THE INFLUENCE OF POLYPROPYLENE ANKLE-FOOT ORTHOSES ON THE GAIT OF CEREBRAL PALSIED CHILDREN

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This thesis is dedicated to the children of Dundee and Tayside whose friendship and enthusiastic co-operation made this research programme both pleasant and possible.

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ABSTRACT

Clinical experience in Dundee in the use of polypropylene ankle-foot orthoses (AFOs) with cerebral palsied (CP) children had indicated that the use of the AFOs could affect markedly their gait.

A research programme was established to investigate the influence of polypropylene AFOs on the gait of CP children. This included the use of a TV-computer gait analysis system. A 2-dimensional analysis was conducted which included the calculation of the external moments created by the ground-to-foot force vector in the sagittal plane at the hip, knee and ankle joints. A total of eight CP children were analysed walking barefoot and with a range of prescriptions of AFOs and associated footwear adaptations. Gait analysis was conducted on six normal children to obtain data for comparative purposes. In parallel to the gait analysis the influence of AFOs on the muscle activity of the ankle-foot complex was monitored using a force transducer and electromyography.

Analysis of the data indicated that the kinetic aspects of the gait of CP children were different from normal children. The use of AFOs resulted in a modification of the nature of the ground-to-foot reaction force and the external moments generated in the sagittal plane at the joints of the leg. Alteration of the characteristics of the associated footwear resulted in similar modifications to the gait patterns. An appropriate prescription resulted principally in the reduction of excessive external knee extension moments in mid stance and in the ability to generate improved push-off forces in late stance.

The results of the research programme have confirmed the clinical impression, and attitude to management, that the AFO-footwear characteristics selected for a given child are critical. It is now apparent that further kinetic improvements, not necessarily observable clinically, may be possible by further fine-tuning of the characteristics.

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CHAPTER 1

INTRODUCTION

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1.1 INTRODUCTION

This chapter outlines the aetiology of cerebral palsy, the incidence and the clinical presentation. The various approaches to its management are described briefly, including the use of orthoses.

The role of polypropylene ankle-foot orthoses (AFOs) in the management of cerebral palsied (CP) children, developed and adopted for clinical practice in Dundee, is described. The influence of the characteristics of the AFOs on gait, observed clinically, is discussed.

The research programme set up to investigate the influence of AFOs on gait is described. This includes the research objectives and the measurement techniques adopted.

1.2 CEREBRAL PALSY

1.2.1 Aetiology

Cerebral palsy has been described as "a persistent, but not unchanging, disorder of movement and posture appearing in the early years of life and due to a non-progressive disorder of the brain as a result of interference during it's development", (Little Club,1959). This upper motor neurone lesion results in abnormalities of muscle tone, which vary in severity and distribution depending on the nature of the brain disorder.

Most of the cases of cerebral palsy arise as a result of occurrences at two critical periods in the child's early life. During the first few months of gestation when the foetal brain is being formed, interruptions in the normal course of cerebral development may occur as a result of a variety of factors. The exact reasons for these are unknown and may only be postulated but relate, for example, to the mother's health at this time. This may alter the course of cerebral development so that at birth the brain may contain areas which are either under-developed or missing, (Fig. 1.1). In other cases the child's cerebral development may have progressed without any untoward incident during the nine months gestation and therefore will be normal at birth. Perinatal difficulties may occur such as a prolonged labour or forceps delivery. In these cases trauma may occur either by mechanical damage to the brain tissues or by hypoxia. If cerebral palsy occurs as a result of incidents at either of these critical periods the child will present with characteristic abnormalities of the neuromuscular system. These are significantly different depending on when the lesion arose and will be described later.

There are many other causes of cerebral damage to which a child may be subjected in the early years of life. These include virus infections, hyperthermia as a result of a febrile condition,

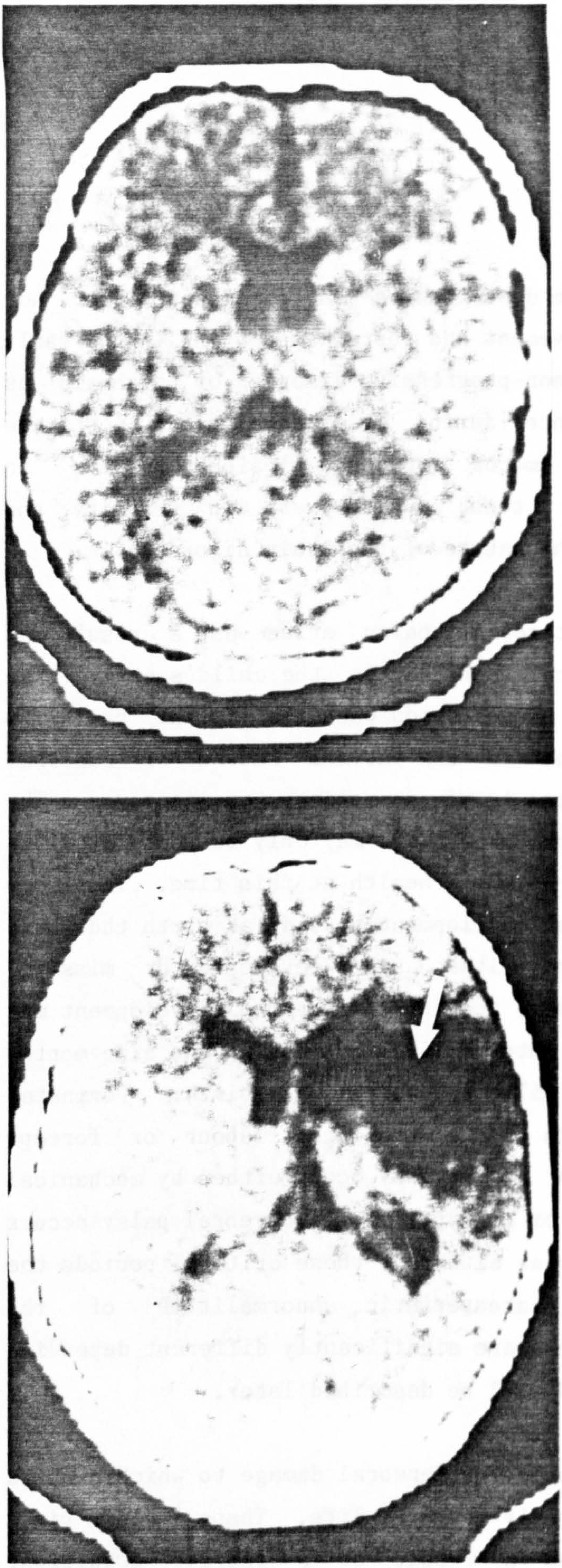


Fig. 1.1

Examples of CT brain scans.

Top - normal child.

Bottom - hemiplegic child with porencephalic cyst.

cerebro-vascular accidents (CVA), brain trauma as a result of road traffic accidents (RTA) and tumours. If the resulting damage occurs within the first three years of life, when the brain is still developing, the child may be considered to be cerebral palsied. This is perhaps open to debate but certainly many of the features with which the child presents are similar to the principal forms of cerebral palsy. If the brain damage occurs when the child is over the age of three years they are not considered to be cerebral palsied. However, many of the features are the same.

1.2.2 Incidence

In the western hemisphere the incidence of cerebral palsy has steadily declined, principally due to improved prenatal care and perinatal techniques, (Nevill,1978, Pharoah,1981). In the 1950's an incidence of three per thousand live births was typical. This has been reduced to nearly one per thousand. Obviously there is considerable variation depending on the geographical position, the local socio-economic level and the degree of health care available. In the developing countries the incidence is likely to be considerably higher.

It is the impression of workers in the field that although the absolute number of cerebral palsied children being born is reducing, the magnitude of the total management problem remaining is not reducing and may indeed be increasing. This is due to a number of factors. The spectrum of the cerebral palsied population is changing. The improvements in health care appear principally to be influencing the milder forms of cerebral palsy. It is in the total numbers of these milder forms that the principal reductions have taken place. Less progress has taken place in reducing the incidence of the more severe forms. Thus, while the overall numbers may have decreased, the proportion of the severe forms has increased. Indeed some centres have indicated that the incidence of the severe forms has actually increased. This is probably due to higher survival rates consequent to improved health care rather than an increase in the number of severely affected cerebral palsied children being born. At present these are clinical impressions only - the statistical evidence is not yet published.

In Dundee with a population of about 250,000 there are approximately three new cases of cerebral palsy each year. If Dundee is considered typical of the United Kingdom population there are therefore sixty new cases per year in Scotland and six hundred in the United Kingdom. The present caseload of cerebral palsied children in Dundee is about one hundred and fifty.

1.2.3 Presentation

The brain is an extremely complex organ, different regions of it being responsible for the control of different body functions. Cerebral abnormalities may result from a wide range of causes, each capable of affecting different regions of the brain. Cerebral palsied children, therefore, may differ considerably in the extent and distribution of their brain abnormalities. Consequently there is also considerable variation in the child's clinical presentation - the nature and extent of the child's disabiity.

In most instances the child will have a disordered neuromuscular system with consequent problems of posture, equilibrium and movement. In addition there may be problems relating to vision, hearing and speech. There may also be more subtle problems relating to conceptual understanding or learning. From a management point of view all of these problems must be considered together when determining the child's programme. The neuromuscular problems cannot be considered in isolation.

It is, however, useful for discussion purposes to classify the

Fig. 1.2

Left hemiplegic CP child.

Fig. 1.3

Diplegic CP child.

children according to the functional problems of the neuromuscular system. There are different ways of achieving this. In Dundee, Ingram's classifications have been adopted, (Ingram,1964).

The three principal categories of interest are hemiplegia, diplegia and quadriplegia (also named bilateral hemiplegia or spastic tetraplegia).

Hemiplegia

In hemiplegia a unilateral spastic paresis occurs affecting the arm more than the leg, (Fig. 1.2). Initially there is poverty of movement in the arm and leg with reduced muscle tone and tendon reflexes. After about three months tone increases, with tendon reflexes becoming brisker than on the unaffected side. The hand may become clenched with the thumb held across the palm. Dwarfing of the affected limbs is common.

Diplegia

In diplegia there is paresis of all four limbs, more marked in the legs than in the arms, (Fig. 1.3). Diplegia is subdivided into hypotonic, dystonic and spastic stages. The child commonly progresses through all these stages but may occasionally remain for a prolonged period, or permanently, in the hypotonic or dystonic phase. Characteristically in the hypotonic phase the infant shows some poverty of movement, delayed motor development, hypotonicity, reduced tendon reflexes and exaggeration of primitive reflexes. In the dystonic phase the muscle tone at rest is not significantly high but there is an increase in extensor tone when the child is handled. Primitive reflexes tend to be retained well beyond the normal age when they would otherwise have disappeared. In the spastic or hypertonic phase there is an increase in muscle tone at all times,

Fig. 1.4

Quadriplegic CP child.

even when the child is at rest. Because of the hypertonicity of the flexors and their strength relative to the extensors, there is a high risk of the development of flexion contractures. In established cases the pelvis and lower limbs may be small in comparison to the rest of the body.

Quadriplegia

In quadriplegia there is spastic paresis, often asymmetrical, of all four limbs but with more marked involvement of arms than legs, (Fig. 1.4). Severe brain damage may be apparent from birth. The infant shows poverty of movement with gradually increasing hypertonicity in all four limbs resulting in a marked functional disability.

Other categories of cerebral palsy exist. These include the ataxic cerebral palsies which may be subdivided into cerebellar ataxia, characterised by hypotonia, incoordination of voluntary movements, intention tremor and impairment of balance; ataxic diplegia in which spasticity of diplegic distribution is superimposed on ataxia, and the dysequilibrium syndrome characterised by pronounced difficulty in maintaining an upright body posture and in being aware of the position of the body in space.

The final category of interest is dyskinetic cerebral palsy which is characterised by involuntary movements and disorderly changes of tone affecting the head, neck, trunk and all four limbs.

In practice many children exhibit characteristics of more than one type of cerebral palsy although usually one type predominates. The problems occurring in cerebral palsy are therefore diverse and varying in severity from child to child. Nevertheless when

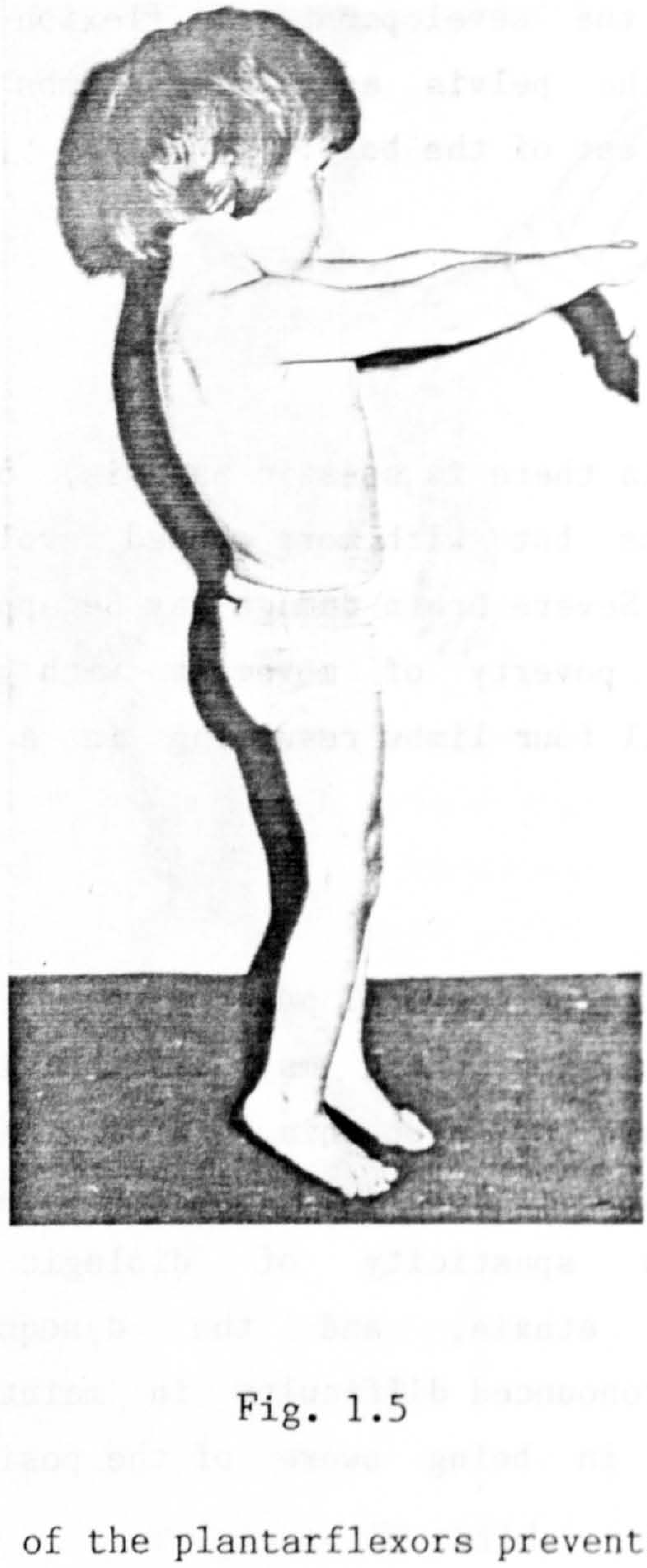


Fig. 1.5

Hypertonicity of the plantarflexors preventing the child from attaining heel contact and standing balance.

considering their locomotion problems there are certain common features which may be considered typical. The most important of these is abnormal muscle tone. The children are frequently weak with high muscle tone occurring as a result of reflex activity rather than voluntary activity. They therefore find it difficult to adjust in a controlled fashion to the changing demands of their environment. Consequently they may experience difficulty, for example, in attaining standing balance or walking in a controlled fashion, (Fig. 1.5).

Imbalance may occur between the resting tone of the flexors and extensors. As a result there is the ever-present danger of the development of contractures which will add further complications to the child's ability to perform. During growth spurts the muscle growth may lag behind the bone growth giving the appearance of the development of contractures. The child may temporarily lose some of the functional abilities already mastered and appear to regress, until the muscle growth catches up.

Finally it must be remembered that cerebral palsied children will never have had the opportunity to experience the sensation of normal locomotion. This is in contrast to adults who acquire upper motor neurone disorders in later life, such as CVA's. The CP child therefore has to learn to walk with all the difficulties of a normal infant with the additional complications of an impaired neuromuscular system.

1.3 MANAGEMENT METHODS

As mentioned previously, the cerebral palsied child usually presents with a wide range of problems. Some of these problems may relate to discrete aspects of the child's development. When formulating a management programme, however, the total child must be considered. The inter-relationships of the problems must be understood and compromises made where necessary.

The complexities of the situation require that many different professional skills must be brought together to form the management team. All aspects of the child's disability must be assessed so that the exact nature of the problems may be determined. Management objectives must be defined and a programme created to attempt to achieve these. It is usual that a paediatrician co-ordinates the management team and is responsible for determining the order of priorities and compromises that are necessary to create the management programme.

Over the past few decades significant changes have taken place in the relative priorities given to different management objectives. In previous years paramount importance was given to the child eventually attaining the ability to walk independently. This was perhaps at the expense of other aspects of the child's total problem. In recent years greater understanding has been obtained on the importance of communication skills and activities of daily living. Consequently the emphasis on the management of those aspects has increased to the point where they are considered to be of greater importance in the long term than walking ability. This implies that the proportion of time available during the child's treatment periods for activities relating to the solution of their locomotion problems may become limited.

The reduction in time available for the management of locomotor problems means that either the goals must be set at a lower level or that techniques must be improved to achieve similar goals to those attainable before. This is further compounded if it is considered desirable to attempt to achieve higher standards than before in the solution of locomotor problems.

There are four main approaches to the management of the child's locomotor problems - physiotherapy, orthotics, chemotherapy and orthopaedic surgery. Ideally any management programme should include elements of all of these where appropriate. An integrated approach usually reduces the demands on any one element. The resulting level of success is usually far higher than that achieved by employing any one approach singly. This fact, however, has not deterred some professionals from single-mindedly pursuing their own speciality to the point of discounting the benefits of other approaches.

It is relevant to outline the principal objectives of the four main approaches. Although these can be listed separately many of the objectives are common and would, indeed, be achieved only by co-ordinated action between the disciplines involved.

1.3.1 Physiotherapy

Many different schools of thought have arisen over the past few decades relating to the physical treatment of cerebral palsy, (Barrett and Linn,1981, Cassidy-Conway and Zawaki,1983, Conrad and Bleck,1980, Levitt,1982, McKinlay,1978, Seeger et al.,1981, Seeger and Caudrey,1983). Each is largely based on its own interpretation of the salient neurological phenomena, resulting in differences of concepts and methods of treatment. Examples of these methods are Bobath, Vojta, Temple Fay, Doman Delecato and Peto. These differ significantly in the details of types and intensity of the physiotherapy methods involved. There are also differences in what are believed to be the effects on the child, and the neurological reasons for these. There are, however, some common concepts which apply to most of the above methods.

The one unifying belief is that regular treatment from an early age is the best way of ensuring that the cerebral palsied child will achieve his maximum potential. Most methods attempt to reduce muscle tone to normal levels by inhibiting abnormal disabling reflexes and thus at the same time allowing voluntary movement. Normal postural reactions, which are pre-requisites for balance and normal movement, are therefore facilitated. Some methods utilise the repetition of various reflex patterns claiming that the initially automatic responses will eventually become active movements. Most of the methods have the underlying belief that in the early years of the infant's life the brain is in a plastic state and is thus amenable to alteration. It is claimed that the treatment method adopted, when successful, has in some way modified the original brain lesion, perhaps by stimulating a re-arrangement of brain interconnections. This is a highly contentious issue and one with which most neurologists would disagree.

Sophisticated handling methods and programmes of treatment have been developed in accordance with the various interpretations of the problems and the desired objectives. None of these methods has yet been subjected to independent clinical trials and evidence of their efficacy is mostly empirical. There are many obstacles to a structured evaluation such as the wide range and variety of motor handicap presenting, the diversity of the other associated problems such as sensory disorders and intelligence, the difficulties of matching, the variation in motivation of child, parents and therapists, and the ethical problems of leaving a control group without treatment.

Despite the above difficulties these various schools of thought have attracted much interest in the physiotherapy profession. This has resulted in many cases in the generation of a wide following whose members display confidence in the method ranging from careful consideration to blind faith.

There is little doubt that many of the handling techniques are beneficial and have arisen as a result of an awareness by the therapist of their favourable effects on the child's neuromuscular system. It is possible to observe and feel which techniques reduce unwanted tone and permit the child to move voluntarily. Whether the child benefits in the long term from these simply as a result of being permitted to learn from the experience or as a result of a favourable modification of his plastic brain is open to considerable debate.

Some physiotherapy departments use an eclectic approach, choosing elements from many of the methods. This is an attempt to create individual programmes of treatment to match the child's individual picture of disability. While this is a less rigid approach than the adherence to a single method, the criticisms mentioned above still apply.

The broad aims of any programme of management should be to ensure optimum motor development and function, and to prevent the development of deformities and contractures which would hinder and distort that function. It could be argued that these aims are attainable without the intensive physiotherapy programmes which concentrate so heavily on attaining permanent modification of the neurological disorder.

In Dundee the physiotherapy approach adopted by the Handicapped Children's Service in the management of cerebral palsy is essentially a functional one. The physiotherapy, however, is part of an integrated multi-disciplinary approach rather than being a separate, isolated entity. A range of management objectives are determined and appropriate action taken to achieve these, including the use of orthoses, and if necessary, drugs and surgery. While there are definite periods when the physiotherapist solely is involved with the child, that activity is part of an overall programme. It is not considered as a physiotherapy method, per se, for the treatment of cerebral palsy.

The management of cerebral palsied children in Dundee will be described more fully later.

1.3.2 Orthotics

Orthoses of different kinds have been used in the management of cerebral palsied children for many years, (Anderson and Meadows,1979, Anderson,1983, Drennan and Gage,1983, Meadows et al.,1980, Rosenthal et al.,1975, Thompson,1983, Westin and Dye,1983). They have been used variously for the treatment of orthopaedic problems such as muscle imbalance, joint contractures, etc., and to aid functions such as standing and walking.

The use of conventionally constructed orthoses remains widespread despite the introduction in the last decade of modern thermoplastic orthoses. The principal conventional orthoses used for the lower limbs are the traditional "long leg calipers" (KAFOs) and "below knee irons" (AFOs) with the use of "T-straps" to control valgus and varus deformities. Associated with the use of these orthoses, or separately, are orthopaedic footwear and insoles of various designs.

These orthoses are prescribed principally by orthopaedic surgeons, possibly in conjunction with physiotherapists. They are used to maintain the joints of the lower limbs in fixed positions, or to restrict movements to within desired limits.

The "below-knee irons" are used to counteract the spasticity in the plantarflexor muscles, thus maintaining a plantigrade attitude of the ankle joint. This permits the child to bear weight through his heels rather than standing on tip-toe. In addition valgus or varus attitudes of the feet may be controlled by the use of medial or lateral T-straps. The joint movements can either be blocked completely or permitted limited movement depending on the details of the design of the orthosis. The use of back stops, for instance, permits dorsiflexion of the foot while preventing plantarflexion.

The "long-leg caliper" is used to prevent flexion of the knee joint. This is in addition to controlling the ankle-foot complex in the same way as the "below-knee iron". If the knee only is to be controlled, for instance during walking training sessions, fabric gaiters may be used which wrap round the leg to maintain knee extension. Alternatively back shells are sometimes prescribed consisting of aluminium gutters with felt lining which are bandaged in place, or plaster of Paris.

In continental Europe AFOs are often constructed from block leather which totally enclose the lower leg and foot. These are made of a two-part shell construction with the anterior part removable for donning. Orthopaedic footwear is used to provide the walking surface. This footwear obviously must be rather large to accommodate the bulky orthosis.

Plaster of Paris is used in some centres in the fabrication of "tone-inhibiting casts", (Duncan and Mott,1983, Sussman and Cusick,1979). The lower leg and foot are included with the ankle set in an attitude, usually dorsiflexion, which induces a relaxation of the plantarflexors. A walking sole is attached to the bottom of the cast. The purpose of these casts is both short term and long term. They may be worn continuously for several weeks. During this time they maintain the foot in a functional position to permit heel loading and standing balance to be attained. The tone-inhibiting effect reduces the unwanted reflex activity, both in the plantarflexors and throughout the body generally, and permits voluntary movement. This allows the physiotherapist greater scope for activities with the child such as learning to stand and walk. When the casts are removed it is claimed that there is a carry-over effect and the inhibition of tone is maintained for a period of weeks or months thereafter. This may indeed be true but it is likely that the explanation for this observed effect is complex. This will be discussed later.

In some centres plaster of Paris foot cradles are used with similar objectives to the below-knee tone-inhibiting casts described above. They obviously cannot control the equinus position of the ankle directly but can to a certain extent prevent the foot collapsing into valgus. The toes are maintained in a slightly dorsiflexed attitude by the shaping of the front section of the cradle. This tends to induce muscle relaxation in the foot and ankle. This effect may also be noted in the muscle groups throughout the body.

There are many problems associated with most of the methods described above. These relate both to the efficacy of the orthoses themselves and to the levels of understanding and abilities of the various professionals involved in their prescription, supply and use.

Significant problems can occur even when conventional orthoses are used with patients having lower motor neurone disorders such as poliomyelitis. In these cases the paralysis is flaccid with no high muscle tone caused by reflex activity. The demands on the orthosis are, therefore, significantly less than if muscle spasm is present.

The design of many conventional orthoses has developed as a result of a process of trial and error rather than as a result of biomechanical knowledge of the force patterns required to be applied to the limb. Consequently many orthoses are either over- or under-designed. The orthoses tend, therefore, to be either bulky or

Fig. 1.6

Child with conventional HKAFOs.

ineffectual, and sometimes both. There is frequently a lack of intimate fit, and hence efficient load transfer, between the orthosis and limb. This is particularly so when considering control of the ankle-foot complex. The structure of the "below-knee iron" does not in fact contact the foot directly. The side struts are attached to the footwear and it is the footwear that has to control the foot position. Few shoes fit sufficiently intimately to achieve this. The foot frequently is able to rotate within the footwear and this fact may not always be obvious from the outside. These problems are further exacerbated by the fact that the structural integrity of the orthoses and footwear frequently deteriorates.

The additional neuromuscular complexities of cerebral palsy put further demands on the orthoses. If high muscle tone is present the loads generated between the orthosis and limb are likely to be high. This increases the probability of poor control of the position of the limb segments within the orthosis. Apart from the functional problems which result, discomfort may also be experienced. This in turn may stimulate additional reflex activity increasing the muscle tone still further and thus exacerbating the problem.

The orthoses may also be heavy and cumbersome putting additional stress on the neuromuscular system. It is by no means impossible that from the child's functional point of view more may be lost than gained by the use of poorly-functioning orthoses. This fact may have contributed to the antipathy towards their use by many physiotherapists. This attitude, although unfortunate, is certainly understandable. Indeed the word "bracing" often used to describe the use of orthoses conjures up a picture of limb segments being constrained by the use of force - highly undesirable in the case of cerebral palsy, (Fig. 1.6).

The advent of thermoplastic orthoses has opened up the possibilities of avoiding the problems described above and increasing the potential benefits of the use of orthoses. All of

Fig. 1.7

Polypropylene AFOs.

the orthoses mentioned previously now have modern thermo-plastic equivalents. Arguably the most significant of these as far as cerebral palsy is concerned is the polypropylene AFO.

The polypropylene AFO is produced from a plaster model of the child's lower leg and foot, (Fig 1.7). It is designed to be worn in close contact with the limb. It is, therefore, potentially capable of much better control of the position of the ankle-foot complex than a conventional orthosis.

Paradoxically, the polypropylene AFO is also capable of creating greater problems than the use of a conventional AFO. Because of the intimate contact of the polypropylene AFO greater skill is required of the orthotist to achieve a satisfactory fit. The angle at which the orthosis is set is also very critical to achieve optimum functional results and avoid creating other problems. A conventional orthosis is a less efficacious device than its thermo-plastic equivalent. Consequently when it is functioning badly its deterimental effect on the patient is also less. A less-skilled orthotist can therefore "get away with" supplying a conventional orthosis but runs into trouble when attempting to use a polypropylene AFO.

A comment frequently encountered when discussing the use of polypropylene AFOs with therapists from other centres is "we've tried them but they don't work". This is most unfortunate as the experience in Dundee has indicated that the polypropylene AFO, used with understanding and with appropriately trained personnel, can be an extremely useful aid to the management of cerebral palsy.

The use of polypropylene AFOs in the management of cerebral palsied children in Dundee will be discussed later.

1.3.3 Chemotherapy

Drugs of various types have been used in attempts to overcome some of the locomotor problems of cerebral palsy, (Carpenter and Seitz,1980, Carpenter,1983, Joynt and Leonard,1980, Young et al.,1978). They are prescribed principally in cases where high muscle tone is present and is causing significant functional problems. Typical examples of these are hypertonicity of the plantarflexors preventing the attainment of heel contact, or of the adductor muscles resulting in "scissoring" when the legs tend to cross in front of each other. The purpose of the drug is to reduce the abnormally high muscle tone to acceptable levels and, hopefully, thereby improve function.

In the past Diazepam (Valium), a muscle relaxant drug, was used. In recent years Baclofen (Lioresal) has become more common. The effects of the drug are unpredictable and vary from child to child. The outcome depends on many factors such as the severity of the diagnosis and the amount of the drug administered.

Generally speaking the results of the use of drugs in cerebral palsy have been disappointing, for two main reasons. Sometimes the drug has very little effect on muscle hypertonicity even with relatively high doses. In other cases, in addition to the reduction of hypertonicity, undesirable side effects may be experienced. Some of these side-effects may be sufficiently detrimental to the general well-being of the child that the drug usage has to be abandoned.

The side-effects may relate to the locomotor function itself or to other aspects of the child's status. If the child has very little or no voluntary muscle activity he may require to rely on spasticity for his locomotor performance. If this spasticity is removed by the drug he may be left without any ability to stand or walk and would simply sag to the floor if unsupported. In some cases the child may experience drowsiness which may reduce his motivation to move or interfere with school activities. Behavioural changes may also result and other problems such as bedwetting may occur.

Clinical experience has indicated that the children who gain functional improvement without significant, undesirable side-effects constitute only a relatively small minority. In most cases the functional improvements are minimal with the frequent occurrence of undesirable side-effects.

Because of this experience drugs are rarely used as the primary method of management. They may, however, play a useful role in conjunction with other management methods. Minor doses of a drug may produce slight reductions of hypertonicity sufficient, for example, to permit a more easy fitting of an AFO, to allow the use of a standing frame or facilitate physiotherapy techniques.

1.3.4 Orthopaedic Surgery

When cerebral palsied children are born they very rarely have major orthopaedic problems. The principal exception to this is, of course, abnormalities of muscle tone which are functionally significant. Generally speaking the structure of bones and joints can be considered normal. There may, however, be joint laxity consequent to muscle hypotonicity. Orthopaedic problems tend to develop as the child grows older..

