CP	Anatomic dorsiflexion	Functional dorsiflexion, a measure of shoe sole to tibia	Dorsiflexion Plantigrade Plantarflexion	Mild functional dorsiflexion when neutral functional dorsiflexion would have the tibia pitched approximately 7-10° forward with shoe on floor	Wedge adjustable sandal
Sankey Anderson and Young 1989	C	CP	Position of the foot relative to the leg	Position of the leg relative to the ground	Dorsiflexion		
Butler and Nene 1991	C	CP	Ankle angle	Angle between lower leg and grouind	Plantigrade preferred		
Butler Thompson and Major 1992	C	CP					
Hullin Robb and Loudon, 1992	C	SB	Foot shank angle	Tibial floor angle	10° dorsiflexion Plantigrade	Deducible as 0° and 10° inclined	Picture of 0° pitch
Butler Farmer and Major 1997		Head injury Hemiplegia			Plantigrade		
Schmalz Blumentritt and Drewitz 2000	Probably A	Neurological Orthopaedic Normal					
Stallard and Woollam 2003	C	Neurological					

C, Children; A, Adults

Recommends same SAF angle for all legs	*Recommends tuning for individual leg*	*Recognition of importance of AFOFC for determining SAF*	*Recognition of importance of tuning of SAF*			*SAF Tuning Method*
			By description of a process of tuning AFOFCs	*By tuning AFOFCs prior to an evaluation of effects on gait*	*By using a variety of SAFs to evaluate effect on gait or standing*	
	Yes	Yes	Yes		Yes (Gait)	Kinematic and kinetic gait parameters
.	Yes	Yes		Yes		Kinematic
		Yes				
	Yes	Yes	Yes			Kinematic and kinetic gait and standing parameters
	Yes	Yes	Yes	Yes		Kinematic and kinetic gait parameters
Yes		Yes	Yes		Yes (Gait)	Kinematic and kinetic gait parameters
	Yes	Yes	Yes	Yes		Kinematic and kinetic gait parameters
	Yes		Yes	Yes		Kinematic and kinetic gait and standing parameters
	Yes			Yes		Kinematic and kinetic gait parameters

Table II: Publications detailing the SAF equivalent in AFOFC or cast

Authors	*Subject diagnosis*	*Cast/ Orthosis*	*Evidence Of Tuning/ Optimising For The Individual Legs.*	*``Description Of Probable Equivalent To SAF*	*Description Of Probable Equivalent To AAAFO*
Jebsen Corcoran and Simons 1970	Cerebral palsy Spina bifida Cerebrovascular accident Other conditions	FIXED-ANKLE AFO	A theoretical kinematic justification for selection of the 10° inclined SAF is given but there is no evidence of tuning on individual subjects.	' The brace is fabricated so that the tibia is inclined 10° forward from a perpendicular to the floor when the shoe is flat on the floor.'	No description. AAAFO would have been as determined by the footwear when setting the SAF at 10° inclined.
Glancy and Lindseth 1972	Spina bifida Cerebrovascular accident Other Conditions	FIXED-ANKLE AFO	None	' With the brace in the shoe ' the heel portion of the shoe is lifted until the vertical edge of the anterior panel of the shell is 3-5° anterior to a line perpendicular to the level surface.'	Recommends use of a variety of ankle angles, dorsiflexion, plantagrade, plantarflexion according to clinical findings
Fulford and Cairns 1978	Spina bifida	FIXED-ANKLE AFO	Tuned in standing.' The uprights are adjusted until the child can stand vertical without the feeling of falling backwards'.	Using metal double uprights, ' the uprights must be aligned slightly forwards so that the centre of gravity is in front of the ankle joint.'	No description. AAAFO would have been as determined by the footwear when setting the SAF.
Simon et al 1978	Cerebral palsy	FIXED-ANKLE AFO	Kinematic tuning by use of a variable inclined walkway (Rosenthal et al, 1975)	If the AAAFOs used were 7-10° dorsiflexion the addition of a regular Oxford shoe (Rosenthal et al, 1975) would bring the SAF to approximately 10-15° inclined. Alternatively the use of 'ankle dorsiflexion' may refer to the equvalent to SAF.	'The ankle was fixed in 7-10° of dorsiflexion'. Presumably this refers to the AAAFO. If this refers to SAF the AAAFO was less than 10°.
Nuzzo 1983	Cerebral palsy Other conditions Normal	CASTS	Kinematic evidence, from preliminary studies, is given to justify use of the recommended position of the tibia over the foot (SAF). There is no evidence of tuning on individual subjects	'After the cast is hardened the knee is pitched forward by raising the heel from the floor until the skin of the kneecap is just above or slightly behind the metatarsal heads' in order to obtain 'functional dorsiflexion, a measure of the shoe sole to the tibia'	Recommends use of a variety of AAAFO, dorsiflexion, plantagrade, plantarflexion according to clinical findings
Meadows 1984	Cerebral palsy Normal	FIXED-ANKLE AFO	Kinematic and kinetic tuning.	The 'attitude of the shank with respect to the ground' in degrees can be deduced from data given. The most optimal prescriptions were from 4 –17° inclined.	The 'angle of set of the AFO' was dorsiflexed appropriately for each leg of each child. The 'angles of set' used were between 1° dorsiflexion to 8° dorsiflexion.
Nuzzo 1986	Cerebral palsy	FIXED-ANKLE AFO	Evidence that one case was tuned kinematically to 'optimize' the 'amount of functional dorsiflexion required.	'Functional dorsiflexion', 'a measure of the angle between the sole of the shoe and the tibia. when the ankle region is rendered rigid by fusion, cast, prosthesis or braces.' Neutral functional dorsiflexion would have the tibia pitched approximately 7-10° forward with the shoe flat on the floor.	No description of AAAFOs used but refers to Nuzzo 1983 which recommends a variety of AAAFO, dorsiflexion, plantagrade, plantarflexion according to clinical findings.
Cusick 1990	Neuromotor dysfunction	CASTS	None	Build an angle of 5° of anterior pitch between the floor and the shaft section	Recommends use of a variety of ankle angles, dorsiflexion, plantagrade, plantarflexion according to clinical findings
Hullin Robb and Loudon 1992	Spina bifida	FIXED-ANKLE AFO	The effects on gait of three prescriptions of AFOFC were measured, by kinematic and kinetic analysis, prior to a recommendation of two of the three.	' Tibial Floor Angle ' is shown diagrammatically. Data given allows deduction of successful Tibial Floor Angles, either 0° inclined with rocker sole or 10° inclined with flat sole.	The 'angle of ankle dorsiflexion' used in the AFOs was 0° plantigrade and 10° dorsiflexion

Table III: Reasons for exclusion from the retrospective data analysis

Exclusion Criterion	*All Diagnoses*	*Cerebral Palsy*	*Spina Bifida*	*Other diagnoses*
Population before exclusions	*151*	*92*	*6*	*53*
Declined or unable to attend	4	3	0	1
Walks with walking aid	13	11	1	1
Lost to follow-up	2	1	0	1
AFOFC not complete by end of study period	5	2	0	3
AFOFC not appropriate for clinical condition	8	0	0	8
Clinical condition too mild to warrant AFOFC.	36	18	1	17
Clinical condition too severe for AFOFC to be effective	3	3	0	0
AFOFC not tuneable due to contracture proximally	2	2	0	0
Wearing hinged AFOFC	2	0	0	2
Tuned AFOFC data missing	2	2	0	0
Population After Exclusions	*74*	*50*	*4*	*20*

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