Nearly all the orthopaedic problems which occur are as a result of muscle hypertonicity or imbalance between antagonists, (Tardieu et al.,1982 a,b). These can in themselves constitute significant functional problems which require intervention. They may also lead to the development of muscle contractures - permanent shortening of the muscle belly. The muscle becomes less contractile and hence its usefulness as a functional unit diminishes. The tightness of the muscle may limit the range of motion of a joint. If this situation persists the joint capsule may also become contracted. In extreme cases the articular surfaces of the joint may grow in a distorted fashion and lose their abiity to slide smoothly over each other. If the long bones are subjected to perpetual imbalance of muscle tension they may tend to grow in a deformed fashion. An example of this is internal torsion of the femur, caused by tight internal rotator and adductor muscles.

Orthopaedic intervention has two principal objectives: the improvement of function and the prevention of deterioration. There are many ways in which these may be achieved, (Banks,1983, Fixsen,1979, Hoffer et al.,1971, Makley and Kim,1983). The simplest of these is tendon lengthening which is carried out to compensate for the shortening of a contracted muscle belly. In severe cases a tenotomy may be performed which involves complete severing of the tendon to eliminate the effect of a severely spastic or contracted muscle. Tendon transfers may be performed in an attempt to redistribute muscle function around a joint. Osteotomies may also be performed, generally on older chldren, to counteract a bone deformity. Joint arthrodesis may also be considered in extreme cases involving the removal of the articular surfaces and the fusion of the adjacent bones.

Many different operations have been developed over the years in attempts to improve the surgical techniques employed and the quality of the functional results. There are, however, certain operations which may be considered as standard practice even although details of their techniques may differ between centres. These may be grouped for discussion purposes by their influence on the major joints of the leg.

Ankle-Foot

Probably the most common orthopaedic procedure in cerebral palsy is lengthening of the Tendo-Achilles (T.A.). This is performed in cases where contracture of the triceps surae (gastrocnemius and soleus) is preventing dorsiflexion of the ankle. Many different surgical techniques have been developed to lengthen the tendon. They all have the same objective of creating a longer tendon to compensate for a shortened muscle belly, thus restoring the range of passive dorsiflexion. This operation is called a "correction". Perhaps a more accurate description would be "compensation". The original deformity still remains, namely the shortened muscle belly. The contractile properties of the muscle itself remain diminished. Other surgical techniques have been developed involving the muscle belly itself in an attempt to reduce the primary problem. The T.A. lengthening, however, remains the most common approach.

Other operative procedures involving the ankle-foot complex are tendon transfers and arthrodeses. Tendon transfers are performed in attempts to redistribute the muscle power around a joint and provide more balanced function. Typical of these are transfers of the insertions on the foot of some of the pre-tibial muscles. These transfers alter the muscle's properties as invertors or evertors of the foot while retaining their action as dorsiflexors. In severe cases arthrodeses of a number of joints of the ankle-foot complex may be necessary if soft tissue surgery has failed to provide an adequate functional result. In these cases fixed, but functionally useful attitudes of the joints are considered to be preferable to the motion imposed by severely spastic and imbalanced muscles.

Knee

The most common problem encountered at the knee is flexion contracture. This is normally a consequence of contractures of the hamstrings which have arisen because of spasticity in these muscles. Weakness of the antagonistic quadriceps frequently exacerbates the problem.

In some cases lengthening of the hamstrings may be considered adequate to restore the range of knee extension to normal. In more severe cases it may be necessary to move the insertions of the hamstrings from tibia and fibula to the femoral condyles. This removes the effect of the hamstrings as knee flexors but retains their effect as hip extensors.

If the knee extensors are weak it may be that the child is not able to use the increased extension range of the knee directly. This may, however, be possible with the assistance of an AFO. If all the hamstrings have been removed from the tibia and fibula there is the danger of a subsequent hyperextension deformity developing. To safe-guard this one of the tendons (frequently the semimembranosis) is left intact on the medial side.

Hip

There are three principal problems encountered at the hip joint relating to abnormalities of internal rotation, adduction and flexion. A child may have one or any combination of these. The causes are principally over-activity of specific muscles. In mild cases passive correction may be possible with the child at rest. In more severe cases contractures may have developed resulting in permanent disability.

Excessive internal rotation is a common problem in cerebral palsy. While some of this occurs at the hip joint itself, femoral neck anteversion and internal femoral torsion may also be present. This results in the foot being grossly internally rotated. In some instances the range of passive rotation may be limited to between 45 degrees of internal rotation and 90 degrees or more of internal rotation, no external rotation being possible. The child may experience severe difficulty when walking because of the toe of the swinging foot catching behind the heel of the other. In these cases lengthening of the offending muscle alone may not be adequate and a femoral derotation osteotomy may be required.

Hyperactivity of the adductors may result in a "scissor gait" with the legs alternately crossing behind each other. This is extremely disabling. In these cases adductor tenotomies may be performed removing the adducting effect of some of the muscles. A neurectomy of the anterior branch of the obturator nerve may also be considered which reduces the stimulation of the remaining muscles which have adduction effects.

Flexion contractures are common, possibly caused in part by the fact that the children spend a large proportion of the day in a seated posture. This lack of extension can cause problems when the child attempts to stand upright, or during the later part of stance phase when walking. To compensate for the lack of hip extension, lumbar lordosis is often increased. Division and sliding of the insertions of the flexors may reduce the flexion contracture. However, the degree of functional improvement depends to a certain extent on the ability of the extensors to utilise the increased range of motion.

There is considerable debate within the orthopaedic profession concerning the optimum programme of surgery in cerebral palsy. Some consider that the number of operations should be kept to a minimum and performed one at a time as the need becomes apparent. Others consider that it is preferable to perform multiple operations on the one occasion. The arguments for these alternative approaches concern the inter-relationships of the surgical procedures and their effects on function, and the frequency and length of periods of hospitalisation.

The arguments for and against orthopaedic surgery in cerebral palsy are complex. These relate to the desired objectives of the surgery itself, the quality of the function that results in the short term and long term, and the relative merits of a surgical approach compared with the other methods of management. The problems of objective evaluation of the outcome of the other management procedures with cerebral palsy apply equally to orthopaedic surgery.

Many of the orthopaedic procedures involve the modification of spastic muscles which had either produced a deformity or impeded function. If the operative procedure does not permanently remove the effect of the muscle there is the potential danger of further deterioration of that muscle, such as additional contracture, and the re-occurrence of the original problem. Indeed it can be argued that the operative procedure itself, while producing an immediate and desirable short term improvement may actually accelerate the process of further deterioration. This is particularly so, for example, with the T.A. lengthening. Clinical evidence suggests that the triceps surae become more spastic after surgery. The lengthened tendon may permit adequate dorsiflexion to gain heel contact with the ground but this is likely to be a temporary situation until the muscle contracts further. Obviously further surgery is implied. It can be argued, however, that the short term gain of heel contact is justified, particularly as the operative procedure is relatively simple. The additional lengthenings necessary in later years may be seen as an intended programme rather than as a response to failures.

Perhaps the most significant argument against T.A. lengthenings is the fact that despite the improvements in function as a consequence of an increased range of dorsiflexion, the plantarflexors themselves may not function well as active motor units. This can cause problems in the attainment of push-off in late stance.

Perhaps the clearest argument for an orthopaedic approach is in the case of the child with spasticity of the adductors causing a "scissor gait". If this problem is severe the child is virtually precluded from any significant progress in walking ability. Adductor tenotomies are likely to result in a major functional improvement. This releases the child to develop his walking ability. Despite the period of post-operative recovery necessary, this approach is likely to be more satisfactory in the long run than prolonged periods of physiotherapy or attempts to use cumbersome orthoses.

Orthopaedic surgery, however, like the other management methods, is likely to be more beneficial to the child if considered as part of an integrated programme rather than as a total solution in itself.

1.4 THE USE OF POLYPROPYLENE ANKLE-FOOT ORTHOSES IN THE MANAGEMENT OF CEREBRAL PALSIED CHILDREN IN DUNDEE

1.4.1 Clinical Service

Polypropylene AFOs have been used in the management of CP children in Dundee for about ten years, (Anderson and Meadows,1979, Anderson,1983, Meadows et al.,1980). The pattern of referral and the structure of the orthotic service have altered significantly within that period. These have been due to changes within the Departments of Orthopaedics and Paediatrics, the establishment of the Handicapped Children's Service which co-ordinates the therapy involvement, and the development of the clinical and technical services at Dundee Limb Fitting Centre. The latter developments have resulted in the establishment of Tayside Rehabilitation Engineering Services.

In the early years the referrals were made by the Children's Orthopaedic Service. The children were usually the older ones, often of school age. They were referred for orthoses in response to a variety of orthopaedic problems. These were often related to gait problems caused by spasticity and frequently the classic one of toe-walking. A significant proportion of the referrals was for the fitting of orthoses following surgical procedures such as T.A. lengthenings. Footwear adaptations such as heel wedges, flares, insoles and toe caps were common.

The children were referred to the orthotic clinics held at Dundee Limb Fitting Centre and the assessment, prescription and supply processes were included within the routine orthotic service.

The development of community screening clinics within the Tayside Area has greatly improved the early detection of cases of cerebral palsy. Once the children have been noted to have problems they are referred to Armitstead Child Development Centre for a two-week period of assessment. During this time they are assessed by a wide range of professionals including physiotherapists, an orthotist and a rehabilitation engineer. Subsequent to this period of multi-disciplinary assessment an integrated management programme is determined.

The most significant consequence of the screening programme as far as the orthotic involvement is concerned is the much earlier age at which the initial contact with the child is made. This in turn has altered the spectrum of problems with which the child presents and the objectives of the management programme.

In previous years the referrals to the orthotic service were primarily by orthopaedic surgeons with requests for orthoses in response to the orthopaedic problem which had developed. Now the referrals are effectively from the paediatrician when the child is sufficiently young that orthopaedic problems have not yet developed. This has resulted in a change of emphasis in the orthotic management. Whereas in previous years the orthoses were used primarily to solve orthopaedic problems they are now used to prevent the development of orthopaedic problems. Even more significantly a greater awareness now exists of the breadth and complexities of the child's functional requirements and the role that orthoses may play in the attainment of function.

The clinic team concerned with the physical management of the child consists of physiotherapists from the Handicapped Children's Service, an orthotist and a rehabilitation engineer from Tayside Rehabilitation Engineering Services and an orthopaedic surgeon from the Department of Orthopaedics. All of those involved in the team have developed a special interest in cerebral palsy.

The multi-disciplinary team approach which has been developed permits the integration of the physiotherapy, orthotic, chemotherapy and orthopaedic approaches to the management of the child's physical

Fig. 1.8

AFOs maintain the foot in a functional position.

problems. Although the child's management programme is formulated by the complete team there are times when the emphasis may be on any one aspect. Thus the orthotist alone may be involved or the physiotherapist.

During the past ten years over one thousand AFOs have been produced for about 150 children. Most of these were produced in the last five years reflecting the increase in awareness of the role that AFOs can play in the management programme.

1.4.2 Management Objectives

Polypropylene AFOs may be used to attain a wide range of management objectives. The details of these depend on the particular problems with which the child presents. It is possible, however, to divide the management objectives into two main categories - functional and orthopaedic.

Functional Objectives

AFOs are used to prevent the foot adopting an equinus position because of plantarflexor spasm. By maintaining the foot in a functional position, approximately plantigrade, the child is permitted to develop his functional abilities, (Fig. 1.8).

The most fundamental ability is the attainment of independent standing balance. This is important from the point of view of the child's daily activities and also because it permits the physiotherapist to adopt a "hands off" approach to therapy.

Walking in a controlled fashion is obviously one of the most desired objectives. It may be necessary with the more severe children to use various walking aids such as sticks or wheeled

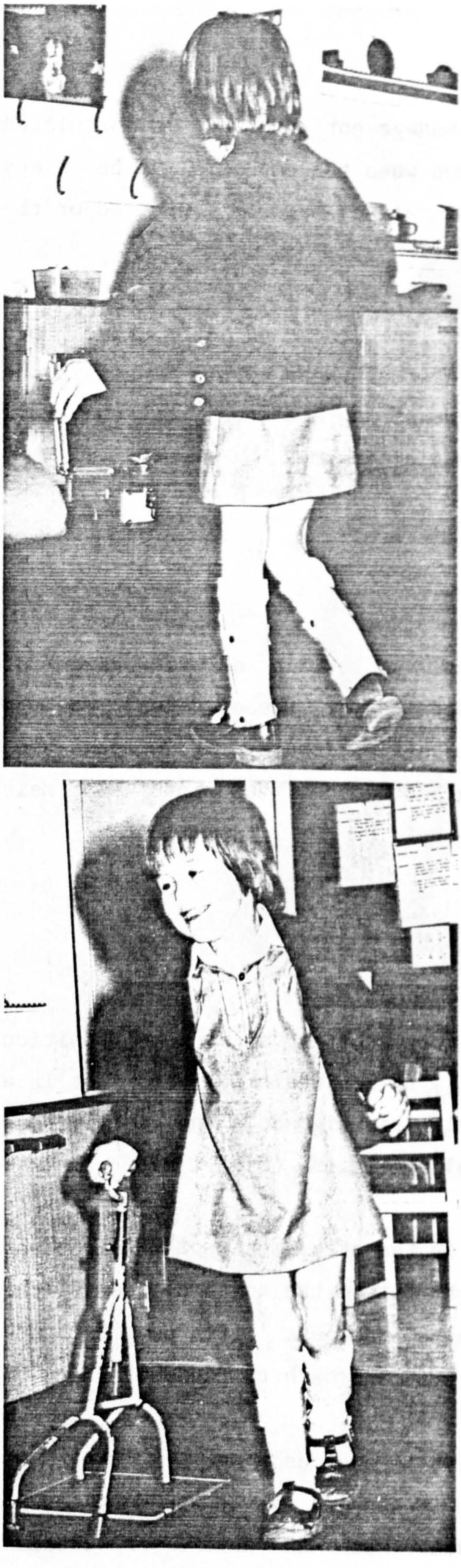


Fig. 1.9

Controlled walking.

Top - unaided.

Bottom - using stick.

walking frames (rolators) in addition to AFOs, (Fig. 1.9).

Very important, but perhaps not so obvious, is the ability to rise from the ground to standing. This is often a very difficult task for a child to perform but one which is functionally very important, (Fig. 1.10). If a child is unable to do this it means that whenever he falls over, which may be frequently, he has to crawl to a piece of furniture or a wall to use it to assist him to stand up. This is further complicated if he is outside.

The characteristics of the AFO may require to be slightly different for optimum performance of these different functions and compromise may be necessary. The overall objective of improving the child's functional abilities is to allow him to explore his environment as an infant, thus stimulating his development. It is to be hoped that he would attain his developmental milestone without falling too far behind when compared with a normal child. If his independent function develops to a sufficiently high level, and assuming he is of adequate intelligence, he may then be able to cope with a normal school environment.

Of great importance is the child's ability to function at a sufficient level to participate in the breadth of activities enjoyed by his normal peers and family.

Orthopaedic Objectives

AFOs can be used to respond to a number of orthopaedic problems or to prevent their occurrence. These problems may relate to the ankle-foot complex itself or elsewhere. Hypertonicity in the plantarflexors may result in the ankle adopting a plantarflexed attitude. In this situation the plantarflexors are in a shortened state. If this is allowed to persist for significant periods of time the muscles may become contracted permanently. The range of

Fig. 1.10

Rising to standing.

dorsiflexion of the ankle, active or passive, will become restricted. This has adverse functional implications. The muscles themselves will also lose their contractile properties and will therefore function less well as active motor units.

AFOs are used to prevent the ankle adopting a plantarflexed attitude and thus to maintain the muscles in an elongated state. In this way the onset of contractures may be avoided or at least minimised. If the child is severely involved AFOs for night use in addition to those used during the day may be indicated. With the less-severely involved children, night AFOs alone may be adequate if day AFOs are not required for functional purposes. The child who spends most of the day seated may also require AFOs to prevent contractures. This is true even if the child is hypotonic if the feet are allowed to dangle unsupported by a foot plate.

If a contracture of the plantarflexors has occurred it is possible to reduce it gradually by the use of serial AFOs. In this case a number of AFOs set at increasing angles of dorsiflexion are used with changes at about monthly intervals as the contracture is reduced. Once the contracture has been reduced to a satisfactory condition continued use of night or day AFOs may be appropriate to prevent re-contracture.

If prevention or reduction of contracture has failed, surgery such as T.A. lengthening may be necessary. In these cases AFOs are used to maintain the ankle attitude and the elongation of the muscle-tendon combination after removal of the plaster casts. Thereafter day or night AFOs may be indicated to prevent further contracture of the muscle belly.

If the child's ankle is constantly in a plantarflexed attitude, either because of the hypertonicity or contracture of the plantarflexors, significant problems may occur at the knee. The child will have great difficulty attaining standing balance or

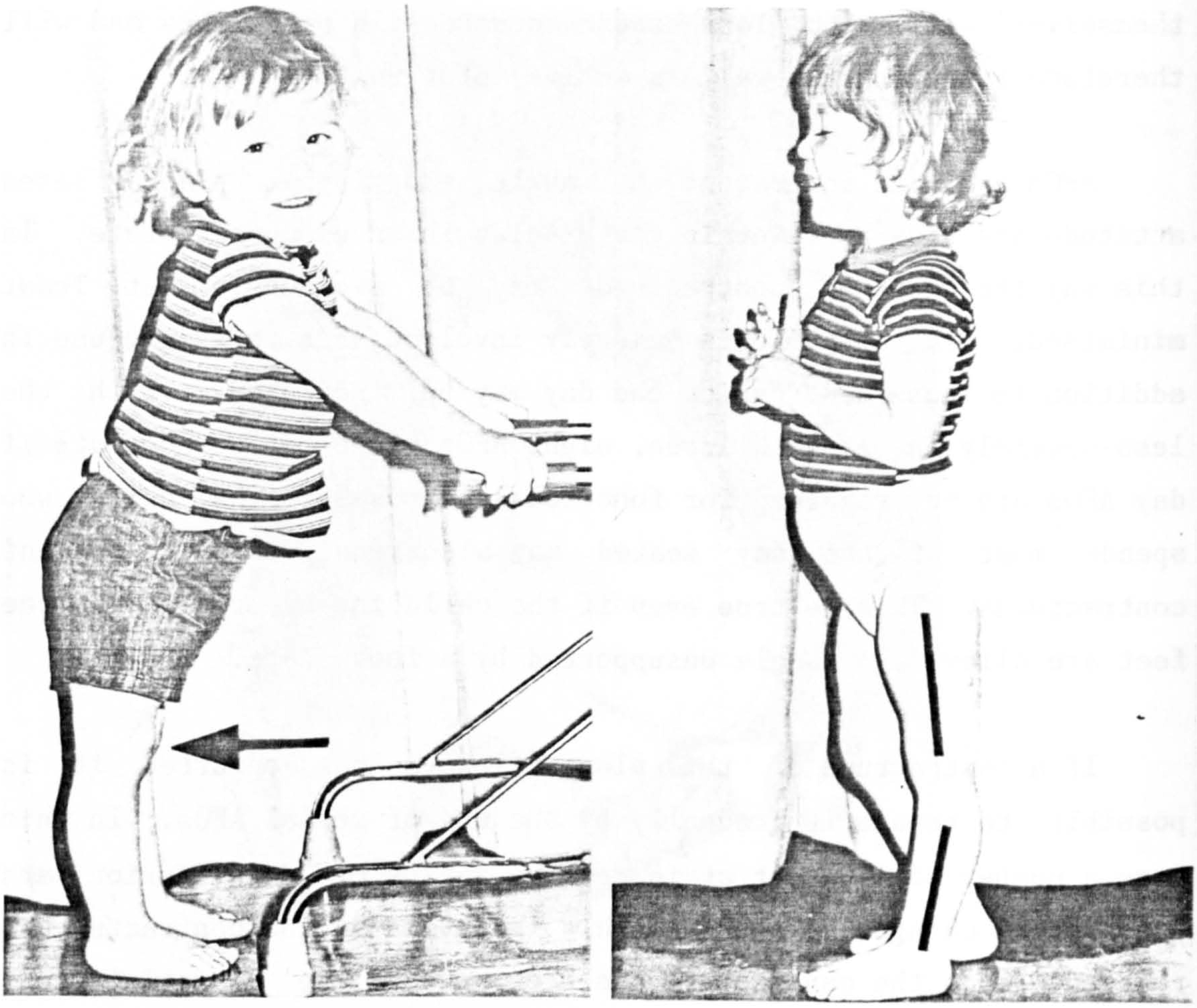


Fig. 1.11

Uncontrolled plantarflexion (left) will tend to cause hyperextension of the knees as illustrated by this child who was lost to follow-up for one year during which the AFOs were not worn (right).

controlled walking. He will tend to adopt either of two manoeuvres in response to his inability to attain a plantigrade or dorsiflexed ankle. He may adopt an attitude with flexed hips and knees, and stand on tip-toe - often with an even more plantarflexed attitude. He may however, choose to maintain heel contact with the ground and allow his lower leg to lean backwards as necessitated by the ankle plantarflexion, (Fig. 1.11). In this case he will need to lean his trunk forwards to maintain his balance. He achieves this by excessive hip flexion but also by allowing his knees to be forced backwards into full extension. If this persists the knees will tend to become lax and eventually considerable hyperextension will result. Not only will this cause functional difficulties but it is undesirable for structural reasons. Eventually permanent joint deformities may occur which will pose serious orthotic problems in later life as well as being severely functionally disabling.

AFOs, therefore, are used to maintain the ankle in a dorsiflexed attitude, thus permitting the lower leg to lean forward while maintaining heel contact. This prevents the knees from being forced into hyperextension and permits flexion if desired.

A very common and serious problem encountered in cerebral palsy is "rocker-bottom" or "broken" foot, (Fig. 1.12). This may occur in cases where the child walks with the ankle in constant plantarflexion. Initially the weight will be borne on the forefoot. This places extremely high loads on the midfoot structures. Eventually the ligamentous structures become lax, the integrity of the joints is lost and the midfoot collapses. This condition is frequently overlooked as it is easily disguised by the wearing of shoes. From the outside it may look as if the foot is normally shaped with a plantigrade ankle. Examination will reveal, however, that the hindfoot and ankle joint remain in a plantarflexed attitude, often with a vertical talus, with the forefoot dorsiflexed and everted relative to the hindfoot. The arch has collapsed and the weight may often be borne on the bony prominences of the

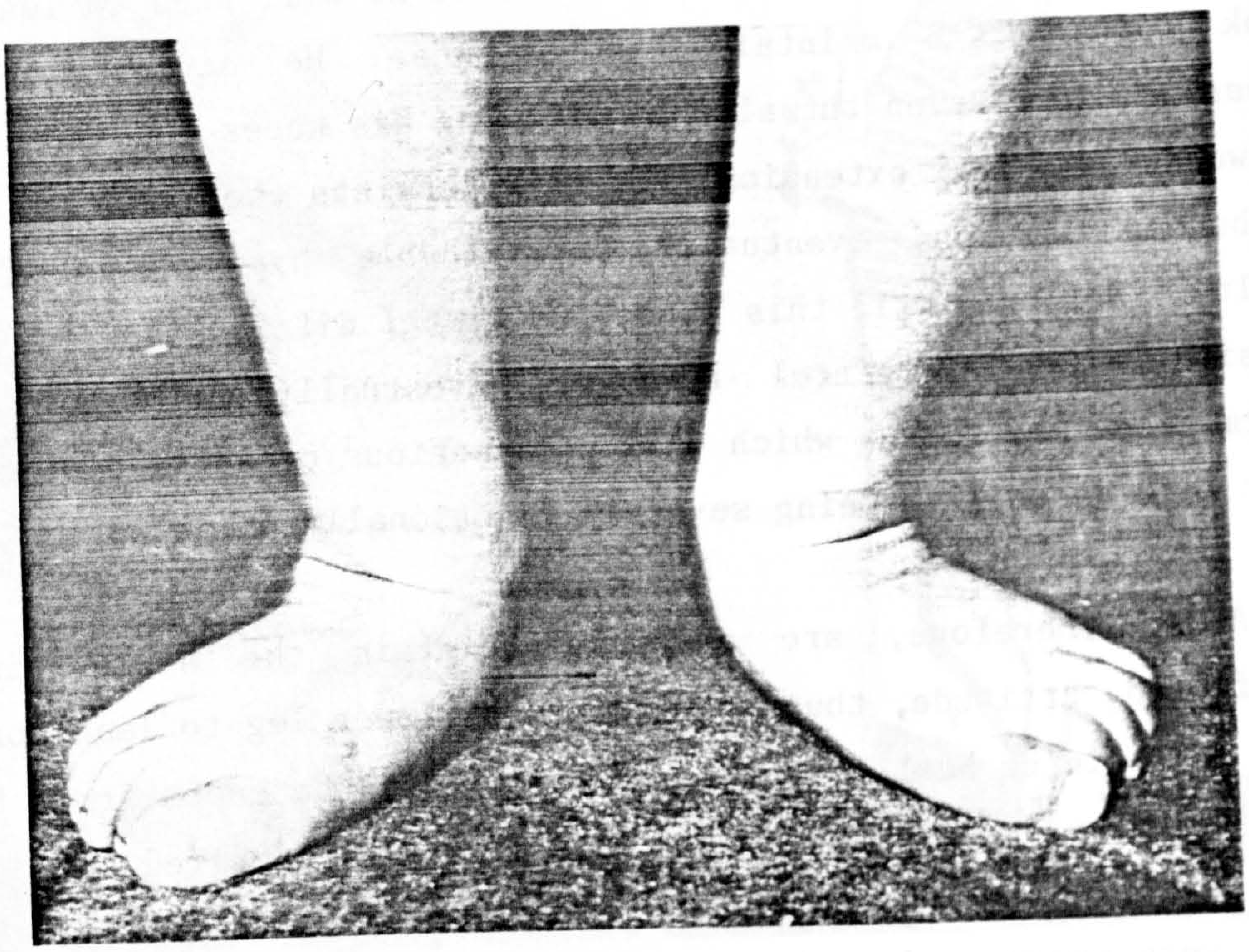


Fig. 1.12

"Rocker-bottom" feet.

midfoot. This may be extremely uncomfortable and is poor functionally. If allowed to persist the joints will grow with abnormal shapes preventing eventual correction. This poses severe problems in the short and long terms in attaining a comfortable fit of orthoses or footwear.

AFOs are used in an attempt to control the initial plantarflexion of the ankle, thus maintaining heel contact. A more even distribution of loading on the foot is attained thus protecting the midfoot structures of the growing child.

Valgus or varus attitudes of the hindfoot may arise as a result of muscle imbalance or hypotonicity. These tend to be self-perpetuating as the deforming forces become greater with increasing deformity. Obviously if this problem is not rectified the deformities may become permanent. AFOs are used to control the attitude of the hindfoot and minimise or counteract the deforming forces.

1.4.3 Production of Orthoses

The polypropylene ankle-foot orthoses are produced using the methods of production which have become standard practice for most thermoplastic orthoses. Slight, but significant, modifications have been introduced in the light of experience in Dundee in the use of AFOs with CP children.

Casting

The ankle-foot complex is examined to check for the existence of any of the orthopaedic problems mentioned previously. These would influence the attitude of the ankle-foot complex chosen for casting. If, for instance, the foot tended to collapse into valgus,

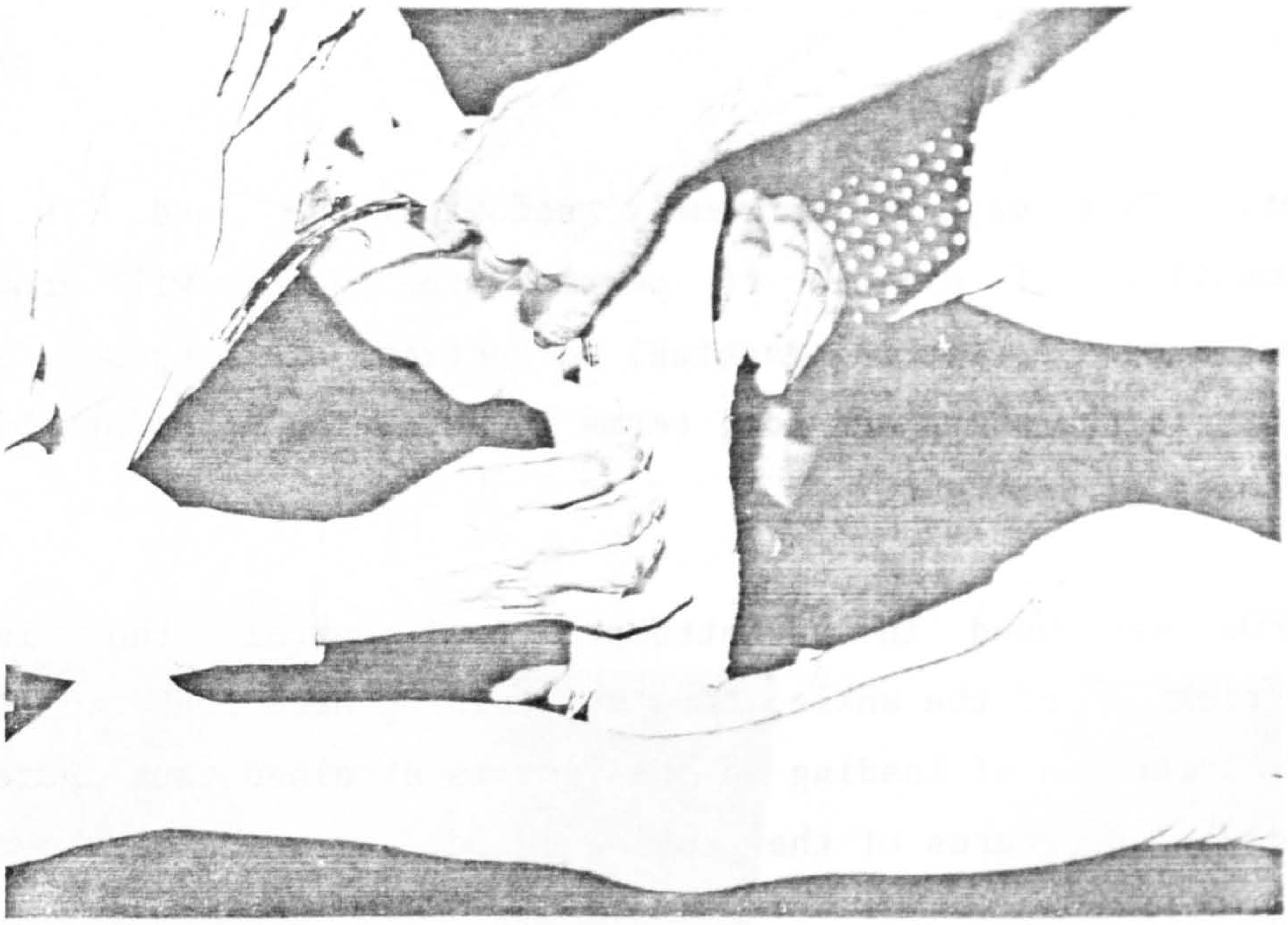


Fig. 1.13

Casting procedure.

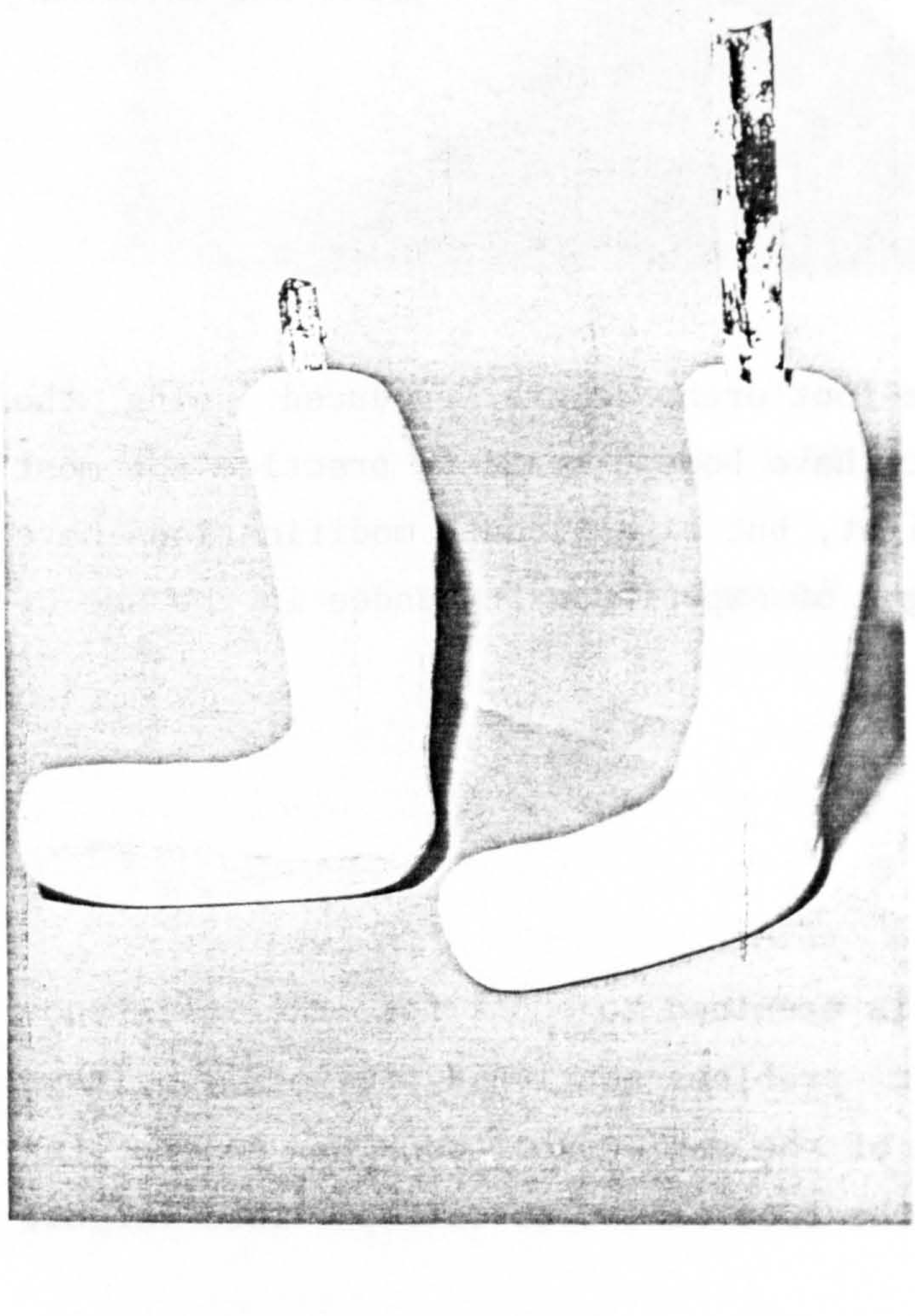


Fig. 1.14

Positive models.

a slightly inverted attitude would be adopted. The angle of dorsiflexion or plantarflexion chosen for the ankle is also extremely critical. This will be discussed later.

A normal wrap-casting process is employed using plaster bandages to create a negative cast of the lower leg. As the plaster sets the orthotist maintains the chosen attitude of the limb segments by hand pressure.

The child is normally cast lying supine on a plinth. It is essential to choose a method which permits the child to relax otherwise it is extremely difficult to maintain the chosen ankle-foot attitude. Some children, especially the younger ones or those who are severely involved, may be afraid of lying supine on a high plinth and will, therefore, become tense. In these cases they are cast lying on a low plinth or even on a floor mat.

Some children may have retained strong primitive reactions which result in increased extensor tone when lying supine. This will obviously increase the difficulty, for example, of dorsiflexing the ankle to achieve the desired attitude when casting. In these cases the extensor tone can often be reduced by placing the child prone with the head turned away from the particular side being cast, (Fig. 1.13). A mirror strategically placed will permit the curious child to see what is happening behind his back thus maintaining the relaxed position.

Selection of the appropriate ankle-foot attitude and the casting posture to be adopted can only be accomplished after thorough examination of the child by the orthotist and physiotherapist.

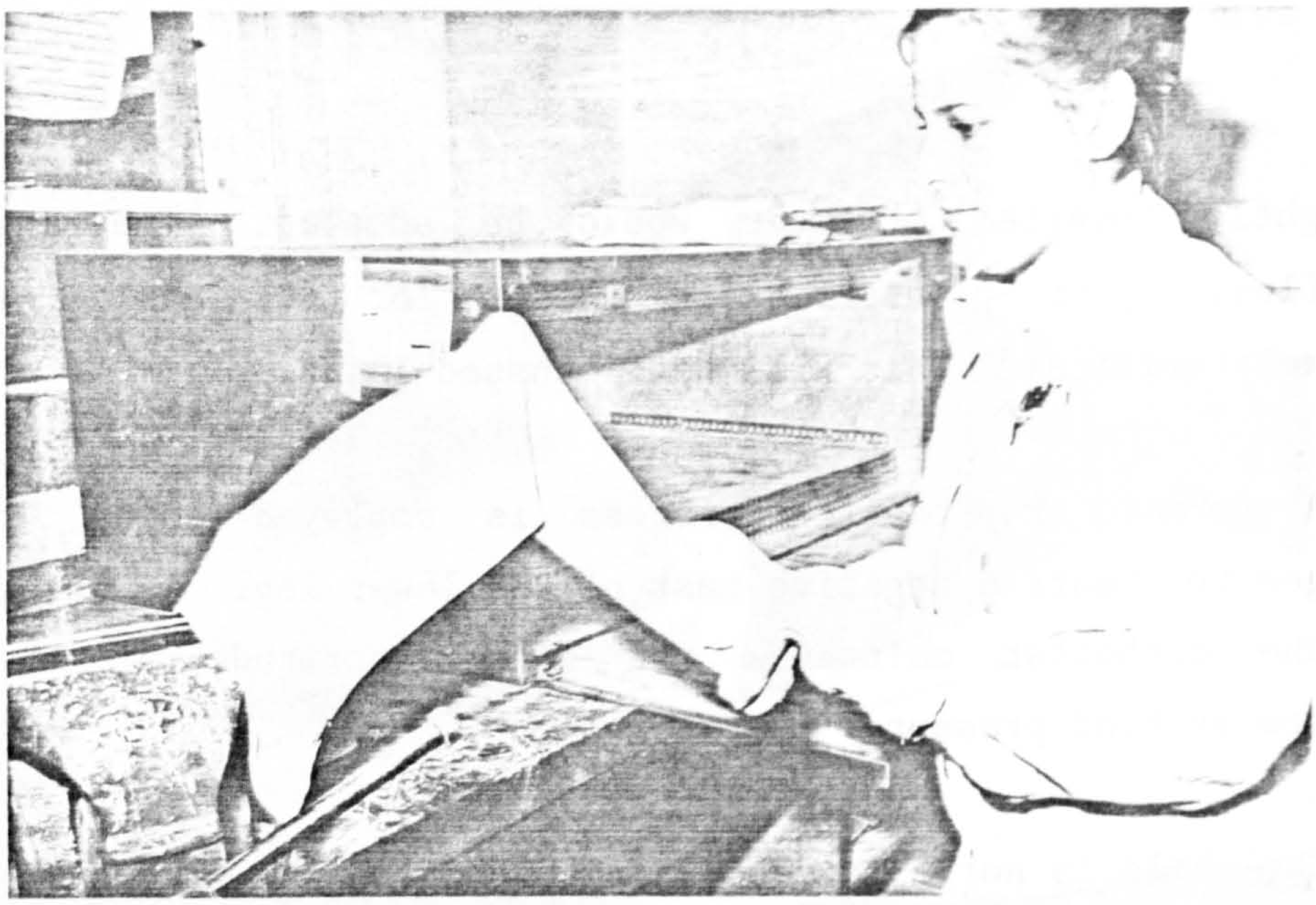


Fig. 1.15

Drape moulding of hot polypropylene.

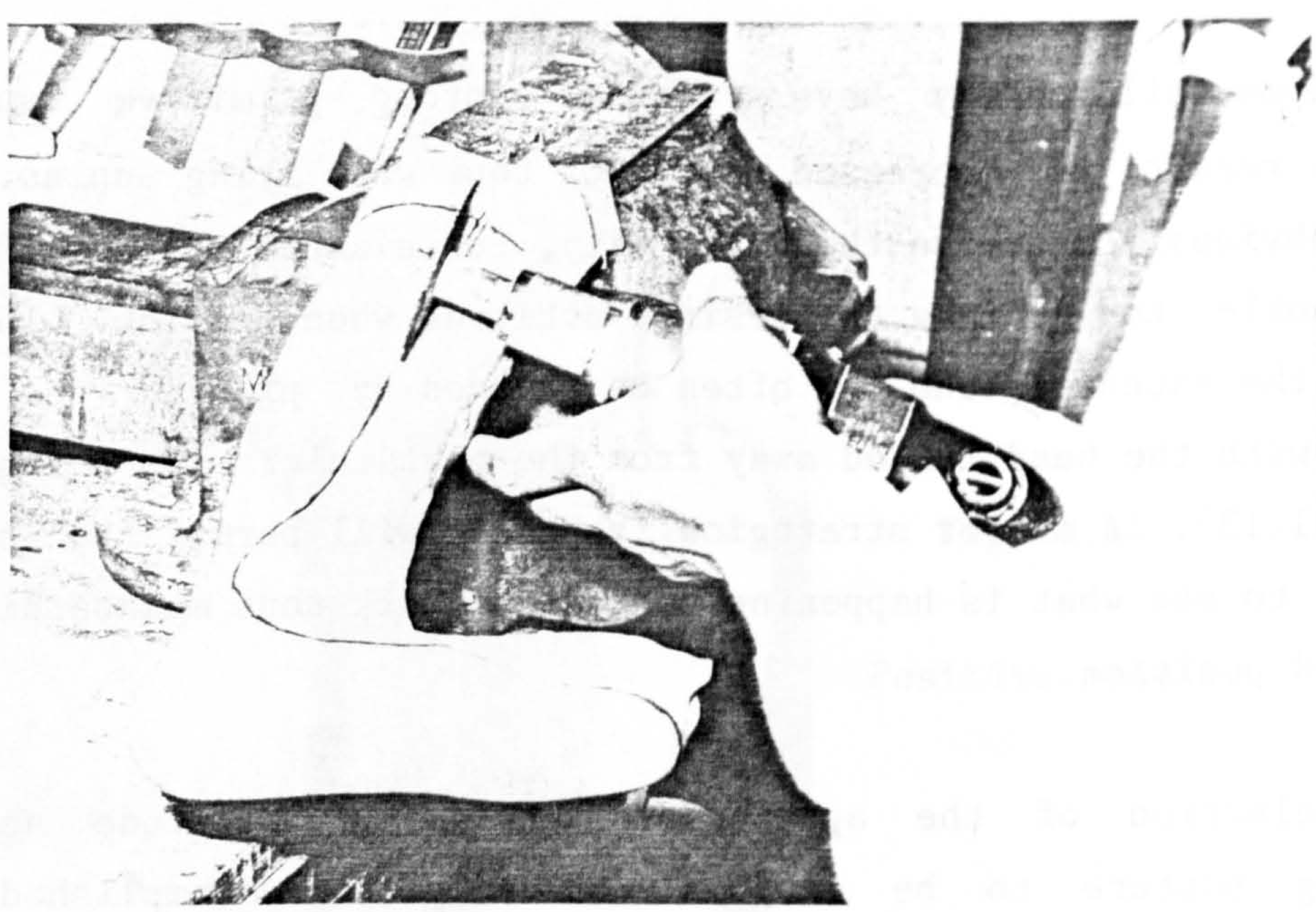


Fig. 1.16

Cutting of cooled polypropylene.

Fabrication

After removal of the wrap-cast from the child it is filled with liquid plaster to produce a positive model. This is rectified by the orthotist who adds plaster to the model where pressure relief is desired, such as over bony prominences, and removes plaster where loads are to be applied to the limb segments. Plaster is added at the top of the calf to prevent the top trimline of the AFO digging in when the child is crawling. Plaster may be removed from beneath the toe section to increase the extension of the toes if this is considered necessary for a given child. Finally the plaster model is smoothed overall, (Fig. 1.14).

The AFO is produced from 3mm polypropylene sheet. This is heated in an oven at 180 degrees Centigrade for ten minutes. The hot plastic is then draped over the plaster cast and worked into the contours to ensure accurate moulding, (Fig. 1.15). It is then firmly bandaged over and left to cool. Vacuum-assisted techniques would improve this part of the process but are not yet available.

The trimline is marked on the plastic and cut with a cast-cutter saw, (Fig. 1.16). The plastic is then removed from the cast, the rough edges smoothed off and Velcro straps attached.

In addition to the top calf strap typical in polypropylene AFOs for adults, an ankle strap is attached at approximately 45 degrees to the calf and foot sections. This is the strap that maintains the ankle in dorsiflexion when plantarflexion spasm occurs and is therefore vital, (Fig. 1.17).

Finally, a small "peep-hole" is drilled in the foot section under the heel. This is used to determine whether the child's heel is contacting the bottom of the AFO and full correction is being maintained.

Fig. 1.17

AFOs ready for fitting.

Fitting

The AFO is applied to the child and a check made to see that any deformity is being adequately controlled and the chosen ankle-foot attitude is being maintained. If not it may be necessary to add small internal plastazote pads to make minor adjustments to the imposed attitude. If this is not adequate an additional rectification or recasting may be necessary.

Any potential, undesirable pressure points must be relieved by easing out of the polypropylene after local heating with a heat gun or by off-loading the points with adjacent plastazote pads.

The footwear must then be fitted over the AFO. In most cases conventional footwear is acceptable and is preferable to orthopaedic footwear for cosmetic reasons. Many modern shoe styles, for example sports shoes, are adequate for use with AFOs.

The principal functional purpose of the footwear is the addition of the walking surface to the sole of the AFO. The footwear plays only a minimal part in the control of the foot attitude, this being achieved by the AFO itself.

It may be necessary to modify the characteristics of the sole of the footwear depending on the prescription details. This may entail wedging or flaring. If the child has a leg length discrepancy a raise may be required.

Once the AFO-footwear combination is considered to be fitting correctly an initial check is made by the orthotist to ensure that adequate function is being provided by the AFO. It may be necessary to alter the heel height to influence the nature of the gait achieved. While some of the changes necessary may be obvious immediately to the orthotist they may not become apparent until later involvement by the physiotherapist.

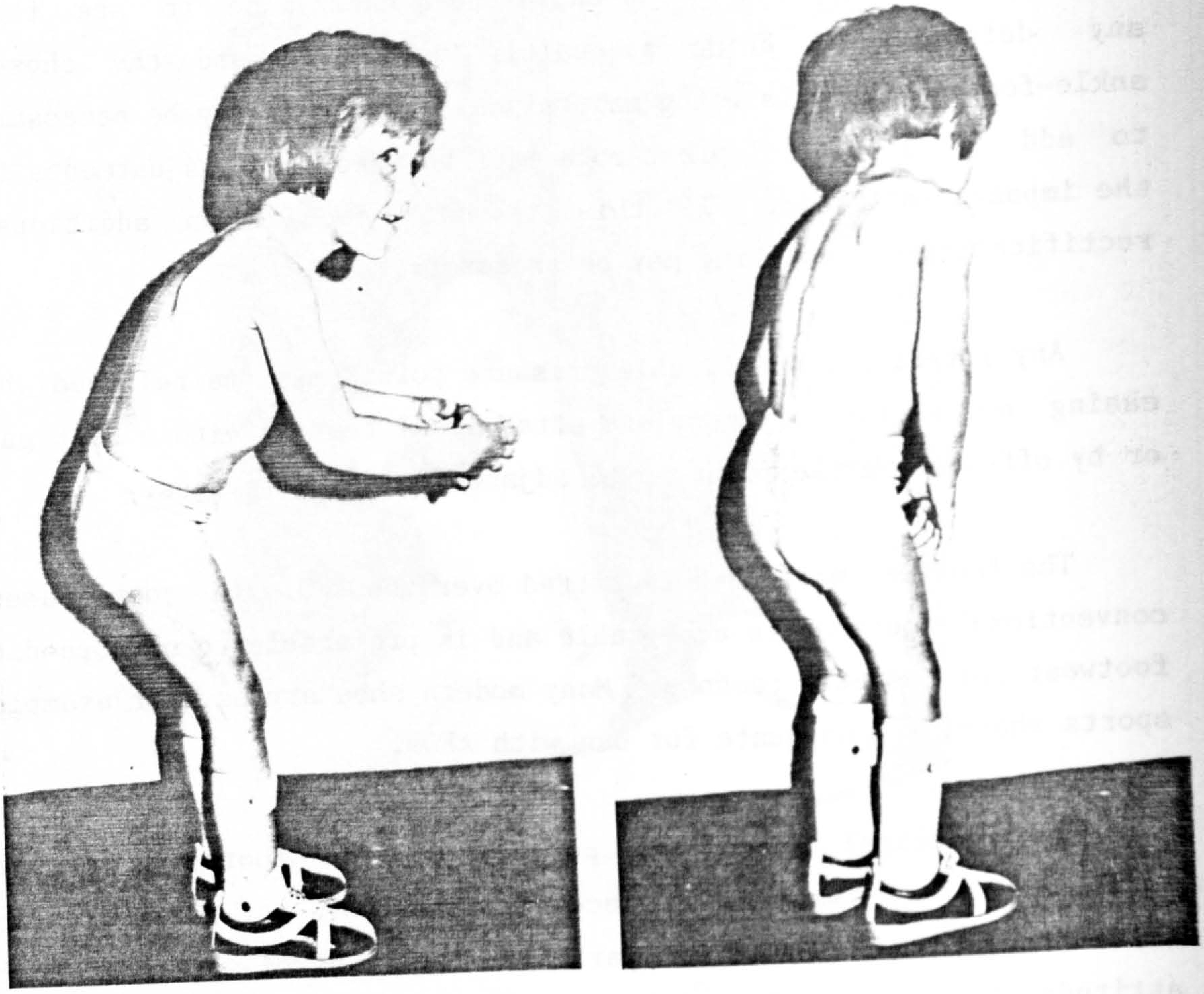


Fig. 1.18

AFOs with increased dorsiflexion (right)
may improve standing posture.

1.4.4 Use of Orthoses

The functional abilities of many of the CP children may improve immediately with the wearing of the AFOs. In these cases the physiotherapist need not necessarily become heavily involved. It is always preferable that the child improves his repertoire of function by learning himself rather than having a programme of formal physiotherapy imposed upon him. Whether this is possible or not depends on many factors including the severity of the disability and the suitability of the characteristics chosen for the AFO-footwear complex. Some children may not necessarily appreciate that their functional abilities have improved with the use of the AFOs. For instance they may not realise that they now have independent standing balance. In these cases the physiotherapist may encourage the children to let go of any support by using toys. In this way the children will gradually become familiar with their newly gained balance.

The quality of independent standing balance is to a certain extent influenced by the characteristics of the AFO-footwear complex. These include, for example, the angle at which the ankle joint is held and the heel height of the footwear, (Fig 1.18). These characteristics become much more critical when considering the more demanding functions such as walking and rising to standing.

The accuracy with which these characteristics are prescribed and attained by the AFO-footwear complex depends on the quality of the child's assessment and the orthotic production techniques. These have improved with the increasing experience of the clinic team. It is now possible with many children to determine these characteristics adequately so that the child's functional abilities are improved satisfactorily. However, with the more severely involved children, or the younger children who are having a first fitting, it is not always possible to predict the fine details of the required characteristics. In these cases they are determined as accurately as possible to permit an initial fitting. Once the child attempts to stand or walk it may become apparent if changes are necessary and if so what they should be. However, the nature of these required changes may not become clear until sometime later.

The physiotherapist is usually the member of the clinic team who spends the longest periods of time with the child and is therefore in the best position to assess the nature of the required changes in the characteristics. This may be achieved by experimentation. For instance, it is possible to place layers of cardboard between the heel of the AFO and the shoe. This effectively increases the heel height and pitches the lower leg further forwards. These small changes may make significant differences in the quality of function and are therefore important.

Unfortunately the ideal characteristics required might not be the same for different aspects of the child's functional repertoire. For instance, the AFO may require to be extremely dorsiflexed to facilitate the complex function of rising to standing but this may be inappropriate for a good standing posture or for walking. In these cases it is important for the physiotherapist to evaluate the relative merits and determine the appropriate compromise for a given child.

With many children, and especially the younger ones, the status of their neuromuscular function may change significantly as they develop. This may imply changes in the required characteristics of their orthoses. It is therefore important that the physiotherapist is alert to this possibility so that if necessary the child will be reassessed and a new prescription determined.

It is important that a daily programme for the use of the AFOs is worked out for any child. This will depend on many factors including the severity of the child's involvement and his stage of development. It may be that he may require to be on the ground for significant periods of time, either sitting or crawling. If this is the case it may be appropriate to remove the AFOs during these periods as their use can sometimes make these functions more awkward to achieve.

In summary, the success to which AFOs may be used in the child's management programme depends on the accuracy of assessment and prescription, the quality of the production techniques, the development of an appropriate daily programme for their use and the constant reassessment of the child and the influence of his AFOs.

1.5 THE INFLUENCE ON GAIT OF POLYPROPYLENE ANKLE-FOOT ORTHOSES

Clinical experience in Dundee has indicated that the use of polypropylene AFOs can have a significant influence on the walking ability of CP children. The degree of success or failure in their use depends on many things including the skills of the clinic team and the nature and severity of the child's disability.

The prescription objectives and the results obtained may differ according to the diagnosis. There are, for instance, significant differences between the functional problems of hemiplegic and diplegic children.

The hemiplegic child has one leg which is essentially normal and thus has the ability to compensate to a certain extent for the functional problems of the involved leg. He is usually able to walk without the use of an AFO, usually in a very asymmetrical fashion. The AFO is used to improve the symmetry of the gait and to attempt to produce a more normal gait pattern.

The diplegic child has both legs involved. Depending on the severity he may not be able to stand or walk without the use of AFOs. The objective of the use of AFOs may be to permit the attainment of a controlled gait. However, the gait pattern considered functionally optimum for the child may not necessarily be a normal one.

As mentioned above the influence that AFOs may have on the gait of CP children varies considerably depending on the details of the individual child's disability and the chosen prescription objectives. Nevertheless there are certain features of the influence of AFOs on gait which are common to all CP children while perhaps varying in extent.

The gait of CP children is characterised by the poor quality of

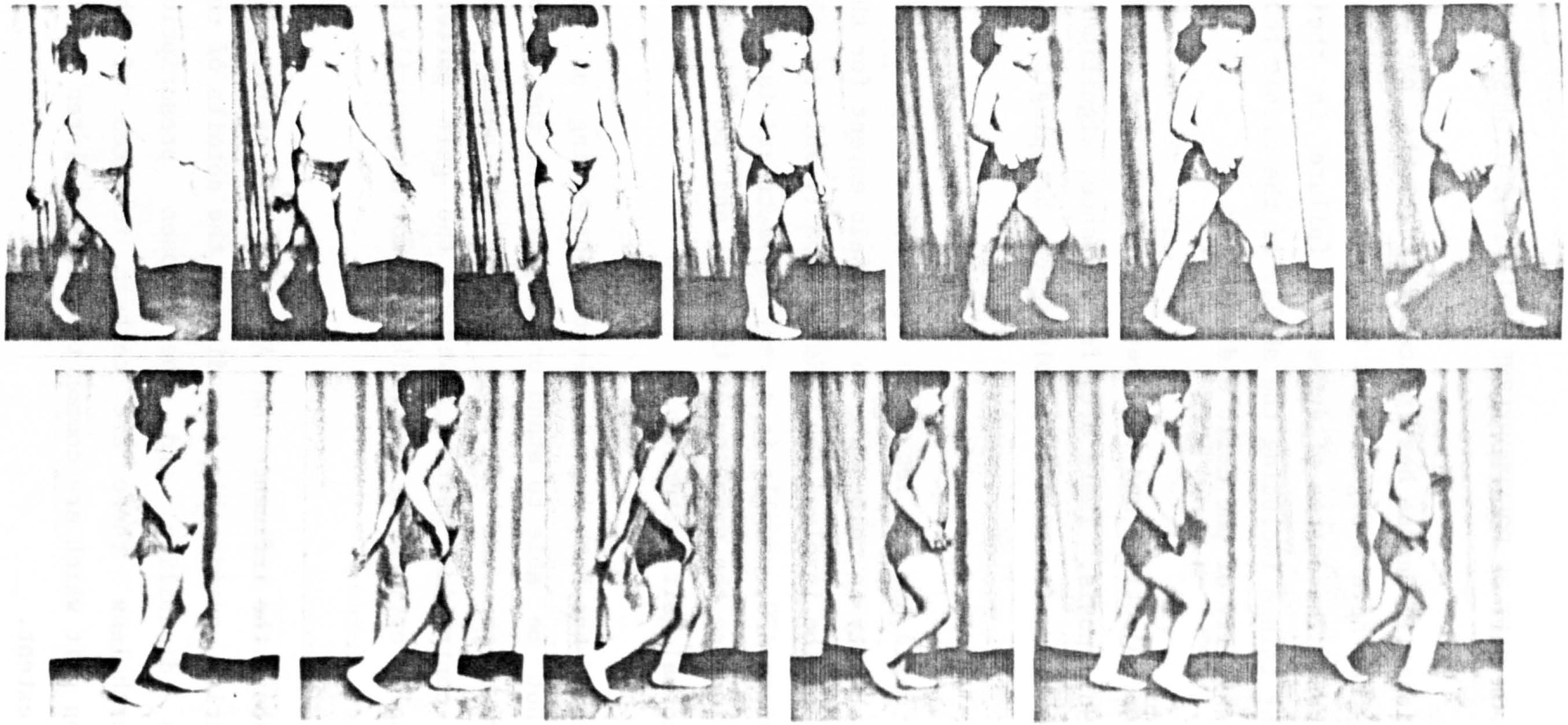


Fig. 1.19

Diplegic CP child walking barefoot. The gait is laboured and poorly controlled. Top - there is a lack of ankle dorsiflexion, with knee hyperextension and increased lumbar lordosis. Bottom - when this child wishes to walk faster she adopts a flexed-knee gait.

control displayed. The CP child is unable to respond smoothly to the varying demands of the gait cycle. A jerky, uneven gait results with the joints often moving rapidly between positions of flexion and extension, (Fig. 1.19). The angular excursions of the joints are often excessive. Classically, the child walks on tip-toe with knees either excessively flexed or hyperextended. The gait appears to be laboured and energy-consuming. The step length is frequently small but the cadence relatively high. Consequently the child may progress rapidly across the floor but often with little control of the velocity. He frequently is unable to stop until he runs into a wall or piece of furniture.

Clinical observation suggests that the child has little control of the tensions being generated by the individual muscle groups. Generally the resulting level of the muscle tone appears to vary between extremes of low and high. There may frequently be excessive antagonistic activity.

When AFOs are prescribed and used successfully several changes in the gait may be observed. The most obvious of these is the improvement in the degree of fine control being obtained. The joint excursions may become less excessive with a less rapid alteration between the two extremes, (Fig. 1.20). Generally the child is more relaxed and appears to have a greater degree of voluntary control over his muscle activity and hence leg movements. He may now be able to gain heel contact in early stance phase and may have more normal knee and hip movements.

From a functional point of view he may now be able to control his progress across the floor. In addition to being able to control his velocity he may be able to stop in an open space without having to reach a piece of furniture.

This reduction in spastic muscle activity and improved control of movement may also be observed in other parts of the body.

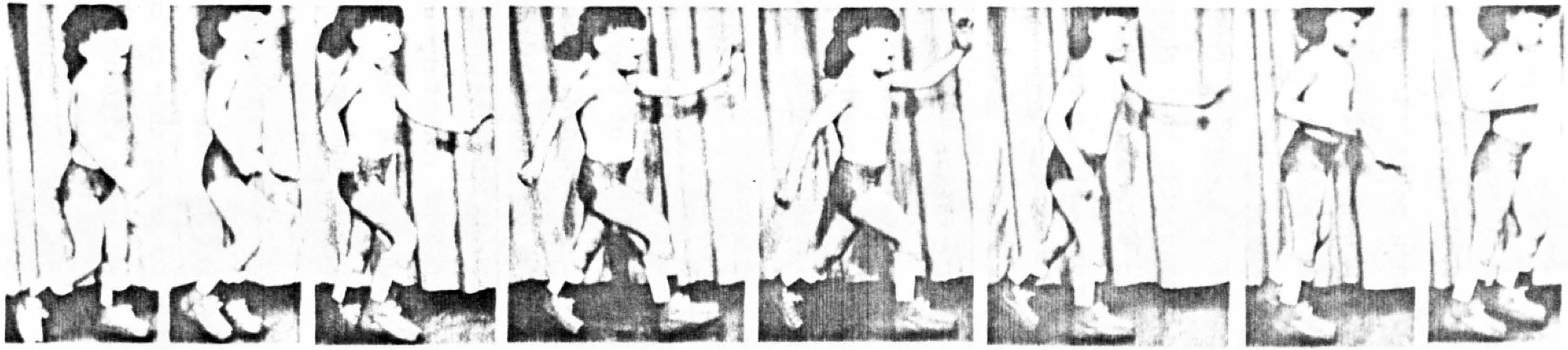


Fig. 1.20

Diplegic CP child walking with bilateral AFOs with cushion heels and rocker soles. This child is now able to walk with a relaxed gait with more normal limb motions. In particular the knee motion is improved.

(Monochrome stills taken from 16mm colour cine film.)

Frequently the motion of the arms may be more normal and relaxed. The spine, too, may be more upright with a reduction of the increased lumbar lordosis common in CP children.

A highly significant observation is the fact that the influence of the AFOs and associated footwear appears to be more-or-less instantaneous with their donning and use. This is typically so with the experienced user. There may, however, require to be a short period of familiarisation with the younger child on the occasion of the first fitting. This may be a matter of minutes or days depending on the individual child.

Significant also is the observation that the influence of the use of the AFO is reversible. When they are removed the child's gait reverts to what it was before the AFOs were donned. Any changes made to the characteristics of the AFOs or the associated footwear will similarly have an instantaneous, but reversible, effect.

Clinical experience has also shown that dramatic changes in the nature of the gait and the quality of the resulting function can arise from very small changes in the characteristics of the AFO-footwear complex. These changes may relate, for example, to the angle of dorsiflexion at which the AFOs are set or the heel height of the footwear.

Clinical experience has shown, therefore, that careful selection of the appropriate AFO-footwear characteristics can significantly improve the quality of the resulting gait pattern. This may in turn influence the details of the management programme and the demands which are placed upon the child and his family. It is thus important that the nature of, and reasons for, the influences of AFOs on gait are understood fully in order to develop improved guidelines for their use.

There are many different schools of thought which attempt to explain the observed abnormalities of function displayed by cerebral palsied children, and in particular their gait patterns. As mentioned previously these are all based on observations of the same salient features but have resulted in differing attempts at explanations. It is upon these different understandings of the same problems that the differing management methods have evolved.

Some of the theories developed are biased towards the neurological aspects of the child's disability. Any influences on the child's gait, either by physiotherapy techniques or the use of AFOs, are explained by the inhibition of certain undesirable reflex patterns and the facilitation of more useful ones. These are often accomplished, it is asserted, by the control of certain limb segments or joints either by the therapist's hands or by an AFO. Other possible explanations may concentrate on the orthopaedic or mechanical aspects such as joint contractures or the imbalance of antagonistic muscle groups.

It is probable that most of these differing schools of thought are neither completely correct nor completely incorrect. It is likely, however, that a more accurate explanation may result from consideration of both the neurological and biomechanical aspects.

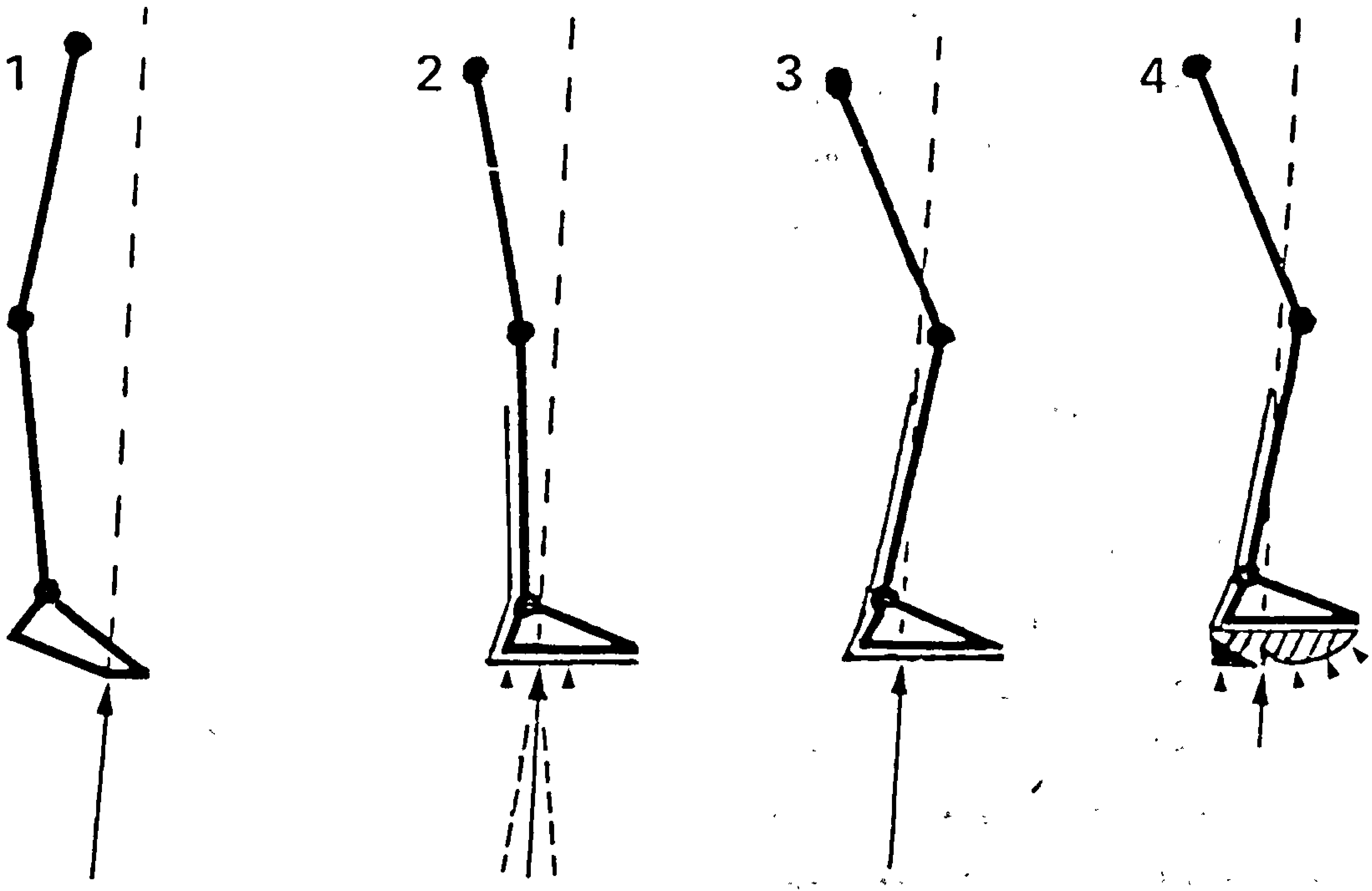


Fig. 1.21

Effect of AFO & footwear characteristics on external moments generated at joints.

1 If ankle-foot attitude is uncontrolled high moments may be generated.

2 Alterations in AFO characteristics influence origin and direction of force vector.

3 Attitude imposed on shank moves knee and hip joint relative to vector.

4 Cushion heel reduces impact forces, rocker sole alters centre of pressure throughout stance.

1.6 RESEARCH PROGRAMME

It was because of the lack of real understanding of the influence of AFOs on the gait of cerebral palsied children and the obvious necessity for improved clinical practice that the research programme reported in this thesis was set up.

Consideration was given to the nature of the gait patterns of CP children, observed clinically, and the influence on it of AFOs. The research objectives were established and the measurements considered appropriate were determined. The measurement techniques were developed and the experimental programme conducted.

1.6.1 Research Objectives

Observation of the gait of CP children indicated that the joint motions were frequently abnormal. Typically they were poorly controlled with extremes of flexion and extension in comparison to normal children. It appeared also that the effort required for locomotion was considerably greater. The use of AFOs frequently altered the observed joint motions and in many cases appeared to reduce the effort required and to improve the control. It was considered necessary to examine the gaits of CP children to gain an understanding of the characteristics of the abnormalities, and the influence of AFOs.

It was known that the use of AFOs and associated footwear adaptations in other pathologies could influence the motions of the joints of the leg, the characteristics of the ground-to-foot force vector during stance phase and thus the external moments imposed on the joints. It was reasonable that similar influences were likely to occur when AFOs were used with CP children, (Fig. 1.21), while perhaps differing in detail.

It was considered that measurement of the kinematic and kinetic factors of gait would reveal the abnormalites in CP gait and the influence of AFOs. These measurements included the angular motions of the hip, knee and ankle joints and the moments being generated at the joints by the ground-to-foot force vector. The latter measurements were considered important as they gave an indication of the demand being placed on the neuromuscular system.

1.6.2 Measurement Techniques

A range of measurements were necessary relating to the biomechanical aspects of the gait pattern itself, the mechanical characteristics of the AFOs and footwear, and the activity of the muscles of the lower leg.

Gait Analysis

The principal part of the experimental programme was biomechanical gait analysis. This was intended to yield information on the motion of the joints of the leg and the nature of the ground-to-foot force vector.

This analysis was conducted on one leg during the stance phase of the gait cycle only. The external moments being applied to the hip, knee and ankle in the sagittal plane were derived, indicating the demand on the neuromuscular system.

The gait analysis was conducted both with and without the use of AFOs and associated footwear. In this way the influence of these on the gait pattern was measured.

In connection with the gait analysis it was necessary to measure the mechanical characteristics of the AFOs and associated footwear. In the case of the AFO the characteristics considered relevant were its stiffness and the angle at which it maintained the ankle joint in the sagittal plane. The characteristics of the footwear measured were the raise, wedge and rocker effects of the sole.

Parallel to these studies gait analysis of normal children was conducted to gain similar information for comparative purposes.

Muscle Activity Monitoring

In order to obtain information on the influence of the AFO on the muscle tone and phasic activity, the loads being generated between the limb segments and the AFO, and the activity of some of the muscles of the lower leg were monitored. This was conducted during both long term and short term tests.

During the long term tests the magnitudes and fluctuations of muscle tone over a period of several hours, for example during a school day, were monitored. During the short term tests the muscle tone and e.m.g. activity were monitored over a number of individual gait cycles.

1.6.3 Research Subjects

The children selected for inclusion in the research programme were already patients whose orthotic management was being conducted by Tayside Rehabilitation Engineering Services. The purpose of the research programme was explained to the parents and their agreement to participate obtained.

The experimental data were obtained in the course of the routine clinical service. Although the time required to conduct the gait analysis session was sufficiently long to require an appointment specifically for this purpose no other alteration to the child's routine management was entailed. Any AFOs or associated footwear adaptations which were involved in the experiments were those with which the child had already been supplied and which were considered to be clinically optimum for that child at the time at which the measurements were obtained. All of the children selected were able to walk without the use of walking aids such as sticks or crutches. Most of the children were able to walk without their AFOs but some were unable to do so.

In addition to the CP children some normal children were included in the research programme to obtain data for comparative purposes.

CHAPTER 2

LITERATURE SURVEY

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This chapter presents the result of a survey of the literature relating to the gait of cerebral palsied children and the influence of AFOs on gait. Particular attention was paid to those papers relating to biomechanical studies. Papers concerning the gait of normal children were also scrutinised for comparative purposes.

The papers reviewed in the survey are listed in Appendix I.

2.2 RESULTS OF SURVEY

During the past three decades a considerable amount of research work has been conducted on the gait of adults. This has included biomechanical analysis of both normal and pathological gait. In comparison there has been very little work reported on the gait of children. Most of that which has been reported relates to handicapped children, there being only a few papers on normal child gait to permit comparison.

This survey has shown that the studies of the locomotion of cerebral palsied children which have been reported can be divided into two broad categories. The first embraces the kinematic and kinetic measurements of gait. These papers relate principally to the measurement of the temporal factors of gait - phasing, cadence etc. - and the angular excursions of the joints of the legs. There are, however, only two papers which attempt to measure the external joint moments, (Simon et al.,1978, Sutherland and Cooper,1978). There is only one paper which examines the influence of ankle-foot orthoses on gait, (Simon et al.,1978). Fortunately this paper is an authoritative one and includes measurement of the external moments. The second category relates to the electromyographic activity of the legs, very often in relation to the effects of surgical procedures. Some of the papers contain elements of both categories but tend to be biased to one or other.

Much of the literature on the locomotion of normal children is of a qualitative nature relating to the development of gait from crawling, through the normal stages of standing and assisted walking, to the eventual attainment of independent, upright locomotion and thence the emergence of a mature, adult-like pattern. There have, however, been a few quantitative studies on normal gait. These again tend to be concerned with the kinematic factors of temporal measurement and joint motions. Very few contain any kinetic data and in none is there any mention of the external moments generated at the joints.

2.2.1 Gait Analysis of Cerebral Palsied Children

There were many stated aims of the studies reported on CP children. The most common was to gain basic information on the kinematic and kinetic characteristics of CP gait. This was frequently accompanied by the evaluation of the particular method of gait analysis as a reliable scientific means of assessment or as a potential clinical tool. Occasionally the purpose of the study was to examine the nature of extreme, and clinically problematic forms of CP gait, (Simon et al.,1978, Sutherland and Cooper,1978), or the effect on gait of treatment, (Baumann et al.,1980, Fleiss et al.,1980, Perry et al.,1981, Riso et al.,1980, Simon et al.,1978). In some cases the investigators recognised the absence of equivalent information on normal children and included some normals in their studies, (De Bruin et al.,1980, Parker and Bronks,1980, Skrotzky,1983, Van der Straaten and Scholten,1978).

The measurement techniques used varied from the most simple footprint on paper studies, (Levine and Knecht,1980, Ogg,1963), to those possible in sophisticated, instrumented gait laboratories, (Letts et al.,1975, Simon et al.,1978, Sutherland and Cooper,1978). Cine-photography has been widely used to obtain kinematic information, at varying levels of complexity with multiple and high-speed cameras, (Baumann et al.,1980, Feldkamp,1978, Fleiss et al.,1978, Parker and Bronks,1980, Simon et al.,1978, Skrotzky,1983, Sutherland and Cooper,1978, Sutherland et al.,1981, Van der Straaten and Scholten,1978). In one case lights attached to the child's limbs produced trails across a photographic plate, (Aptekar et al.,1976b), and in another multiple, sequential Polaroids were used, (Holt et al.,1974). Kinematic measurements were obtained using a range of instrumentation from rulers and protractors to semi-automatic computer systems. In one case the use of a

TV-computer gait analysis system is reported, (Letts et al.,1975). Electrogoniometers attached to the child have also been used. These have been of the single-axis potentiometer design, (Hershler and Milner,1980, Perry et al.,1981, Riso and Makley,1981), and the complex, multi-axial, parallelogram linkage type, (De Bruin et al.,1980, De Bruin et al.,1982). Footswitches attached to the heels and toes have been used to assist the identification of the phases of the gait cycle, (De Bruin et al.,1980, De Bruin et al.,1982, Letts et al.,1975, Perry et al.,1981, Riso et al.,1980). In some cases e.m.g. measurements have also been taken in addition to those measurements mentioned above, (Perry et al.,1981, Riso et al.,1980, Riso et al.,1981, Simon et al.,1978, Sutherland and Cooper,1978, Sutherland et al.,1981). In most cases the tests were conducted either in physiotherapy departments or laboratories depending on the nature of the tests. The child was usually permitted to walk at his desired free-speed cadence, although in some cases this was controlled. In one instance a treadmill was used, (Van der Straaten and Scholten,1978). Force plates were used in only a few cases. (Fleiss,1980, Simon et al.,1978, Sutherland and Cooper,1978).

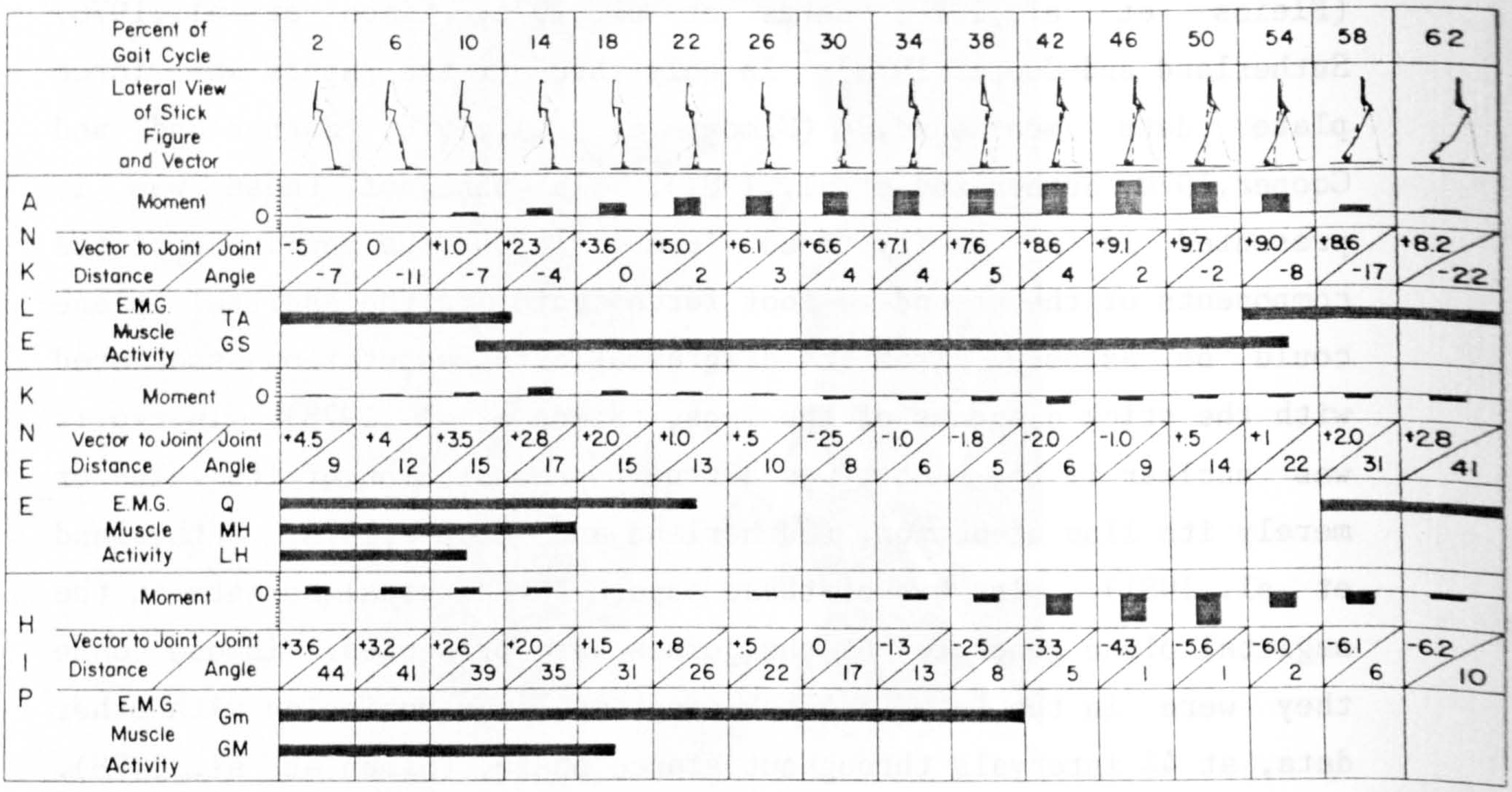
Presentation of the results reflected the principal objective of the majority of the studies of obtaining kinematic data, i.e., temporal information and joint motions. These results were presented in a variety of ways - tabular, bar-chart and graphical. A considerable amount of interest was paid to the analysis of the gait cycle, with the identification of swing and stance phases, double-stance periods, cadence, mean velocity etc., (Feldkamp,1978, Fleiss et al.,1978, Perry et al.,1981, Riso et al.,1980, Riso and Makley,1981, Simon et al.,1978, Skrotzky,1983, Van der Straaten and Scholten,1978). The angular ranges of motion of the joints of the leg in the sagittal plane were also presented by the majority of authors, (Baumann et al.,1980, De Bruin et al.,1980, De Bruin et al.,1982, Feldkamp,1978, Fleiss et al.,1978, Hershler and Milner,1980, Parker and Bronks,1980, Perry et al.,1981, Simon et al.,1978, Skrotzky,1983, Sutherland and Cooper,1978, Van der

Fig. 2.1

Child with body markers and emg leads.
(From Simon et al., 1978.)

Straaten and Scholten,1978). In a few cases stick diagrams of the legs were utilised to present the motions of the limb segments, (Fleiss et al.,1978, Letts et al.,1975, Simon et al.,1978, Sutherland and Cooper,1978). In only three of the papers was force plate data mentioned, (Simon et al.,1978, Sutherland and Cooper,1978, Sutherland et al.,1981). In none of these was it presented in an easily read form. In one the magnitude of the components of the ground-to-foot force vector in the sagittal plane could be assessed from its diagrammatic representation associated with the stick diagrams of the legs, (Simon et al.,1978). In two it was unclear if the vector was a true representation of its value or merely its line of action, (Sutherland and Cooper,1978, Sutherland et al.,1981). In two of these papers the external moments in the sagittal plane generated at the joints were presented. In one case they were in the form of block diagrams, in association with other data, at 4% intervals throughout stance phase, (Simon et al.,1978). In the other they were presented in graph form, (Sutherland and Cooper,1978). In one paper the authors indicate that they have used the technique of predicting ground reaction forces from the calculated values of limb segment accelerations from displacement data, and estimated inertias, (Letts et al.,1975). They did not, however, give any of their results. The accuracy of this method must be held in question because of the difficulties of determining accurate values for each of these variables. In two cases measurements of energy consumption by the analysis of expired air were presented, (Nowotny et al.,1983, Perry et al.,1981).

Two papers are worthy of individual mention. These relate to the investigations of genu-recurvatum in spastic cerebral palsy by Simon, et al., (1978), and of the pathomechanics of progressive crouch gait in spastic diplegia by Sutherland and Cooper, (1978). Both of these papers are from centres which have modern instrumented gait analysis laboratories located in clinical treatment centres. They are both good examples of how quantitative biomechanical gait analysis can be used to improve the understanding and management of



Percent of Gait Cycle	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	62
ANKLE Vector to Joint Distance	-.5	0	+1.0	+2.3	+3.6	+5.0	+6.1	+6.6	+7.1	+7.6	+8.6	+9.1	+9.7	+9.0	+8.6	+8.2
ANKLE Joint Angle	-7	-11	-7	-4	0	2	3	4	4	5	4	2	-2	-8	-17	-22
KNEE Vector to Joint Distance	+4.5	+4	+3.5	+2.8	+2.0	+1.0	+.5	-.25	-1.0	-1.8	-2.0	-1.0	+.5	+1	+2.0	+2.8
KNEE Joint Angle	9	12	15	17	15	13	10	8	6	5	6	9	14	22	31	41
HIP Vector to Joint Distance	+3.6	+3.2	+2.6	+2.0	+1.5	+.8	+.5	0	-1.3	-2.5	-3.3	-4.3	-5.6	-6.0	-6.1	-6.2
HIP Joint Angle	44	41	39	35	31	26	22	17	13	8	5	1	1	2	6	10

Fig. 2.2

Sample of data tabulated from a single gait analysis of a five year old normal child. (From Simon et al., 1978.)

locomotor disorders.

The paper by Simon et al., (1978), is of particular interest since it is the only paper which includes the influence on the external moments of an ankle-foot orthosis - a "fixed-ankle below-the-knee orthosis". The orthoses used were of polypropylene shell construction, (Rosenthal et al.,1975), and essentially similar to those used in Dundee, (Meadows et al.,1980). The techniques involved included high-speed cine photography with semi-automatic computer analysis, a piezo-electric force plate, and multi-channel e.m.g.. A considerable number of body-markers was necessary as well as trailing leads for the e.m.g., (Fig. 2.1). The form of data presentation was shown in this paper although the example given is of a normal child, (Fig. 2.2). This is an extremely comprehensive but compact method of presentation of data. It is, however, somewhat difficult to assimilate rapidly. It could probably be improved by the use of graphs in place of the existing block-diagrams, and by transposing the tables of results of ankle and hip so that they followed the logical anatomical sequence from top to bottom.

The problem investigated, frequently encountered in cerebral palsy, was the tendency of the knee to hyperextend during the stance phase of gait. Fifteen children between the ages of four and sixteen were included in the study.

The results of the gait analysis showed that the children could be divided into two main groups of six patients each. In the first group knee hyperextension occurred early in stance due to spastic activity of the plantarflexors which arrested the forward movement of the tibia, caused the ground-to-foot force vector to pass in front of the knee generating an extending moment, (Fig. 2.3). The femur then continued to move forward producing knee hyperextension. In the second group the activity of the plantarflexors was not sufficient to resist the dorsiflexion moment at the ankle and the

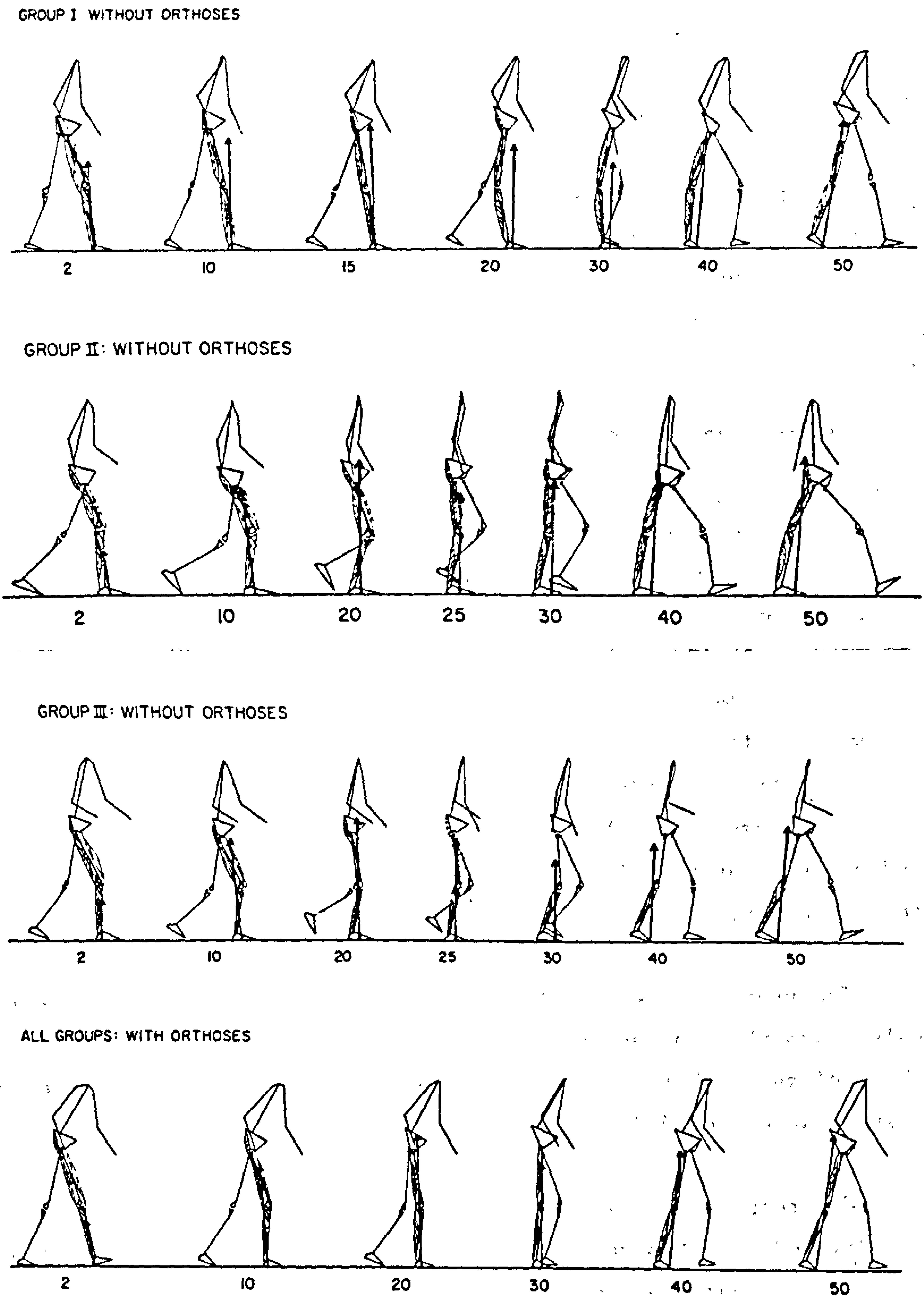


Fig. 2.3

Stick figure and force vector diagrams of CP children with knee hyperextension. (From Simon et al., 1978.)

tibia continued to move forward until the maximum possible ankle dorsiflexion had occurred. At this point the femur would continue to move forward and again knee hyperextension would occur.

In both groups the knee hyperextension was eliminated only by the resumption of forward movement of the tibia. The use of the AFO successfully prevented the occurrence of knee hyperextension. The authors stated that "the fixed-ankle below-the-knee orthosis, by preventing excessive dorsiflexion and plantarflexion, produced more normal moments about all joints, especially the knee." A third group of three chldren whose genurecurvatum had been permanently corrected by the use of the AFO were included, (Fig. 2.3). The authors could give no explanation for the improvement in this group.

This paper shows clearly that the external moments generated at the joints of the leg in cerebral palsy may be distinctly abnormal and that the use of an AFO may modify them significantly.

The paper by Sutherland and Cooper, (1978), on the pathomechanics of progressive crouch gait, is of similar interest to the previous paper. Again cine-photography, force plate and e.m.g. are employed. Four children between the ages of eight and fifteen were measured. Crouch gait could be considered to be the "opposite" of genu-recurvatum and the other "typical" CP gait pattern. It is less dramatic than genu-recurvatum since no sudden alterations of motion take place in this case. The most notable feature is the excessive amounts of flexion which occur throughout the gait cycle, and especially in stance phase, at the hip and knees, and with dorsiflexion at the ankles. These increases in flexion are clearly shown in the graphs presented in this paper.

Of great interest is the relationship of the ground-to-foot force vector to the joints of the leg. Because of the flexed position of the leg at certain instants the line of action of the vector passes a considerable distance from the joints, especially

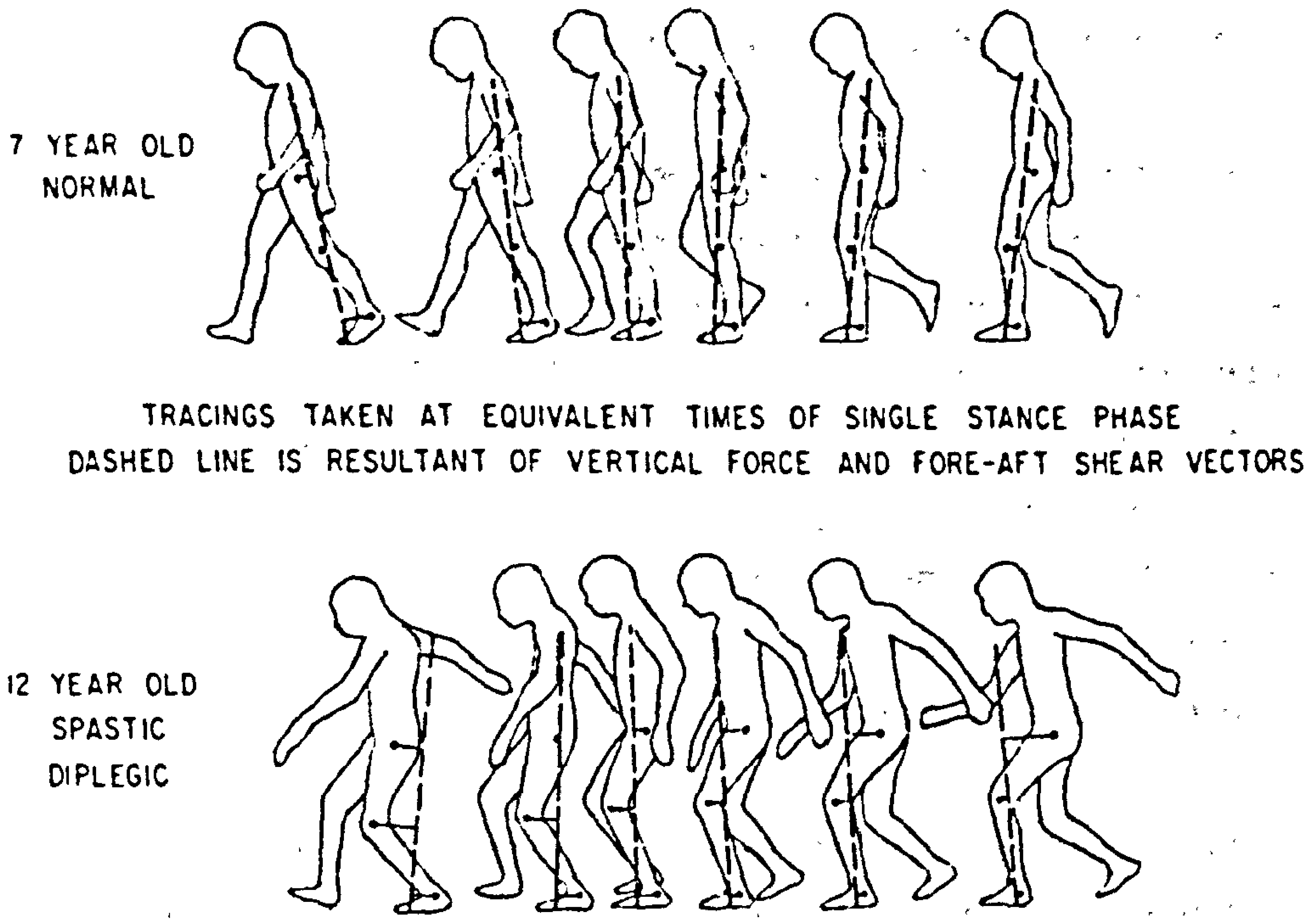


Fig. 2.4

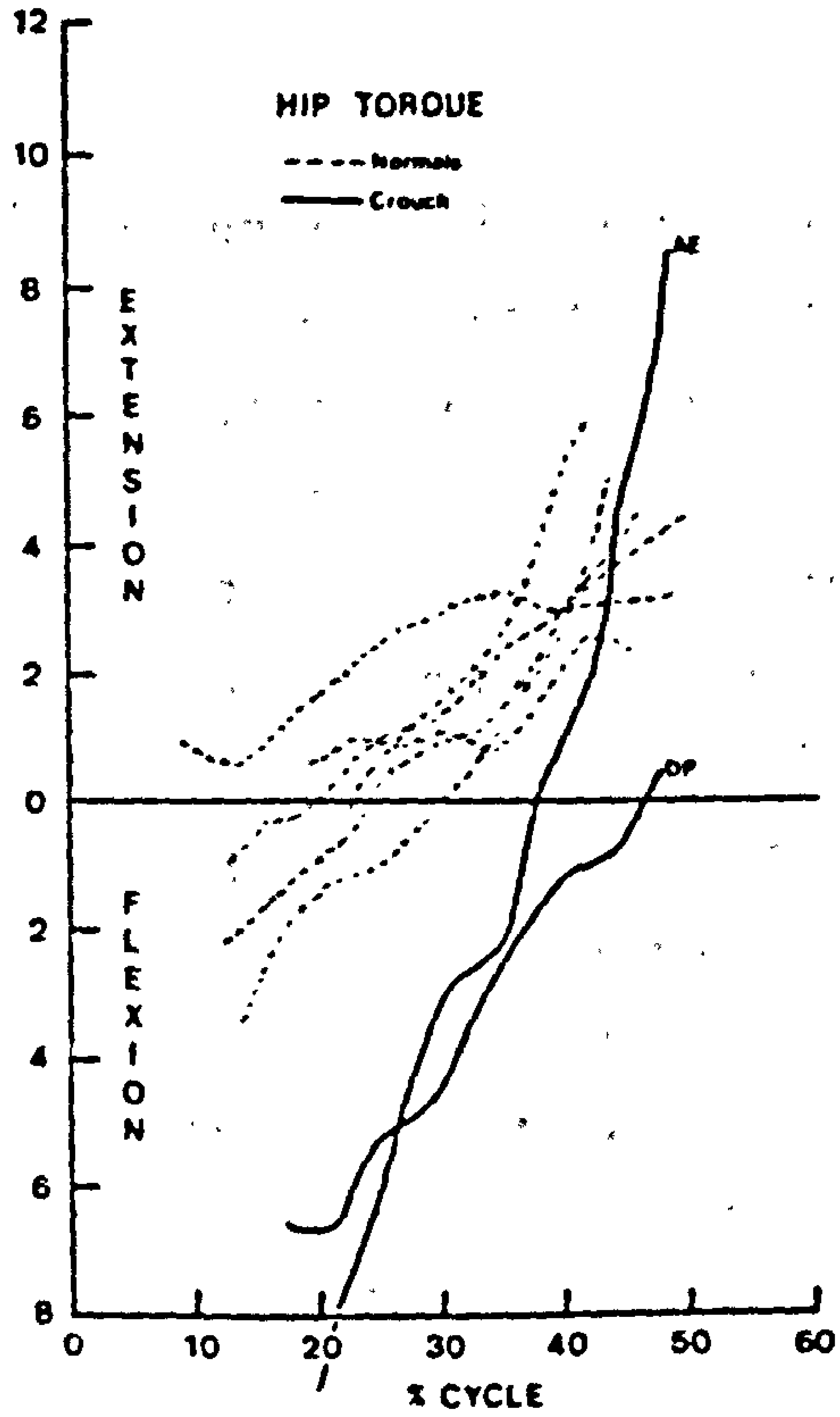
Line of action of ground-to-foot reaction force from a normal and a spastic diplegic child. (From Sutherland and Cooper, 1978.)

the hip and knee. This is quite different from the normal case where at all times the line of action of the vector is never far from any of the three joints, (Fig. 2.4). This implies that high moments may be generated at the joints of the CP child, depending on the magnitude of the forces occurring at these instants. The authors present examples of graphical information on the moments generated at hip and knee, (Fig. 2.5). The moments ("torques") have been normalised by dividing by the child's body weight and height. It can be seen clearly that the values for CP children are considerably different to the normals. Not only are the moments likely to be higher than normal but they may be in the opposite direction to those normally occurring. Unfortunately there is no mention in this paper of the use of AFOs.

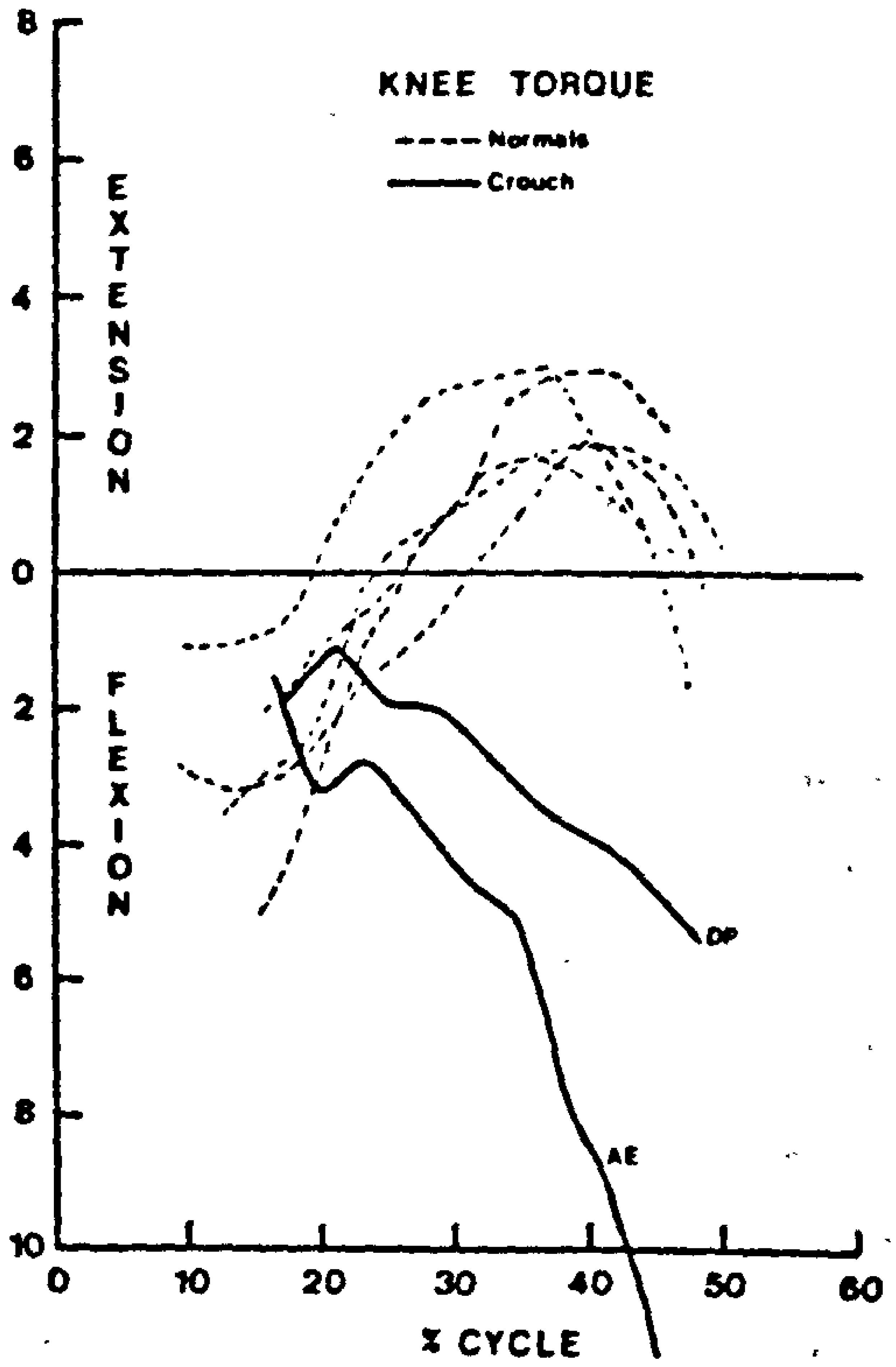
There is very little of direct relevance to the study of the kinetic aspects of cerebral palsy gait, and in particular the influence of ankle-foot orthoses, mentioned in the remaining papers which have been reviewed. There are, however, some points which are of interest relating to the methods of analysis and interpretation in some of the papers.

One of the dilemmas which occur in clinical gait analysis is the resolution of the conflicting demands of the simplicity of method required for clinical purposes with the undoubted complexities of the pathology and its presentation. Few, if any, of the authors resolved this problem. There are two principal difficulties, first the quantification of the recorded data and second its clinical interpretation.

Aptekar, et al., (1976b), used lights attached to the child to produce light trails across a photographic plate, which could not be described as a non-invasive technique. They could only comment that the lines appeared to be more jerky and irregular than normal. Levine and Knecht, (1980), and Ogg, (1963), used footprint measurements which consisted of oil or ink on paper. These were



Hip torque. Patients A.E. and D.P. demonstrate excessive flexion hip torque. The normal subjects show a brief flexion torque followed by extension hip torque.



Knee torque. The normal subjects show knee flexion torque reversion between 25 and 35 per cent of the walk cycle to extension torque. Patients A.E. and D.A. show normal flexion torque at the beginning of single limb support, progressing to severe flexion torque.

Fig. 2.5

External moments generated at hip and knee. (From Sutherland and Cooper, 1978.)

quantifiable, for instance by measuring stride length, width of base etc., but did not necessarily reflect changes at knee or hip. None of these three techniques permitted temporal measurement.

Angle-angle diagrams were presented in some of the papers (De Bruin et al.,1980, De Bruin et al.,1982, Fleiss et al.,1978, Hershler and Milner,1980). De Bruin et al., (1982), in a study of eighteen CP and five normal children, commented that the diagrams of CP children's data were as repeatable as normals, but different. Hershler and Milner, (1980), in a paper which included only one adult CP, processed the information further, for instance relating the area contained within the loop of the graph to its perimeter length. While these may produce repeatable results it is difficult to see how the clinical significance of these or changes in their values would be interpreted.

Some of the work concerning the motions of the joints is of high quality. Nevertheless their interpretation is limited to description of the joint motion rather than the reasons behind this motion which may only be the subject of speculation. An interesting paper by Skrotzky, (1983), of six CP and thirty-nine normal children showed that the gait pattern of mildly involved CP children was more intrasubject variable than the moderately involved (i.e. more severely affected) CP children. She concluded that this may be due to the fact that the mild CPs were capable of varying their walking pattern to a larger extent than the more severely affected children, but at the same time did not possess the same degree of automatic motor-control of non-handicapped children. Van der Straaten and Scholten, (1978), showed by a study of eleven normal and eleven hemiplegic children that angle data was better than temporal data, such as swing to stance ratio, to determine symmetry of gait.

Perhaps the most important comment regarding the necessary factors required for the interpretation of CP gait was made by Sutherland in a review article, (1978). He stated that "the addition of movement measurements and force-plate recordings increases the amount of information available for analysis. Distinctions can then be attempted between primary abnormalities and compensatory mechanisms." In other words it is necessary for clinical interpretation and action to understand why something is happening, not just what is happening.

Two papers included comment on the mechanical efficiency of cerebral palsied gait using the technique of analysis of expired air. Nowotny et al., (1983), using a treadmill, concluded that CP children were only 50% as efficient as normal children. Perry et al., (1981), in the process of evaluating a treatment technique which included some adults noticed too, that the CP patients were less efficient, sometimes by a factor of 2 or 3, compared with normals.

2.2.2 Gait Analysis of Normal Children

The principal purpose of most of the reported studies of the gait of normal children was to obtain basic information. This frequently related to the development of the gait in the early years from infancy until the emergence of an "adult-like" pattern, (Beck et al.,1981, Burnett and Johnson,1971a, Burnett and Johnson,1971b, Scrutton and Robson,1968, Scrutton,1969, Statham and Murray,1971, Sutherland et al.,1980). Two papers considered the mechanical efficiency of gait, (Davies,1980, O.R.L.A.U.,1982).

The techniques employed to obtain the measurements were similar in variety to those employed in the studies of CP children. The most common were again cine-photography, (Burnett and Johnson,1971a, Burnett and Johnson,1971b, Fortney,1983, Grieve and Gear,1966, Sutherland et al.,1980), and goniometry, (Burnett and Johnson,1971a, Burnett and Johnson,1971b). One paper reported the use of light trails on a photographic plate, (Aptekar et al.,1976a), and another of interrupted light photography, (Statham and Murray,1971). Three papers reported the use of footswitches, (Beck et al.,1981, Burnett and Johnson,1971a, Burnett and Johnson,1971b). In three studies force plates were employed, (Beck et al.,1981, Fortney,1983, Hutton and Dhanedran,1979), one of them a multi-segmental type to examine the distribution of load beneath the foot.(Hutton and Dhanedran,1979).

The results which were presented were largely kinematic concerning the temporal factors of swing and stance phasing, cadence, etc., (Beck et al.,1981, Burnett and Johnson,1971a, Burnett and Johnson,1971b, Foley et al.,1979, Fortney,1983, Grieve and Gear,1966, Statham and Murray,1971, Sutherland et al.,1980), and joint motions, (Burnett and Johnson,1971a, Burnett and Johnson,1971b, Foley et al.,1979, Statham and Murray,1971, Sutherland et al.,1980). The only kinetic data presented was the magnitude of the ground reaction force, (Beck et al.,1981, Fortney,1983, Hutton and Dhanedran,1979). There was no report in any paper of the calculation of external joint moments. Two papers presented data on the efficiency of normal gait. One presented results obtained by analysis of expired air and using a treadmill, (Davies,1980). The other calculated efficiency by monitoring heart rate as the child walked within a gait laboratory. (O.R.L.A.U.,1982).

There was some variation in the age at which different researchers considered that a child's gait pattern had become mature and "adult-like". This was probably due to the different forms of measurements which they took and the different criteria by which they chose to judge them. Beck et al., (1981), in a study of fifty-one children indicated that there was little change in the pattern of force plate output after the age of five years when it became adult-like. Grieve and Gear, (1966), looking at the temporal aspects concluded that the adult pattern had emerged by between four and five years of age. Sutherland et al., (1980), in a study of 186 children, showed that, if judged by the increase in duration of single limb support, the adult pattern had become established by three years. Burnett and Johnson, (1971b), in a study of 28 children, looking for what they consider as the determinants of gait concerning pelvic motions and knee flexion in stance, state simply that an adult pattern may occur earlier than generally accepted. In a study of the running patterns of twenty-eight children, Fortney, (1983), observed that the temporal and force measurements of four and six year olds were similar to each other but different from two year olds. They did not state, however, if the older children's measurements were adult-like. One very interesting point mentioned by Beck et al., (1981), is that the force plate outputs of children less than four years of age changed significantly, becoming more adult-like over a period of only three months. This has interesting clinical implications when one considers CP children who may be significantly retarded in terms of motor development. Even at the age of six or seven years they may have a motor development equivalent to a normal four year old. Up to this time, therefore, one could perhaps expect significant changes in their gait patterns towards a more fluent, well-controlled one simply due to the maturation process, although it may require longer than the three month period to produce this. It is, therefore, quite possible that much of the improvement in a CP child's gait which is attributed to the beneficial effects of treatment may in reality be attributable to the child growing up.

Statham and Murray, (1971), in a study of seven children indicate that a child's gait is typically more irregular, with increased amounts of flexion than the adult but that it becomes more like an adult with age. Foley et al., (1979), in a study of twenty children between the ages of six and thirteen, state that their gaits were "more jerky and less flowing" than adults even although the angular motions of the hips, knees and ankles were similar to adults.

One study on energy consumption indicated that the energy consumption of children was proportional to their body weight and significantly higher than that of adults, (Davies,1980). The other study using heart rate measurement, (O.R.L.A.U.,1982), in addition to the data on normal children included the result of one CP child who, when walking with shoes, had an energy consumption twice that of normal children and when barefoot four times normal. It is likely, therefore, that severely involved CP children may have huge energy consumptions when attempting to overcome their early walking difficulties.

2.2.3 Electromyography

There were three main objectives of the work reported on electromyographic gait analysis. These were to obtain basic information on the phasic activity of the muscles of the leg, to examine the nature of specific problems such as joint deformities or abnormal postures, often with a view to surgery, and to examine the results of surgery.

Surface and needle electrodes were used but in addition many of the researchers used other techniques to aid identification of the phasing of the gait cycle. Some researchers used cine-photography or other photographic means (Bennet et al.,1980, Kazai et al.,1976, Knutsson,1980, Sutherland et al.,1968, Sutherland et al.,1969). Others used footswitches, (Griffin et al.,1977, Hoffer and Perry,1983, Perry et al.,1974c, Perry and Hoffer,1977). Quantification of the muscle activity was limited to measurement of time duration in relation to the gait cycle. One paper attempted to quantify the e.m.g. signal itself but fell short of producing a clinically useful method, (Woltering et al.,1979).

The numbers of children studied were considerably less than the other forms of gait analysis of CP and normal children described previously. The most significant finding however, widely reported, was the abnormal muscle activity which was measured. This was often prolonged activity or abnormal phasing, frequently resulting in antagonistic activity. The result of surgery, either tendon lengthenings or transfers, usually was a significant change in the e.m.g. acitivity. Very little comment was made by any of the authors on the reasons for these changes, reflecting the meagre understanding of these particular problems.

Two papers have been written on children who toe-walk - not necessarily true CPs, (Griffin et al.,1977, Montgomery and Gauger,1978). In one study of six toe-walkers who simply had tight calf muscles and six normal children asked to walk on their toes it was noted that in both cases antagonistic activity of plantarflexors and dorsiflexors occurred, (Griffin et al.,1977). When the toe-walkers had successfully had their tight calf muscles stretched by serial splinting techniques resulting in a more normal range of dorsiflexion, the antagonistic activity disappeared and a normal pattern of e.m.g. activity resulted. This is interesting but it does not answer the question as to whether this effect was as a result of principally biomechanical or neurological changes or a combination of both. The other paper, a study on mentally handicapped toe-walkers, postulated that these children deliberately toe-walk to facilitate extensor activity at hips and knees, (Montgomery and Gauger,1978).

One study of early walking in infants commented that reciprocal activity of plantarflexors and dorsiflexors occurred during crawling even although the ankle joint was unloaded, (Kazai et al.,1976).

2.3 CONCLUSIONS

This literature survey has shown that, in comparison to adults, there has been very little work carried out to investigate the gait of children, either handicapped or normal. It has indicated, in particular, that there is only one report concerning the influence of an ankle-foot orthoses on the external moments generated at the joints of the legs of CP children.

There is very little conflict between the results of the various scientific studies. This is due to two principal reasons. First, the studies examine different and widely varying aspects of the kinematics and kinetics of gait. Second, where studies do consider the same subject there is general agreement that the measurements are widely variable because of the clinical nature of cerebral palsy.

It is, however, possible to summarise in a general fashion the results of the survey as it relates to the gait of cerebral palsied children. Their gait is characterised by poor control and irregular angular motion of the joints of the legs. The phasic activity of the muscles is frequently abnormal, often being antagonistic. The gait is significantly more energy-consuming than that of normal children. The few studies of the external moments which are generated indicate that these are often abnormal, generally of greater magnitude, and may even be in the opposite direction to that occurring normally. The one paper which reports on the influence of AFOs indicates that these may modify the moments generated at hips, knees and ankles, making them more normal, especially at the knee.

CHAPTER 3

EQUIPMENT

CHAPTER 3

EQUIPMENT

3.1 INTRODUCTION

A wide range of equipment was used for the investigations. Some items were already installed in the laboratory and were thus available for use. In some instances modifications or developments were necessary. Other equipment was commercially available and was purchased as required. In addition, however, it was necessary to design and construct several items specifically for these investigations.

The equipment was used in three main areas of the investigation - gait analysis, the measurement of AFO and footwear characteristics and the monitoring of muscle activity.

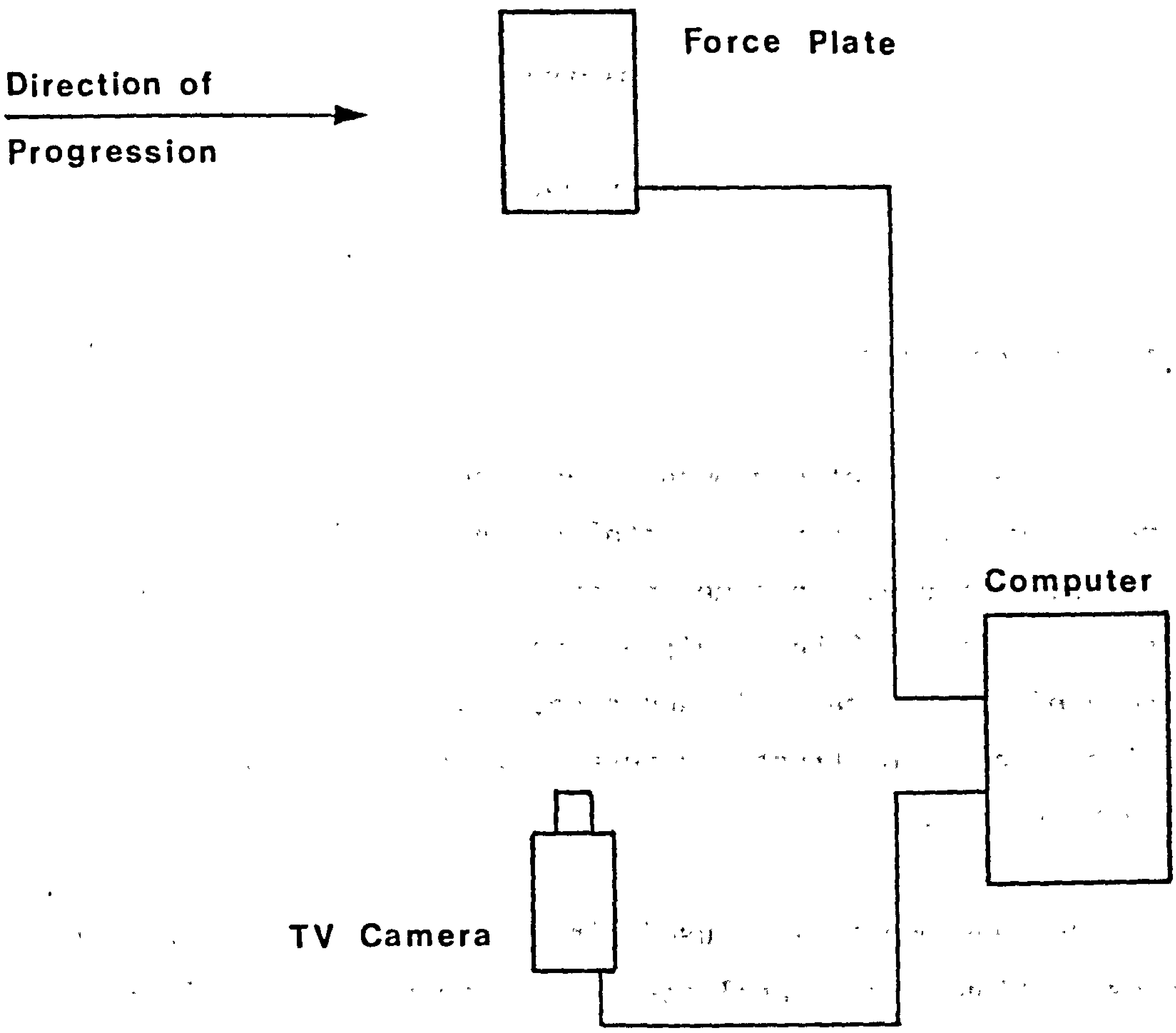


Fig. 3.1

Schematic diagram of
television-computer gait analysis system

3.2 GAIT ANALYSIS

The principal item of equipment used was the TV-computer gait analysis system installed within the laboratory at Dundee Limb Fitting Centre, (Jarrett,1976, Jarrett et al.,1976). It was necessary to modify this system to gain the optimum performance for child subjects. Developments also took place in the design of the reflective markers and the software used for data acquisition and analysis.

3.2.1 Television-Computer System

The analysis conducted was of a single leg during the stance phase. This was two-dimensional and in the sagittal plane. For these reasons it was not necessary to use both cameras or both force plates which were available. A single camera and force plate were therefore used.

The TV camera and force plate were connected via an interface to a DEC PDP11/34 computer, (Fig. 3.1). The system was operated from a terminal situated within the laboratory area. The RT-11 single-user operating system was employed.

The TV camera was a black and white type with a silicon diode tube and f1.4, 50mm lens. It was situated 4.5 metres away from the centre of the force plate and at right angles to the line of progression of the child. the distance of the lens from the floor was 400mm. The field of view above the centre of the force plate was a rectangle 850mm high and 1,000mm wide and centred on the centre of the force plate. A flood light was placed 100mm above the camera and directed towards the field of view.

The force plate used was a Kistler type 9281B piezo-electric multi-component measuring platform. The associated Electronic Unit,

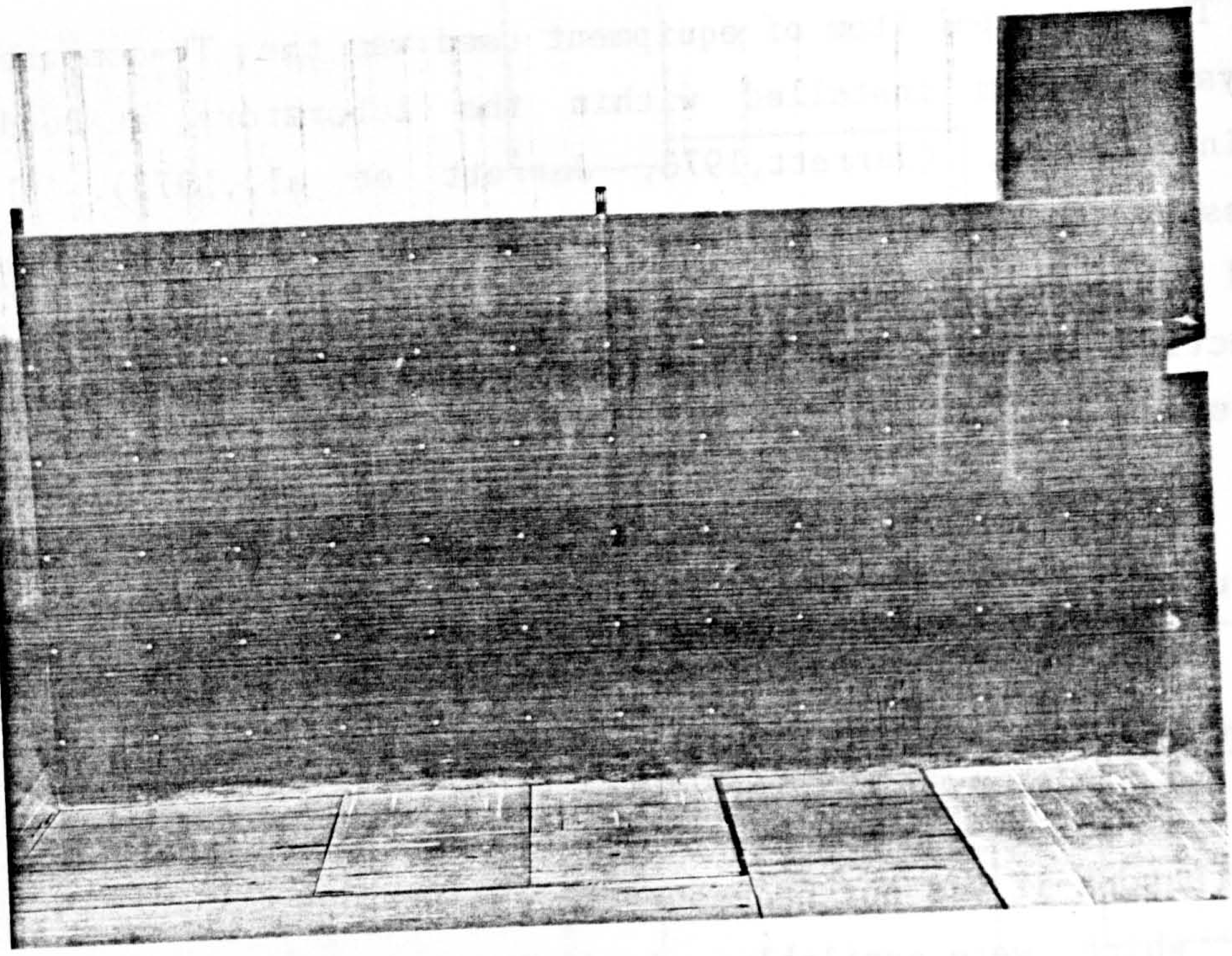


Fig. 3.2

Calibration grid.

type 9851, for 6-component force measurement was used. The analog divider in this unit used to calculate the co-ordinate of the centre of pressure was, however, by-passed, this computation being done by subsequent programming.

The force plate was orientated so that the short axis lay along the child's line of progression.

A calibration grid consisting of a black board with reflective markers placed in a square grid 200mm apart was necessary, (Fig. 3.2). This was used prior to tests to scale the measurement area above the force plate in the field of view of the camera. This process will be described in Chapter 4.

3.2.2 Reflective Markers

A considerable amount of development was necessary for the production of a satisfactory reflective marker for attachment to the skin. The original markers used in the development of the TV computer system were produced from simple balsa wood cuboids with one face semi-cylindrical to which was attached "Scotchlite" retro-reflective tape. These proved to be unsuitable for use with the children because they were very unstable and could easily be knocked off. In addition if the attachment areas rotated in certain directions the projected area of reflective tape facing the camera was reduced to unacceptably low levels.

There were many constraints on the design of the markers. They had to be light-weight and comfortable. They had to be easy to apply and easy to remove after tests but be stable during them. It was necessary that they were sufficiently flexible to accommodate any deformation of soft tissue or to conform to the shape of small bony prominences of high curvature such as the malleoli. They had to present constant target areas of the retro-reflective surface

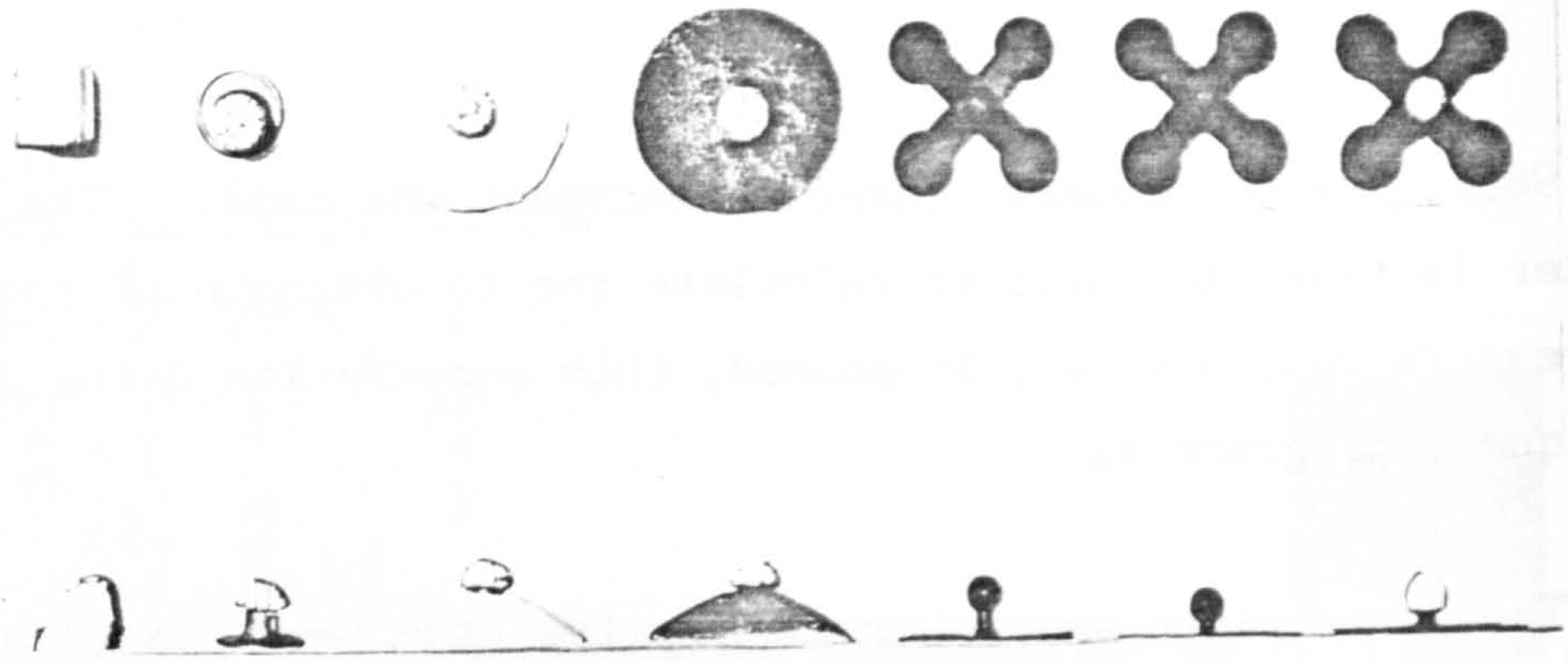


Fig. 3.3

Stages of development of reflective markers.

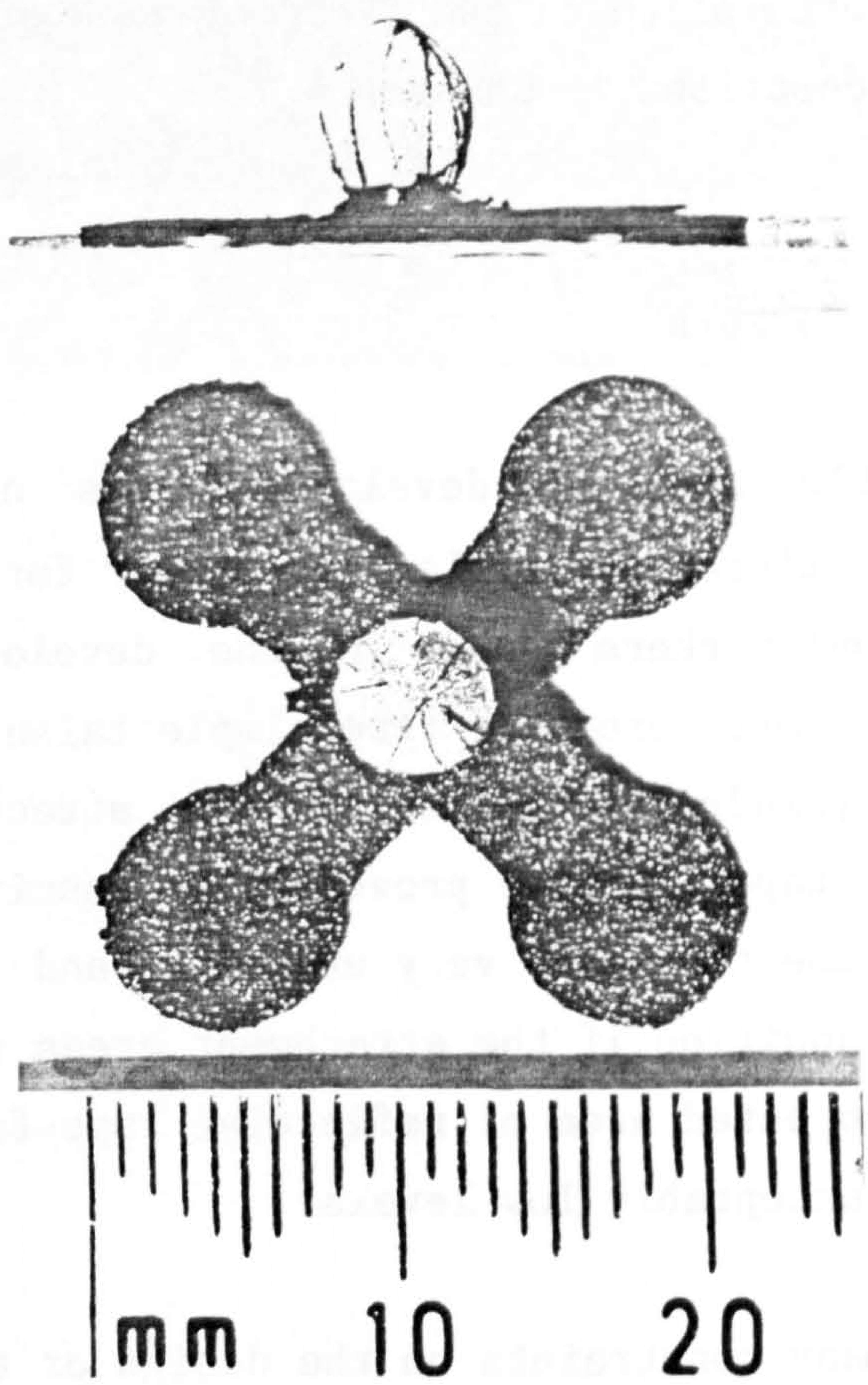


Fig. 3.4

Final design of reflective markers.

despite excess rotations of the body segments about several axes at once. They also had to be cheap and easy to produce.

Figure 3.3 shows the process of development of the markers.

The final design proved to be highly successful, (Fig. 3.4). This was produced by injection moulding in black polythene. The four-legged base section was highly flexible. Double-sided adhesive tape was used to attach them to the skin. This proved to be ideal with excellent fixation even on very small bony prominences, (Fig. 3.5). The upper surface of the base section had a matt finish to prevent any reflection of the light source. The reflective surface consisted of a 4.5mm diameter sphere on a short stalk. "Scotchlite" retro-reflective tape was stuck to the sphere in small strips until the surface was completely covered. This was not an ideal method but proved to be functionally acceptable. The final diameter was approximately 5mm.

Five markers were required for each test. One of these had one leg of the base section removed to permit fixation on the lateral aspect of the fifth metatarsal head, close to the ground.

3.2.3 Software

Programs already written as part of the original development of the TV-computer gait analysis system were modified and extended. This was achieved by collaboration with Dr. S.M. Marlow who was responsible for writing the programs. These related to the acquisition and preliminary manipulation of data using the RT-11 single-user operating system.

The original programs were versatile and thus required the selection of parameters concerning, for example, the number of TV fields to be sampled, the force plate sensitivities etc. They were,

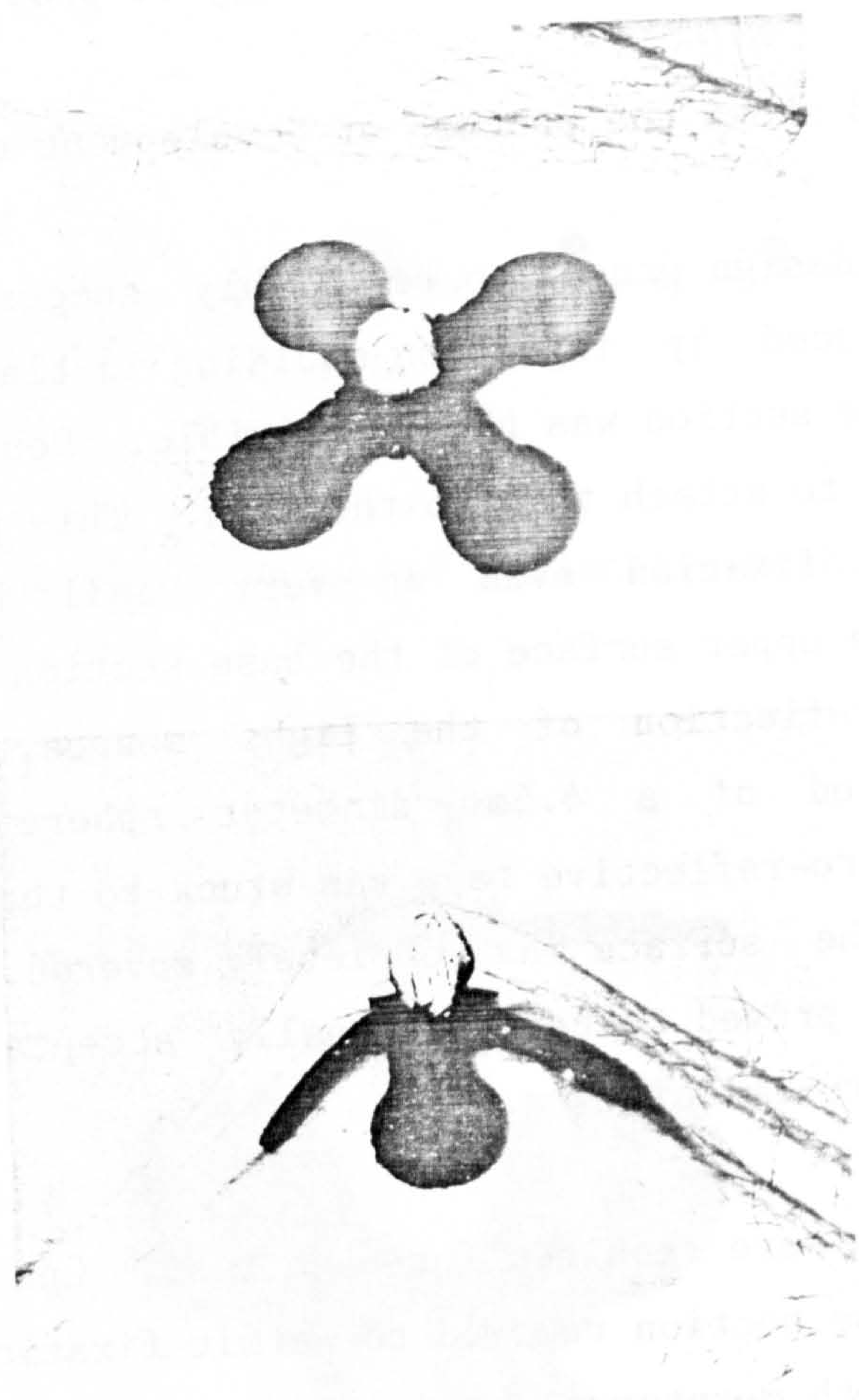


Fig. 3.5

Good fixation of marker was possible even on small bony prominences.

therefore, somewhat ponderous to use and this could cause problems, especially during data acquisition when excessively long intervals were necessary between test runs.

The developments, therefore, related primarily to standardising the variables to a set which was appropriate for the gait analysis of children. This greatly reduced the waiting time necessary between tests and in addition minimised the number of typing errors possible when under pressure during data acquisition.

The programs written for data acquisition and initial manipulation (TV data averaging and trajectory sorting, etc.) utilised the RT-11 system. Programs for subsequent analysis and presentation of data employed the RSX multi-user system. Preliminary work had already taken place to produce programs to operate the Hewlett-Packard 7221A Plotter. These related to the plotting of stick diagrams of the leg with superimposed force vector and the production of graphs of external moments generated at the markers and angular excursions of the joints. Again these programs were versatile and consequently somewhat cumbersome to use.

Software development took place to extend the facilities of these programs but also make them simple to operate. This was achieved by determining a standard set of variables appropriate for children and a standard format of presentation. A flow chart of the operation of these programs is included in Appendix II.

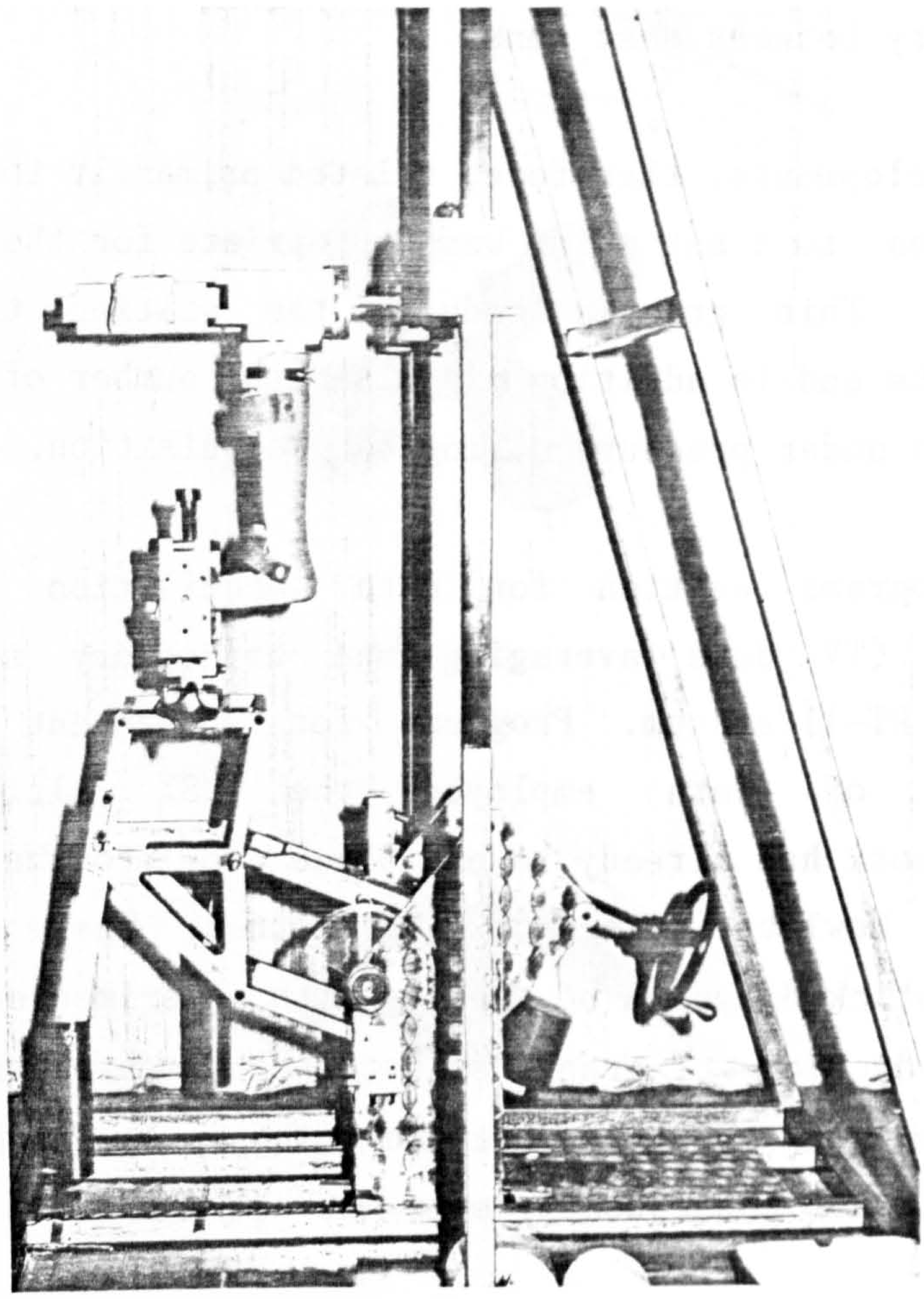


Fig. 3.6

AFO stiffness measurement rig.

3.3 ANKLE-FOOT ORTHOSIS AND FOOTWEAR CHARACTERISTICS

Two principal items of equipment were designed and constructed to measure the characteristics of the AFO and footwear. These were to measure the stiffness of the AFO, and the magnitudes of the raise, wedge and rocker properties of the footwear.

3.3.1 Ankle-Foot Orthosis Stiffness Measurement Rig

It was necessary to measure the stiffness of the AFO in the sagittal plane. This was the relationship of its deformation in this plane to the imposed plantarflexing and dorsiflexing moments.

Unlike conventionally constructed AFOs using metal side-struts, polypropylene AFOs have no discrete joints about which rotation takes place. Instead the deformation caused by loading in the sagittal plane takes place by buckling of the side wall of the AFO in the region of the anatomical ankle joint. The calf and foot sections remain relatively undeformed. Since no discrete axis of rotation exists problems occur in determining the moments being imposed upon the orthosis if it is subjected to a linear force applied to it, there being no easily calculated lever arm.

The design of the AFO stiffness measurement rig utilised the principle of applying a known angular deformation and measuring the resulting moment generated by the AFO, (Fig. 3.6). The rig consisted of an external square tubular structure, a parallel pair of counter balanced double-parallelogram linkages to impose the deformation and a system of clamps to grip the calf and foot sections of the AFO.

The properties of the double-parallelogram linkage were such that a fixed angular relationship existed between the arm of the bottom parallelogram to which the actuating screwed shaft was

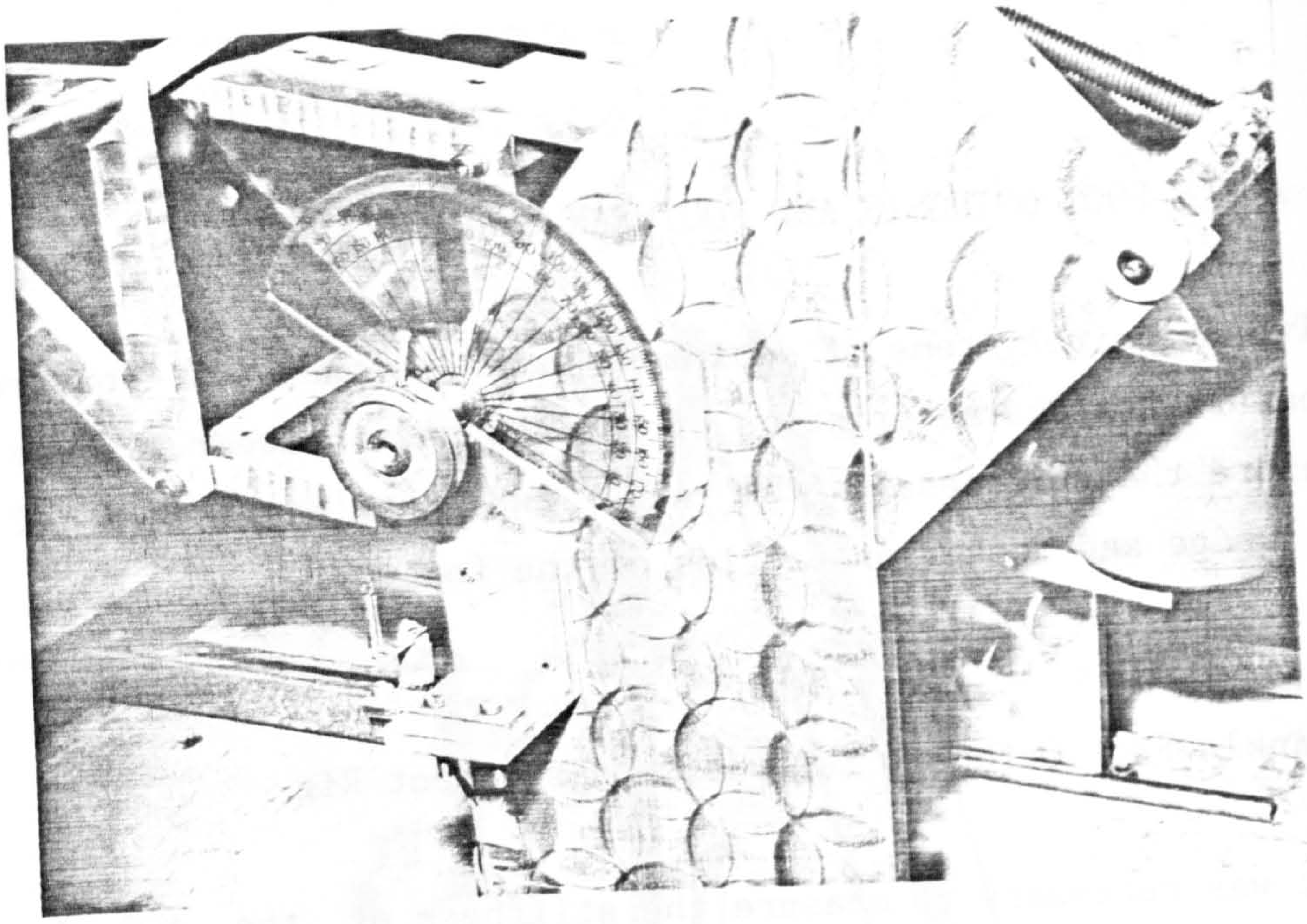


Fig. 3.7

Pulley and strain gauged beam for measurement of rotation of shaft.

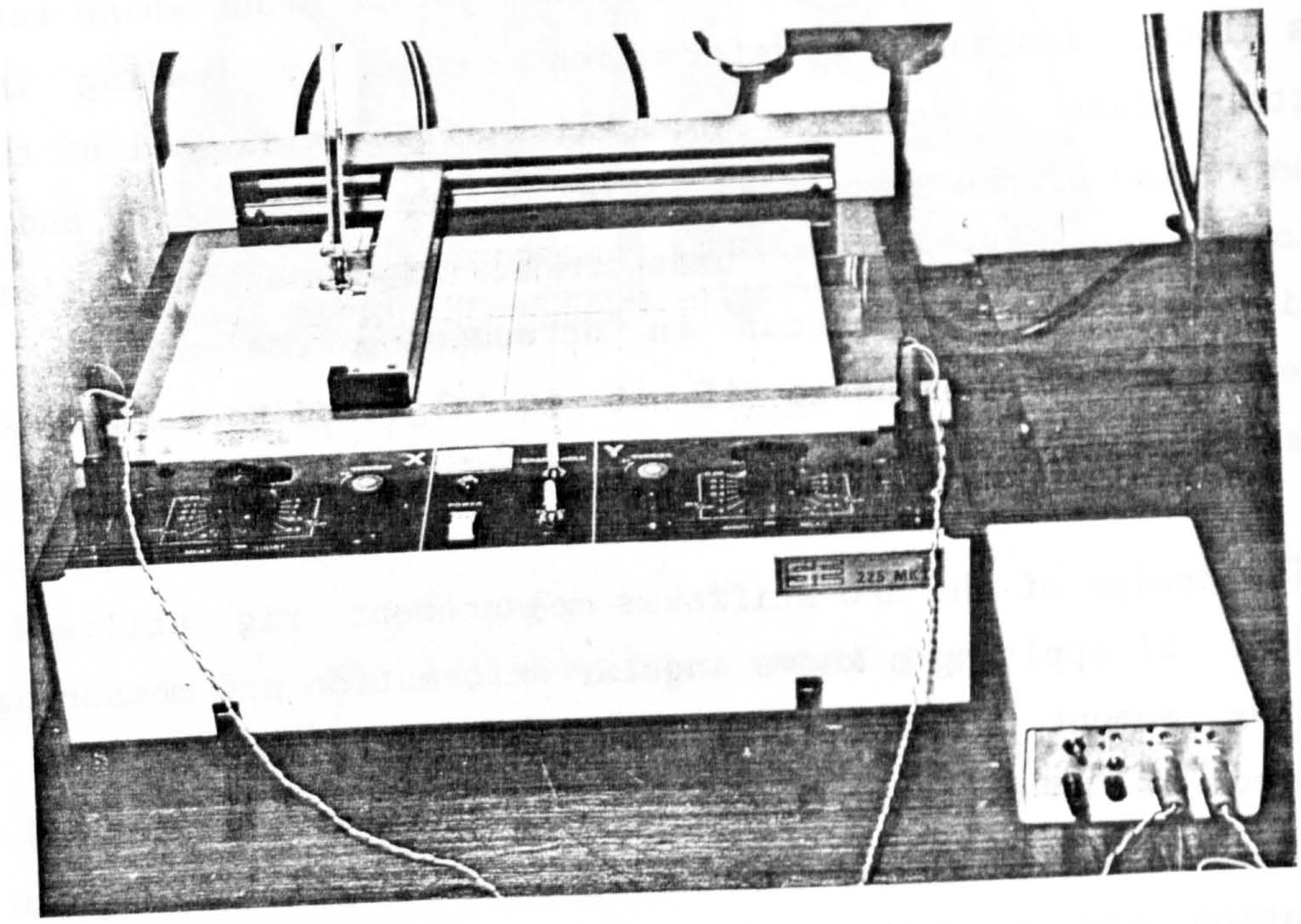


Fig. 3.8

X-Y plotter which permitted direct output of moment/angle stiffness graph.

attached and the arm of the top parallelogram to which was attached the foot section clamp. There was, however, no constraint upon their relative positions in the vertical and horizontal directions. The linkage was thus able to impose a moment upon the foot piece of the AFO but no forces.

The original design of the clamping systems utilised powder grips and was for the purpose of testing adult sized AFOs, (Condie and Meadows,1977). For testing child sized AFOs the top, calf section grip was replaced by a wooden cylinder to which the AFO was firmly clamped using a jubilee clip. A range of cylinders from 40 to 100mm in diameter were available to accommodate the various sizes of the AFO.

The angular deformation was imposed upon the foot section by turning the screwed shaft which rotated one arm of the bottom parallelogram in the plane of the linkage about a horizontal supporting shaft. This rotation was transmitted by the linkages to the top arm of the top parallelogram and hence to the sole piece of the AFO. The rotation was measured from the rotation of the supporting shaft. This was achieved initially by attaching a potentiometer to the shaft. This was replaced later by a pulley system actuating a strain-gauged beam for greater accuracy, (Fig. 3.7). In this case the deformation of the beam was proportional to the angular rotation of the shaft.

The moment being generated by the AFO during deformation was detected by a strain-gauged transducer mounted between the top clamp and the tubular frame. The frame and clamping systems were capable of being adjusted to permit the mounting of the AFO in three different attitudes to measure the stiffness characteristics about the three orthogonal axes. However, for this series of tests only measurement in the sagittal plate was conducted.

The transducers were connected to purpose built bridge

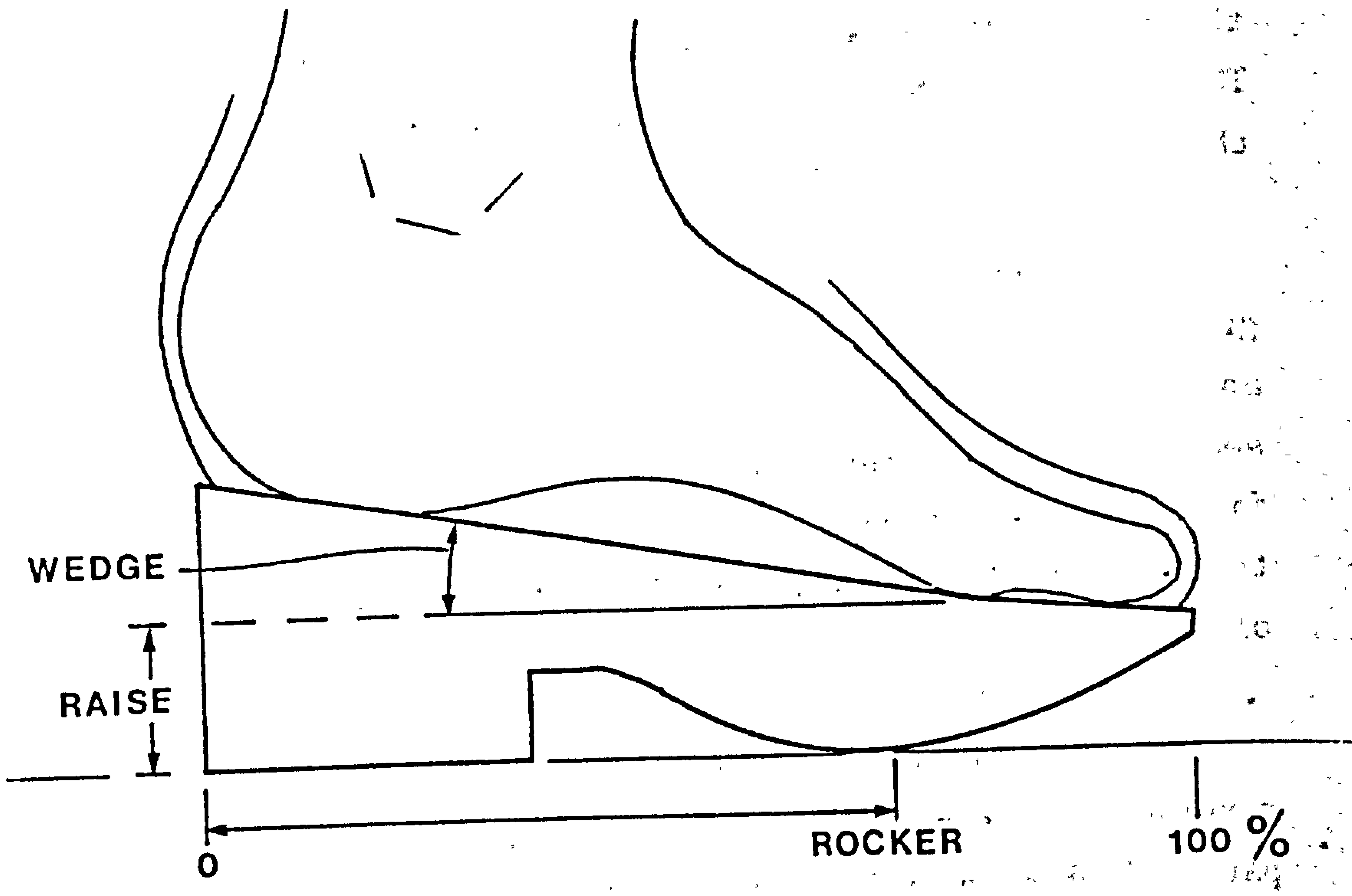


Fig. 3.9

Definitions of footwear characteristics.

amplifiers. The circuits for these are included in Appendix III. The out-puts of these were connected to an S.E. Laboratories 225 Mk II X-Y Plotter, (Fig. 3.8).

3.3.2 Footwear Characteristics Measurement Rig

Three principal measurements were necessary to characterise the footwear - the raise, wedge and rocker properties, (Fig. 3.9). The raise was considered to be the distance from the ground to the bottom surface of the fifth metatarsal head caused by the thickness of the sole at this point. The wedge was considered to be the angle measured at the intersection of a line drawn between the lowest points of the calcaneus and the fifth metatarsal head and a line drawn parallel to the ground. The rocker was considered to be the ratio, expressed as a percentage, of the distance between the rearmost edge of the heel and the point at which the sole curled upwards off the ground to the total length of the shoe.

The measurement rig consisted of a base plate to which was attached a four-segment arm made of square section alloy tubing. (Fig. 3.10). The first and last segments were telescopic. The four segments were linked by pin joints so that the arm was able to move in the vertical plane only. All adjustments were lockable.

On the end of the final segment was attached the internal locating arm consisting of two telescoping sections. (Fig. 3.11). At either end were positioned the locating needles which protruded below small discs. The distance between these two were adjustable from 92mm to 192mm by means of a series of indexing holes at 3mm increments and a locking pin. The purpose of the needles was to obtain firm fixation at the locations of the calcaneus and fifth metatarsal head by pressing into the insole of the shoe.

An external locating arm made from round section rod was also

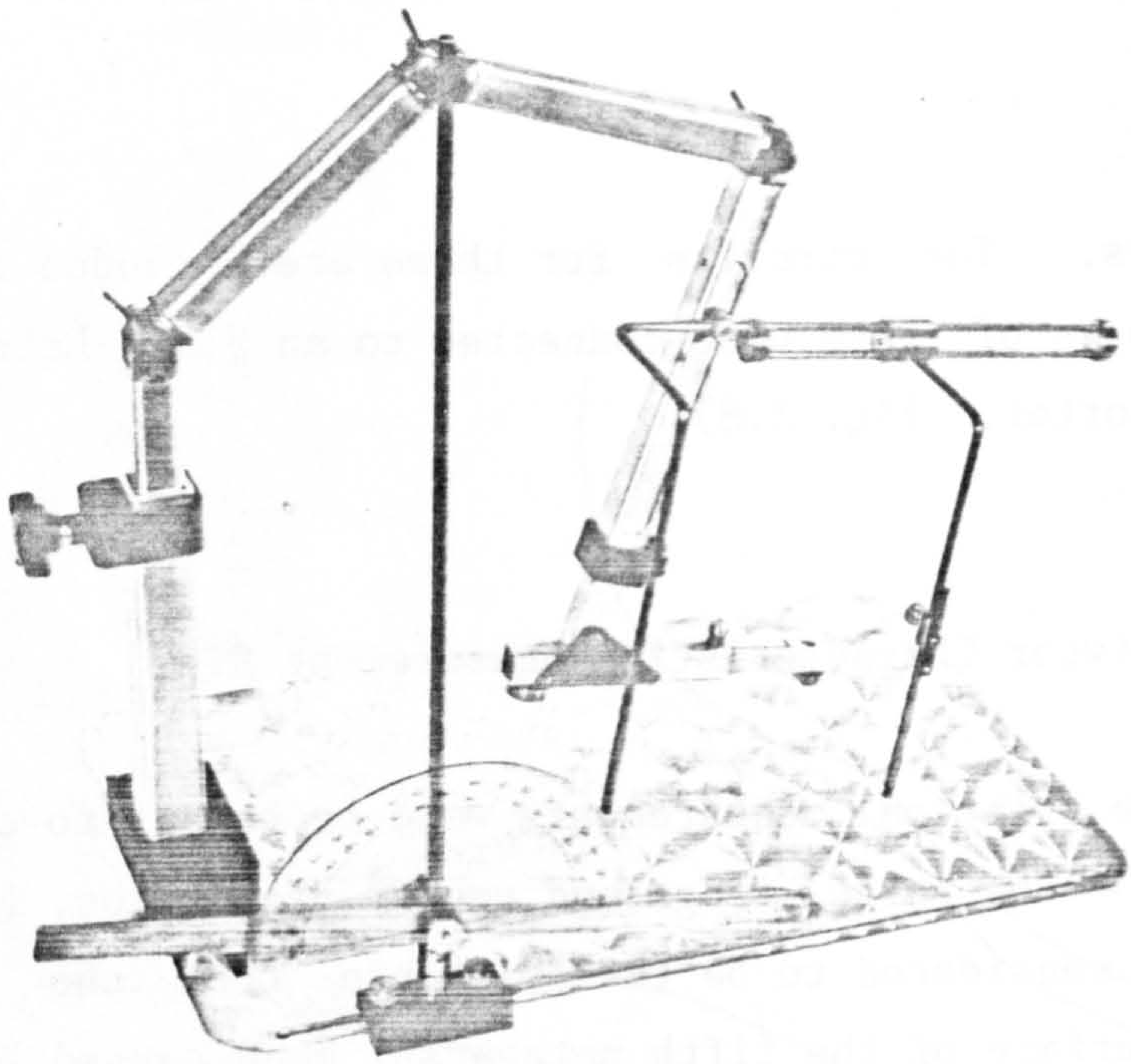


Fig. 3.10

Footwear characteristics measurement rig.

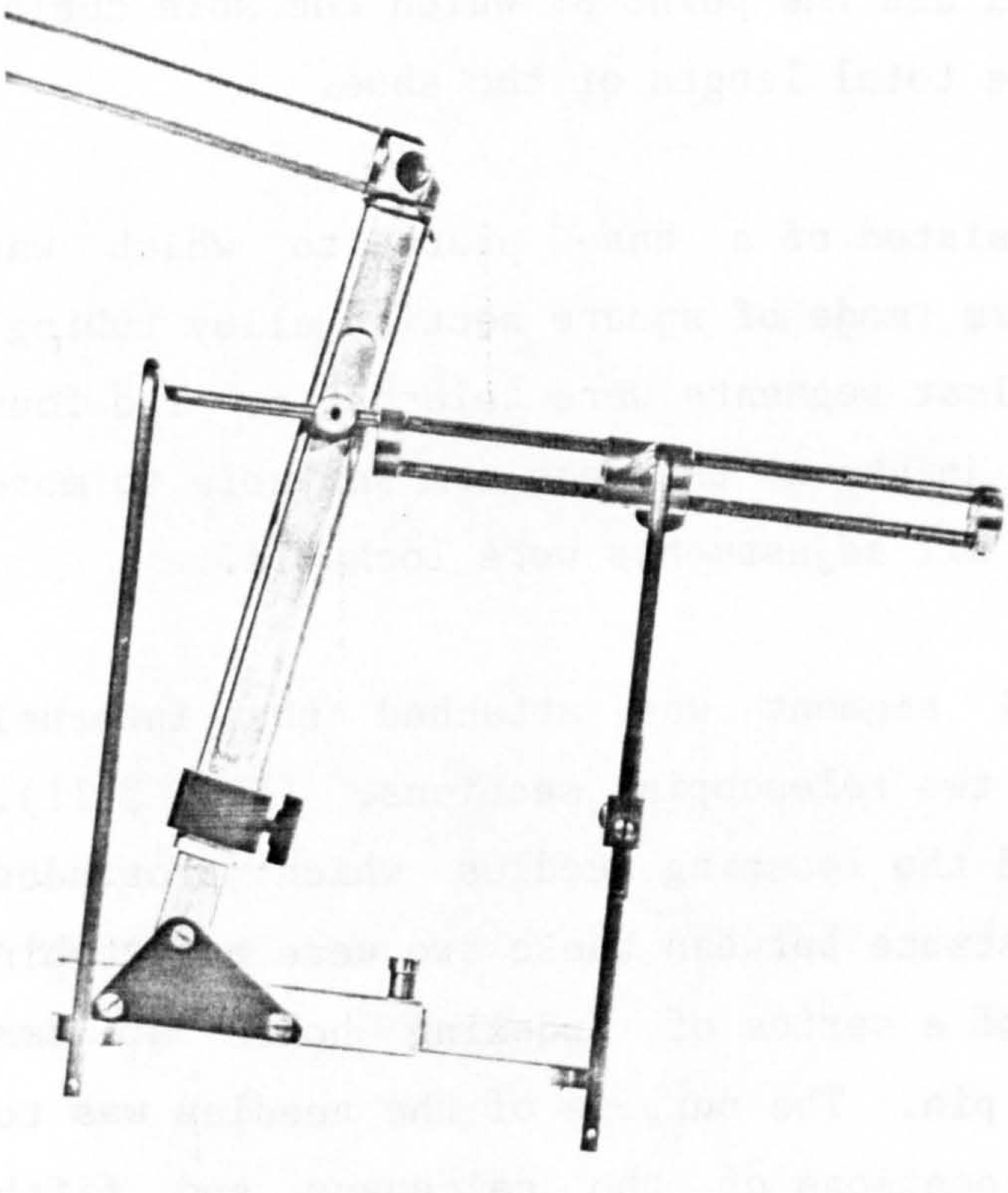


Fig. 3.11

Internal and external locating arms.

attached to the final segments. The two upright arms were adjustable and constrained to move so that their ends could be positioned at identical distances from the ground as the internal needles. It was thus possible to measure the appropriate dimensions with a ruler and protractor from the ends of the external locating arms to obtain values for the raise and wedge properties. The rocker ratio was determined by external measurement of the footwear sole itself. The internal locating arm was attached to the final segment at a 10 degree angle. This was to permit the inclusion of a dorsiflexed AFO within the shoe if necessary.

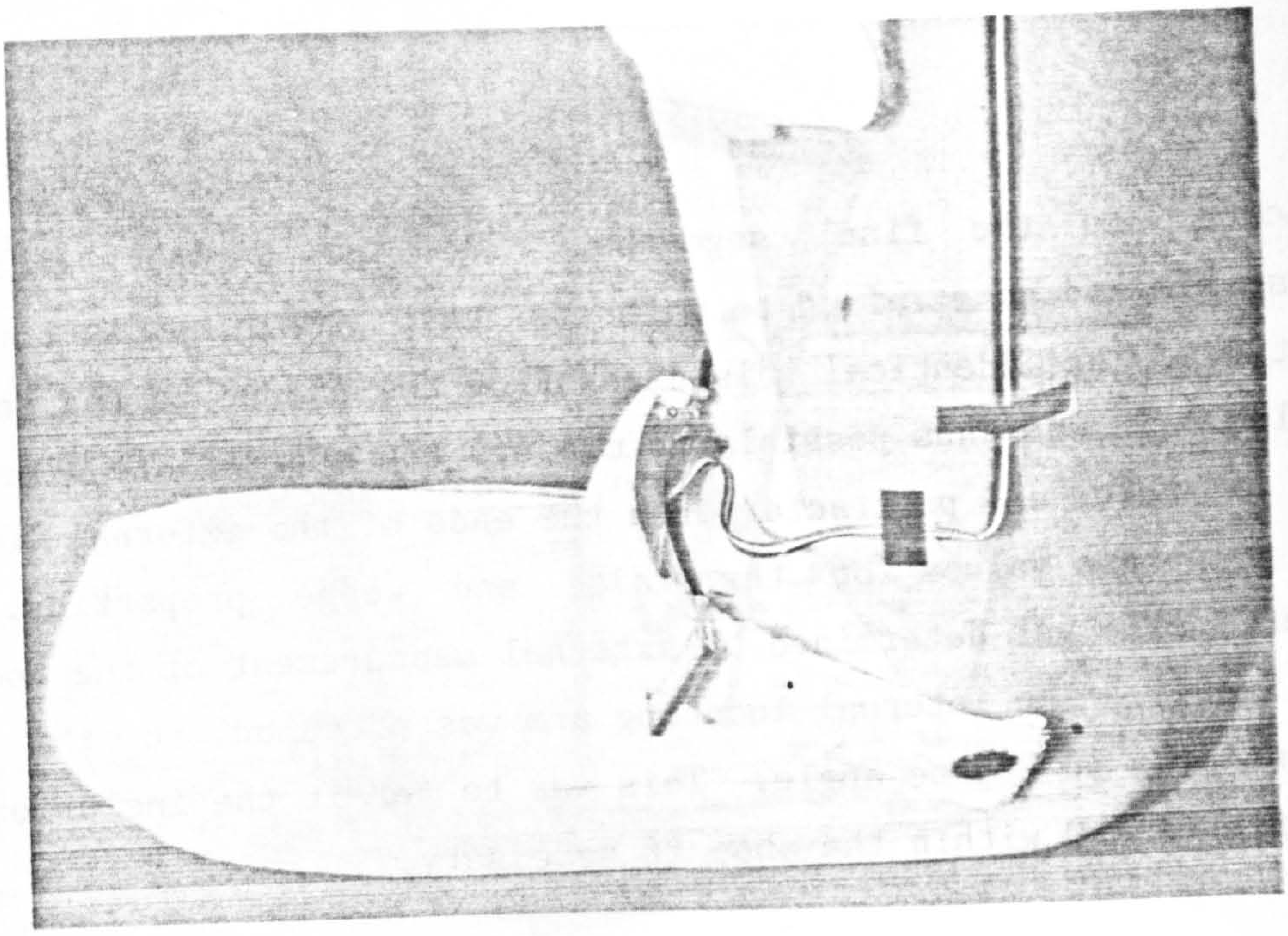


Fig. 3.12

Ankle strap transducer located between strap and dorsum of foot.

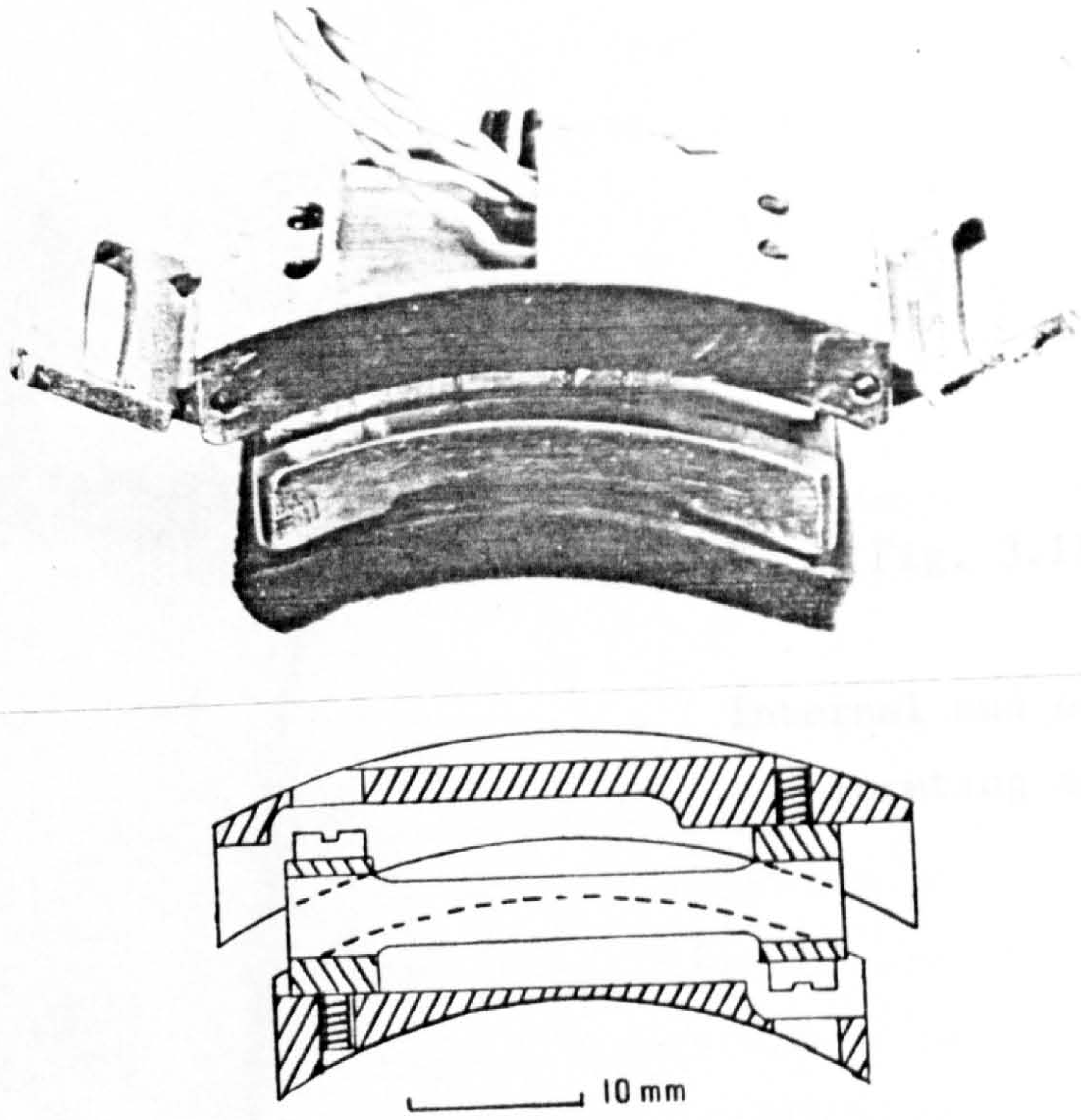


Fig. 3.13

Ankle strap transducer.

3.4 MUSCLE ACTIVITY MONITORING

Three types of transducers were used to gain information relating to the muscle activity of the lower leg. These were the ankle strap transducer, electromyographic electrodes and footswitches. The signals from these were recorded by a Medilog Monitoring System for subsequent playback and recording of traces. The design and development of equipment in this section, in particular the electronics, were conducted in collaboration with Dr. A.E. Trappitt.

3.4.1 Ankle Strap Transducer

A transducer was designed and built to measure the force being applied to the dorsum of the foot by the ankle strap of the AFO, (Fig. 3.12).

Design

The transducer which was made of HE30 TF aluminium alloy, consisted of three main components - an inner and an outer shell, and a central beam, (Fig. 3.13). The two shells were curved to conform to the curvature of the dorsum of the foot. It was necessary also to have as low a profile as possible so that it would not interfere with the fitting of the ankle strap itself. The central beam was straight, (Fig. 3.14). When assembled the complete transducer was Z-shaped with the central beam nesting between the inner and outer shells. The outer shell was attached by bolts to one end of the central beam, the inner shell to the other.

The transducer was designed to be sensitive to purely axial load only, i.e., compression between the shells and perpendicular to the central beam. The maximum load for which it was designed was

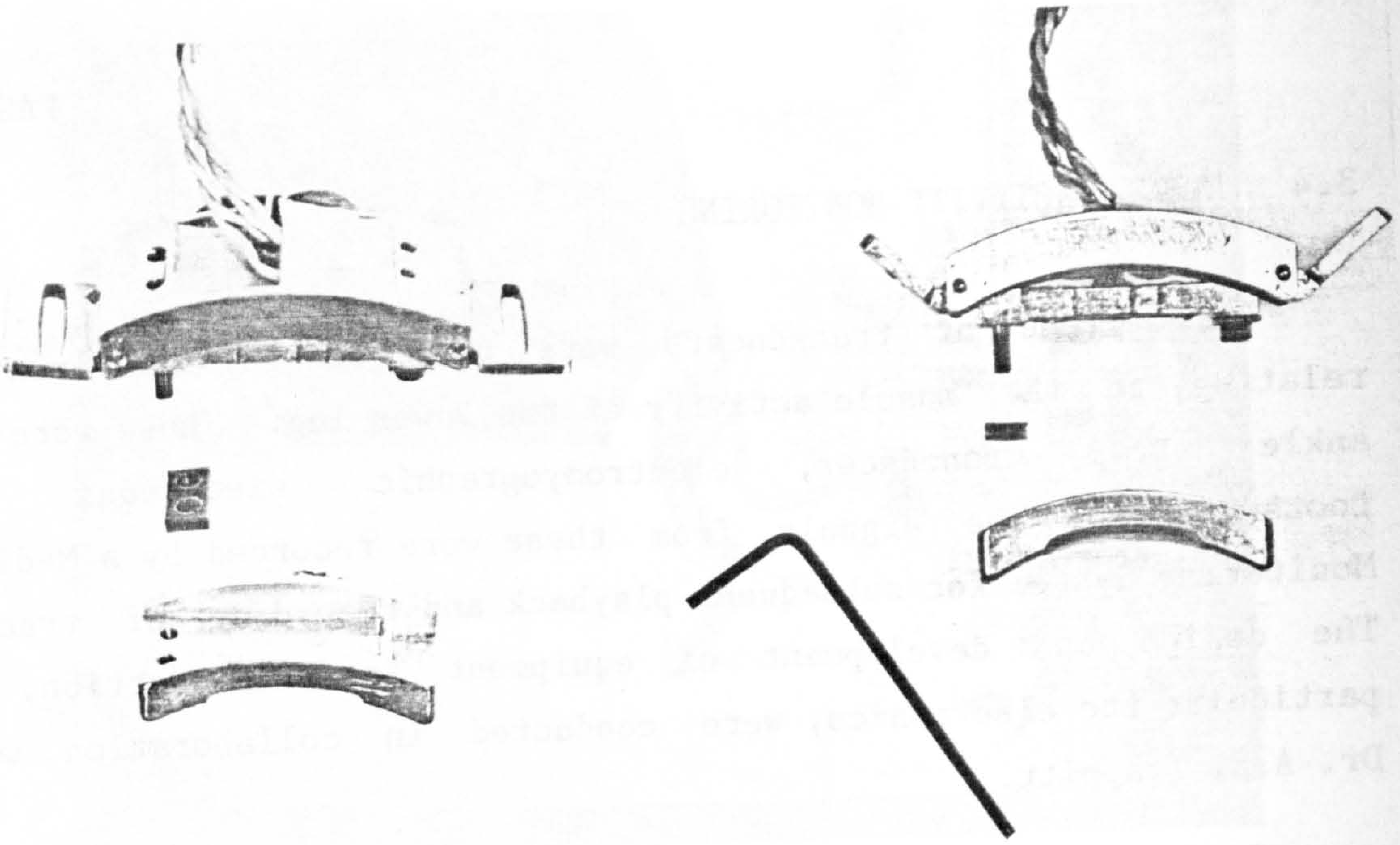


Fig. 3.14

Ankle strap transducer with inner shell removed to reveal straight central beam.

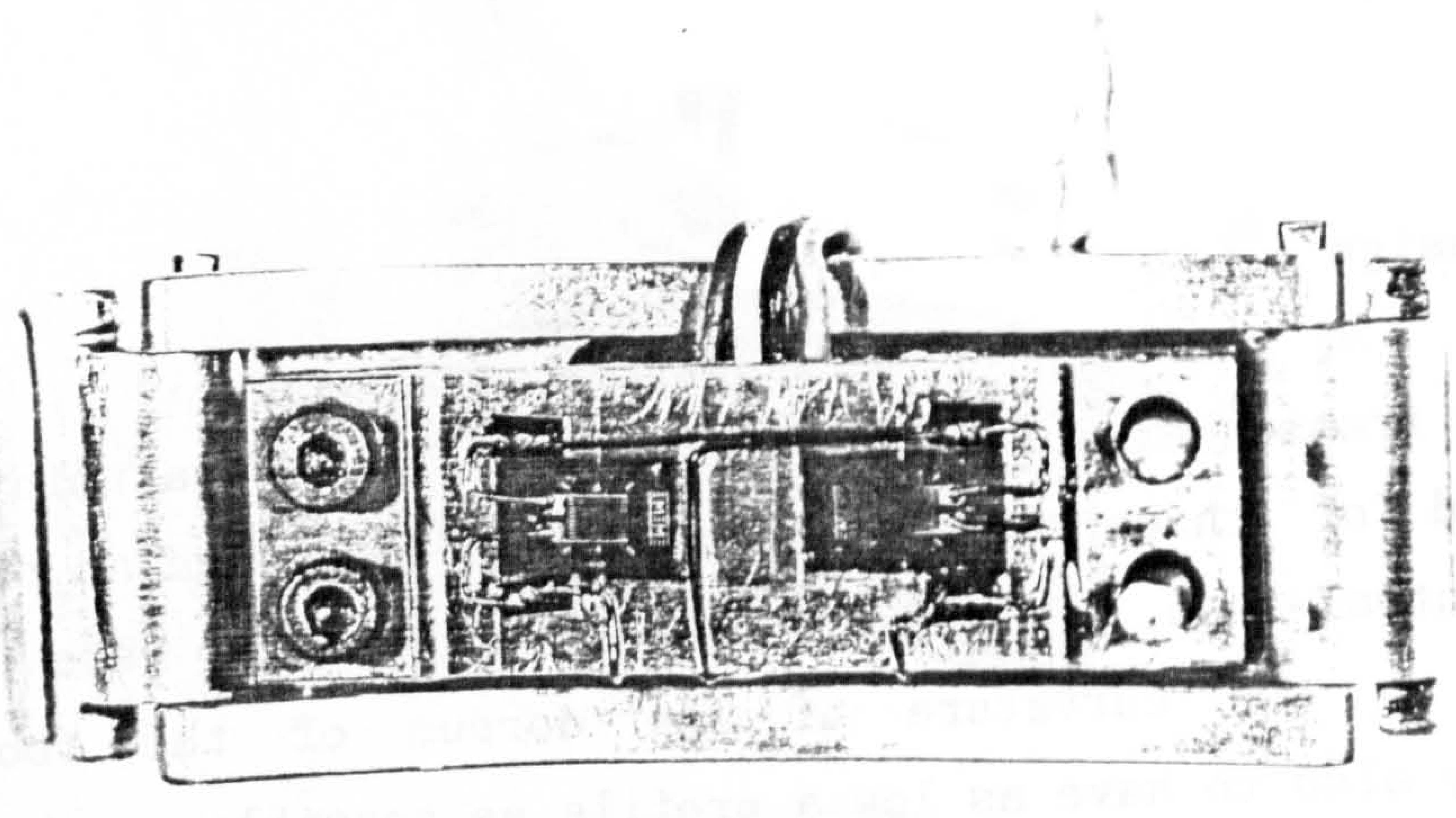


Fig. 3.15

Strain gauge locations on central beam.

200N. The transducer employed the principle of measuring axial force by converting it to a shear force on a beam. In this case the central beam was strain gauged to measure bending moments at two points along its length and the shear force measurement was obtained from the difference between these bending moments, (Fig. 3.15).

This design permitted increased sensitivity and a much lower profile than a column transducer strain gauged to measure axial compression, but with the penalty of increased flexibility. This, however, was probably insignificant compared with the flexibility of the structure of the AFO, the strap and soft tissue.

At the ends of the outer shell lugs were attached to locate the Velcro straps of the AFO. The inner shell was padded with "Evazote" foam for comfort. The relative dimensions of the shells were such that the ankle strap came into contact with the outer shell only and the inner shell with the dorsum of the foot only. This ensured that all the load on the dorsum caused by the ankle strap was transmitted through the central strain gauged beam.

Calibration

A calibration rig was designed and produced to calibrate the transducer. For this purpose the curved inner and outer shells were replaced by flat plates to facilitate mounting and load application, (Fig. 3.16). This rig permitted calibration of the sensitivity of the strain gauged central beam to the anticipated perpendicular compressive loading. The top plate had a matrix of dimples on it so the line of action of the compressive loading could be offset in the two directions across its surface, (Fig. 3.17). This permitted the check for any variation in sensitivity of the transducer beam caused by the offset. This facility was particularly important to examine the influence of variation of the tightness of the bolts.

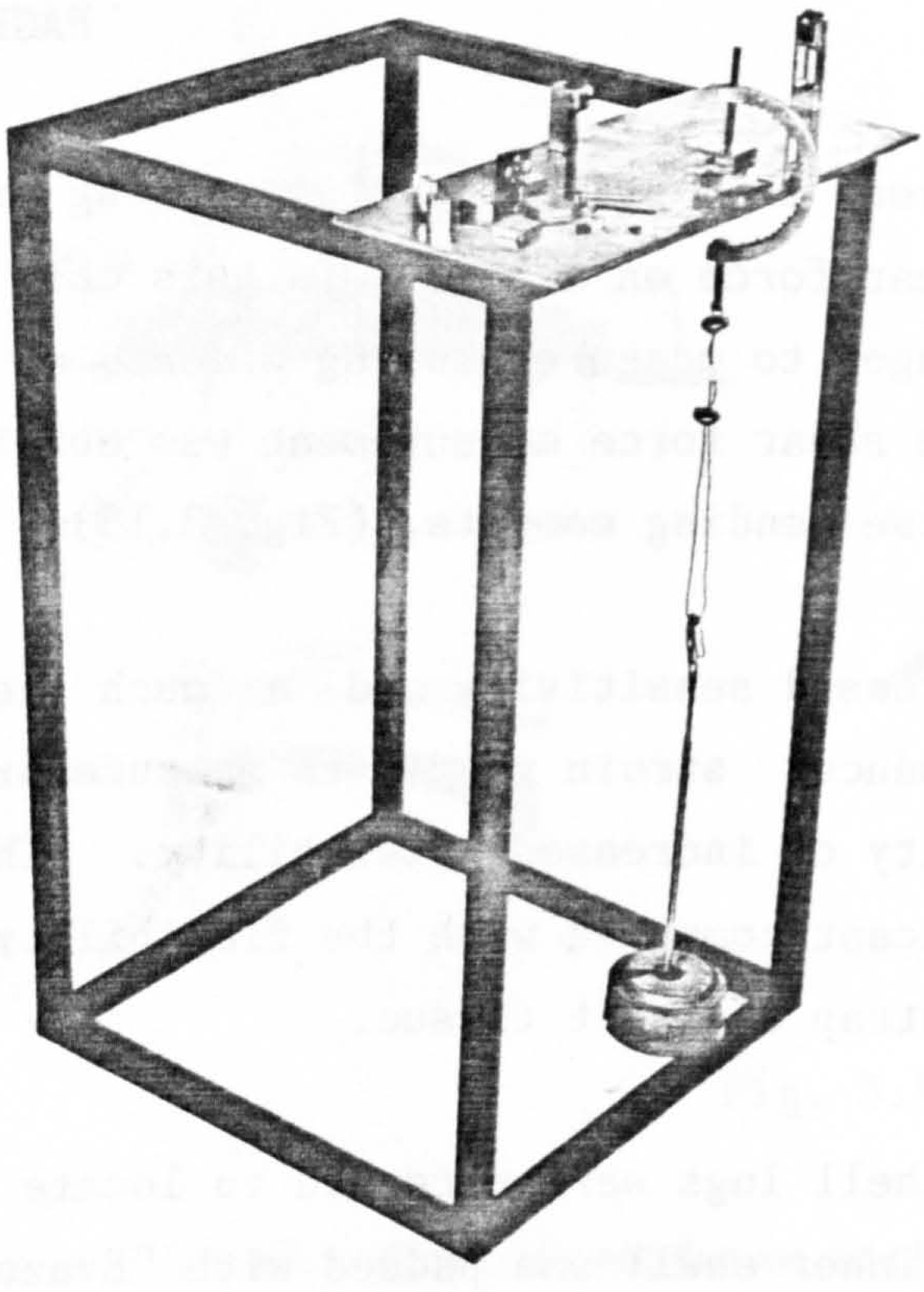


Fig. 3.16

Ankle strap transducer calibration rig.

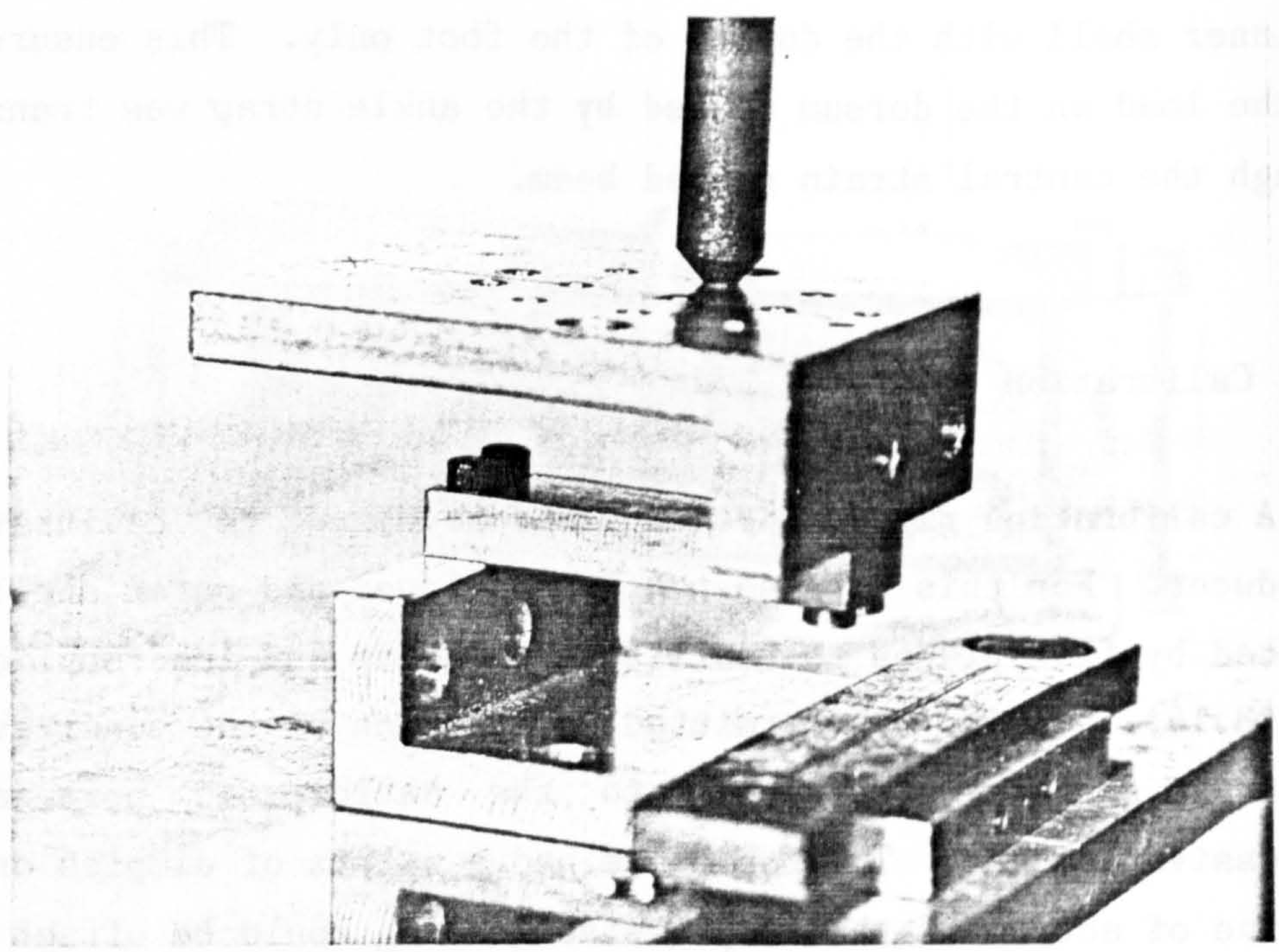


Fig. 3.17

Ankle strap transducer calibration. In this illustration the central beam has been replaced by a dummy of the same external dimensions.

By varying the attitude of the plate-central beam assembly and the methods of load attachment it was possible to load the central beam in other modes to confirm its non-sensitivity. These modes, relative to the central beam, were tension along its long axis, and torsion about the long axis, the short axis and the axis perpendicular to the gauged surface.

3.4.2 Electromyography

Electrodes

Electomyographic studies were conducted to monitor the phasic activity of certain muscles in the lower leg. Silver/silver chloride electrodes produced by Specialised Laboratory Equipment Ltd., England were used, (Fig. 3.18). These were originally designed for paediatric e.e.g. monitoring. They were chosen for the e.m.g. studies because they were conveniently small to permit insertion between the calf of the leg and the AFO. Conducting jelly was also employed.

Skin Impedance Meter

An impedance meter was constructed from a design by Crawford and Smith, (1979), and modified by Dr. Trappitt. This was for the purpose of measuring the contact impedance between the body and the electrodes and thus to ensure adequate conduction to provide an e.m.g. signal of sufficient amplitude for recording. The circuit diagram for this is included in Appendix III.

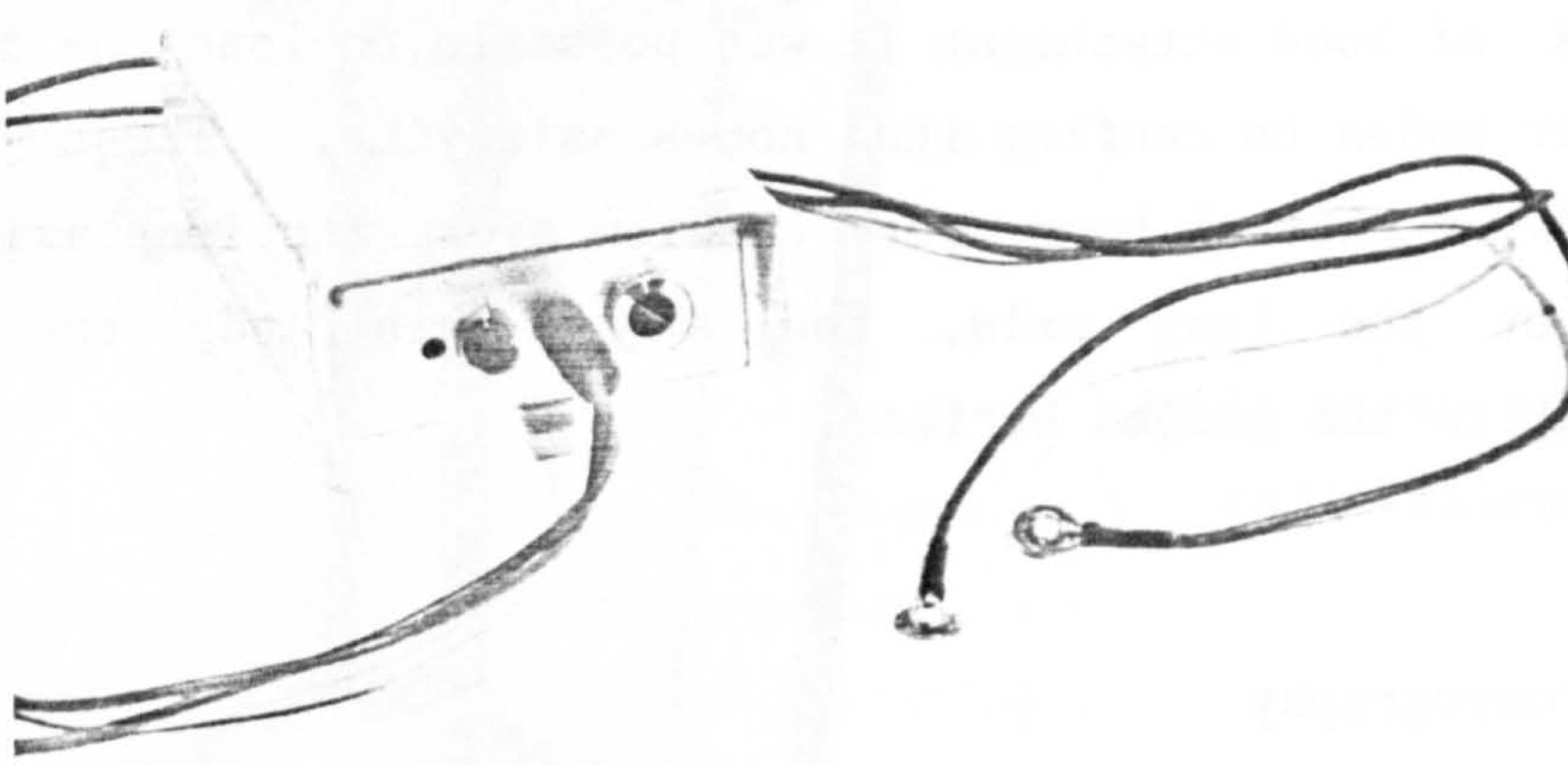


Fig. 3.18

EMG electrodes and skin impedance meter.

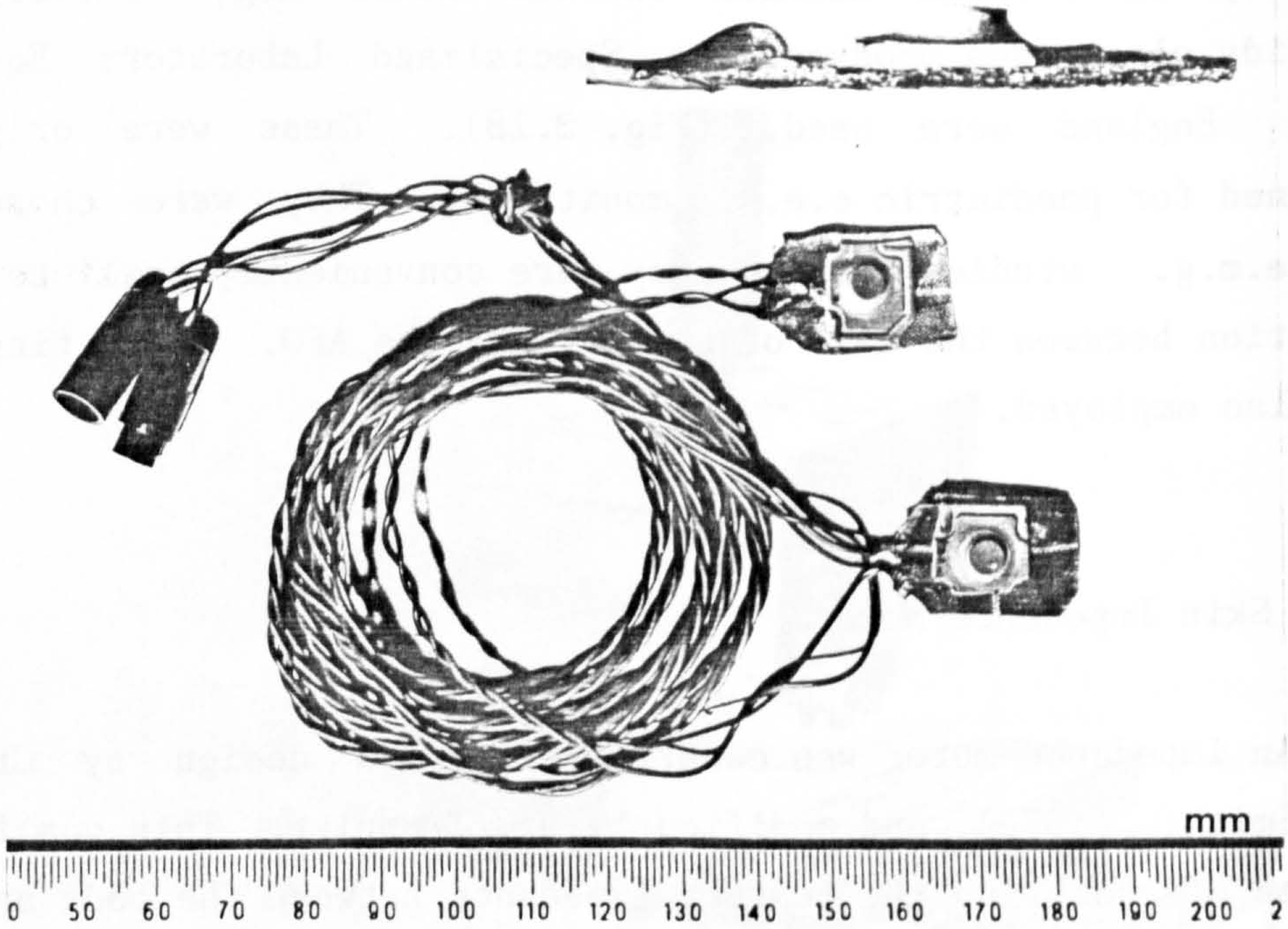


Fig. 3.19

Footswitches.

3.4.3 Footswitches

Footswitches were necessary to indicate the occurrence of heel contact and toe-off at the beginning and end of stance phase during short-term monitoring of muscle activity. This was necessary to permit the synchronisation of the ankle strap load and e.m.g. activity with the phases of the gait cycle.

The footswitches were constructed from single units of a conductive rubber contact keyboard supplied by Maplin Electronic Supplies Ltd., Rayleigh, England, (Fig. 3.19). The conductive rubber element of the unit short-circuited the ends of two wires.

The switches were incorporated into a voltage subtraction circuit included in the power supply monitor unit. This permitted voltages of varying amplitudes to be obtained according to the combination of the switch conditions.

Operation of the switch applied 3 volts to the input of a high input impedance switch amplifier with a gain of approximately one-third. The high input impedance was found necessary to offset the relatively high "on" resistance of the switch. The output of one of the switch amplifiers was fed to the inverting input, while the other was fed to the non-inverting inputs of a differential amplifier, with gains of approximately one-tenth and one-twentieth respectively. These gains were set to give the optimum levels into the recorder. With only two switches it was possible to obtain an indication of four states - heel strike, foot flat (two switches closed), toe-off and swing (two switches open).

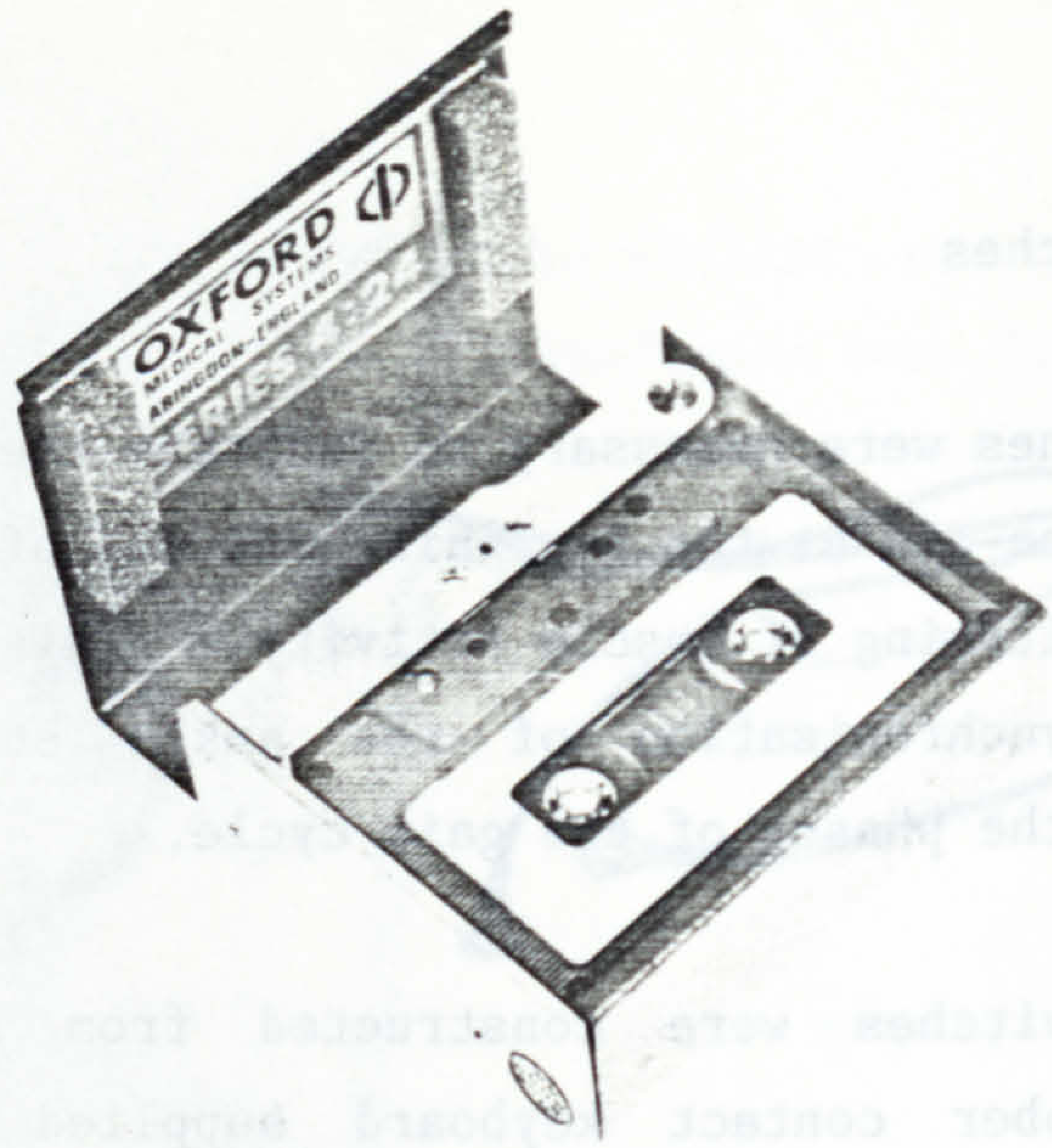


Fig. 3.20

Medilog tape recorder.

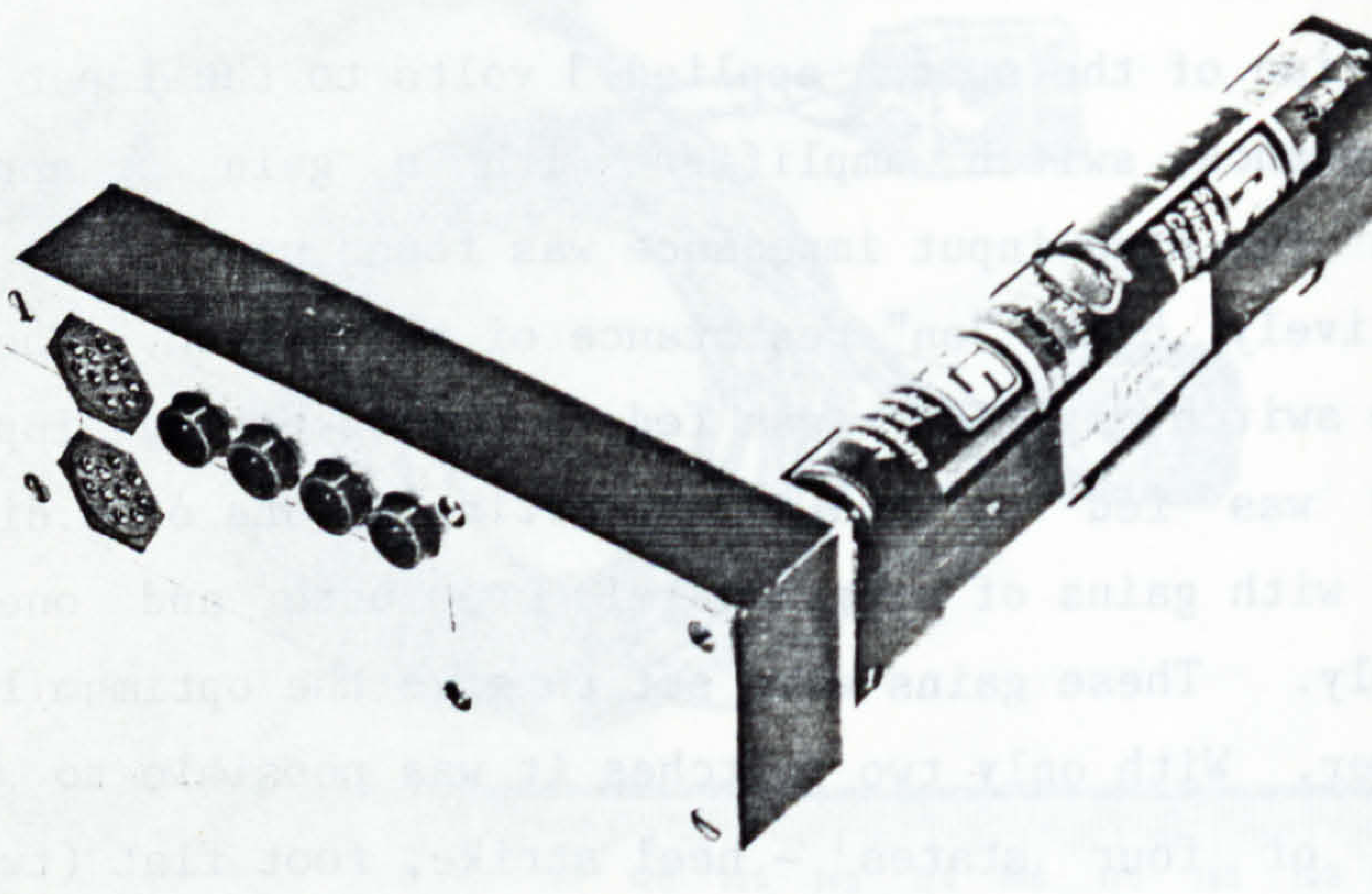


Fig. 3.21

Power supply unit.

3.4.4 Medilog Monitoring System

Recorder

A lightweight miniature tape recorder, produced by Oxford Medical Systems, Oxford, England was used, (Fig. 3.20). This was capable of recording the outputs of the ankle strap load transducer, two pairs of e.m.g. electrodes, the footswitches and timing and event pulses in varying combinations. A maximum of four channels were possible at any one time. The recorder was capable of continuous operation for twenty-four hours. It was fitted with type AM-34 and AD-20 amplifiers to permit the recording of D.C. and A.C. signals respectively.

A leather harness was used to attach the recorder on to the front of the child's chest.

Power Supply and Monitoring Systems

A power supply was constructed to energise the strain gauged bridge on the ankle strap transducer. This consisted of four type AA nickel-cadmium batteries which drove a voltage regulator to produce a bridge supply of 3 volts. The battery supply was able to fall to 4 volts before the output voltage was affected.

This power supply was contained within a unit which plugged directly into the side of the recorder. The outputs from all transducers were plugged into this unit but fed directly through to the recorder, (Fig. 3.21).

A calibration facility was included within this unit for the load channel. By short-circuiting two pins a calibration voltage equivalent to 50N from the ankle strap transducer was connected to the load transducer input. An event signal, achieved by short-circuiting two other pins with a detachable switch permitted the recording of an event, such as the beginning of a test session on the timing channel.

An XM-2 monitor, also manufactured by Oxford Medical Systems was used to monitor the recorder battery condition and the magnitudes of the transducer signals, while preparing for a test session. This unit plugged into the recorder on the opposite side from the power supply unit and was removed before starting the test session.

3.4.5 Playback and Recording System

A type PB2 playback unit, manufactured by Oxford Medical Systems, was used for the replay of tapes from the recorder. The replay speed was x60 of the recorded speed. This unit was fitted with Type PM-3-250 and PD-2 amplifiers for the replay of DC and AC signals respectively.

The outputs from the playback unit were fed into a U.V. recorder, type SE2100, manufactured by S.E. Laboratories Ltd..

The playback unit produced two sets of timing pulses with frequencies which were equivalent to 60Hz and 0.2Hz in real-time. For the long term monitoring studies pulses to the recorder at real-time intervals of one minute, ten minutes and one hour were required.

A timer unit was designed and constructed by Dr. Trappitt which divided the output pulses from the playback unit to give the appropriate timing. The circuit for this is included in Appendix III. A switch permitted the selection of either of the two sets of timing pulses. An additional momentary switch reset the counters to zero.

CHAPTER 4

EXPERIMENTAL PROCEDURE

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1 INTRODUCTION

This chapter describes the procedures developed for the three main areas of data acquisition: gait analysis, AFO and footwear characteristics measurement and muscle activity monitoring.

4.2 GAIT ANALYSIS

A 2-dimensional analysis of the chosen limb was conducted using the television-computer gait analysis system installed in the biomechanics laboratory at Dundee Limb Fitting Centre.

4.2.1 Preparation of Television-Computer System

Prior to the child arriving at the laboratory some preliminary preparation of the gait analysis system was carried out.

The force plate was orientated so that the child walked along the short axis of the plate. This helped to avoid the problems of double stance when the contralateral foot hit the plate also. It was considered essential that the process of adjusting the plate orientation was completed prior to the child arriving in the laboratory to avoid any chance of viewing the large pit containing the plate mounting systems. This might otherwise have resulted in anxiety, or at least deliberate aiming for the plate.

The force plate amplifier sensitivities were set to Fx and Fy = 50 N/V and Fz = 200 N/V.

The camera was positioned as far from the centre of the force plate as possible which was a distance of 4.5m. The calibration grid was placed facing the camera and along the long axis of the plate. A telephoto lens was fitted and focused onto the grid. The aperture was set at f11 which was an initial estimate requiring confirmation or alteration subsequent to the start of the tests.

The camera was switched on at least one hour prior to data acquisition to permit it to warm up and stabilise.

After the system was considered to have stabilised the calibration procedure was conducted. The calibration grid was placed in position over the force plate. A program was run which calculated the size of the field of view and determined the location within it of the force plate. The grid was then removed.

Finally a check was made to ensure that the items required for patient preparation were in order. These included a skin marker pen, reflective markers, tape measure, Polaroid camera, "bathroom" scales, record sheets, chalk, towelling pants, sweets and toys.

4.2.2 Patient Preparation

The child was brought to the laboratory by the mother or another adult with whom it was familiar. In most instances the child was very familiar already with the research team as many of the members had already been involved clinically with the child for several years. No white coats or other uniforms were worn by the staff in order not to impose a clinical atmosphere. Toys were placed in the room to create an informal setting.

Many of the children were already very familiar with the laboratory having attended regularly over the previous years for the purpose of cine-filming. They were, therefore, quite used to being asked to walk up and down the laboratory, frequently with floodlighting and cameras.

The tests were conducted with the child wearing minimal clothing, e.g. towelling pants. In most cases the child would already have had a thorough physical and neurological examination as part of the routine clinical care. If not this was conducted prior to the gait analysis procedures. The record sheets used in this examination are included in Appendix IV.

In this series of tests only one limb was measured by the gait

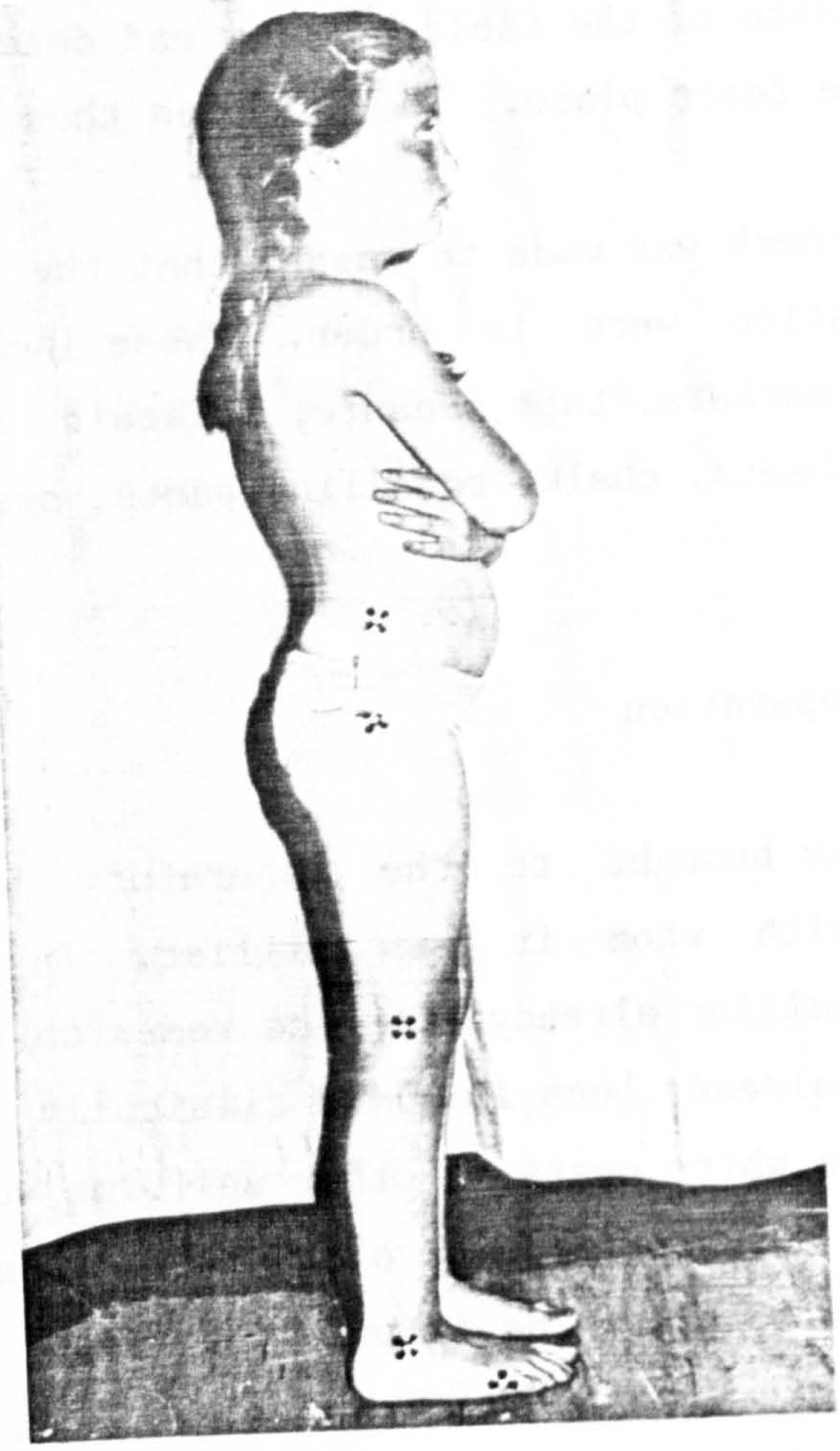


Fig. 4.1

Marker locations.

analysis process. Usually this was the most severely affected side. Ideally both legs should have been measured but this was considered to be unfeasible. There were two reasons for this, the first the overall time-scale of the project and the second the fact that few children had a sufficiently long tolerance to permit prolonged testing on the same occasion.

Marker locations

For the purposes of the kinetic analysis it was necessary to determine the angles throughout stance phase and to know the location relative to the force plate of the joint centres at hip, knee and ankle in the A-P plane. A system of five markers were therefore required - one each at hip, knee and ankle and an additional one on the pelvis and also on the forefoot, (Fig. 4.1). The joint centres were determined by identification of anatomical landmarks and passive movement of the limb segments to observe their relative motions. The chosen location was marked by a cross drawn by a water-soluble felt pen for subsequent attachment of the reflective markers using double-sided adhesive tape.

The marker for the hip joint was placed approximately 20mm superior to the greater trochanter. The marker for the knee joint was placed above the anatomical joint line on the lateral femoral condyle. An approximation had to be made because of the polycentric nature of the rotation of this joint. The marker was, therefore, placed at a point considered to be average for the locus of the instantaneous centre of rotation between full extension (0 degrees) and 45 degrees of flexion.

An additional problem in determining the appropriate location of the knee marker was frequently encountered. This was due to the fact that many of the CP children walked with a marked in-toed gait. This could be due to a variety of reasons including femoral neck

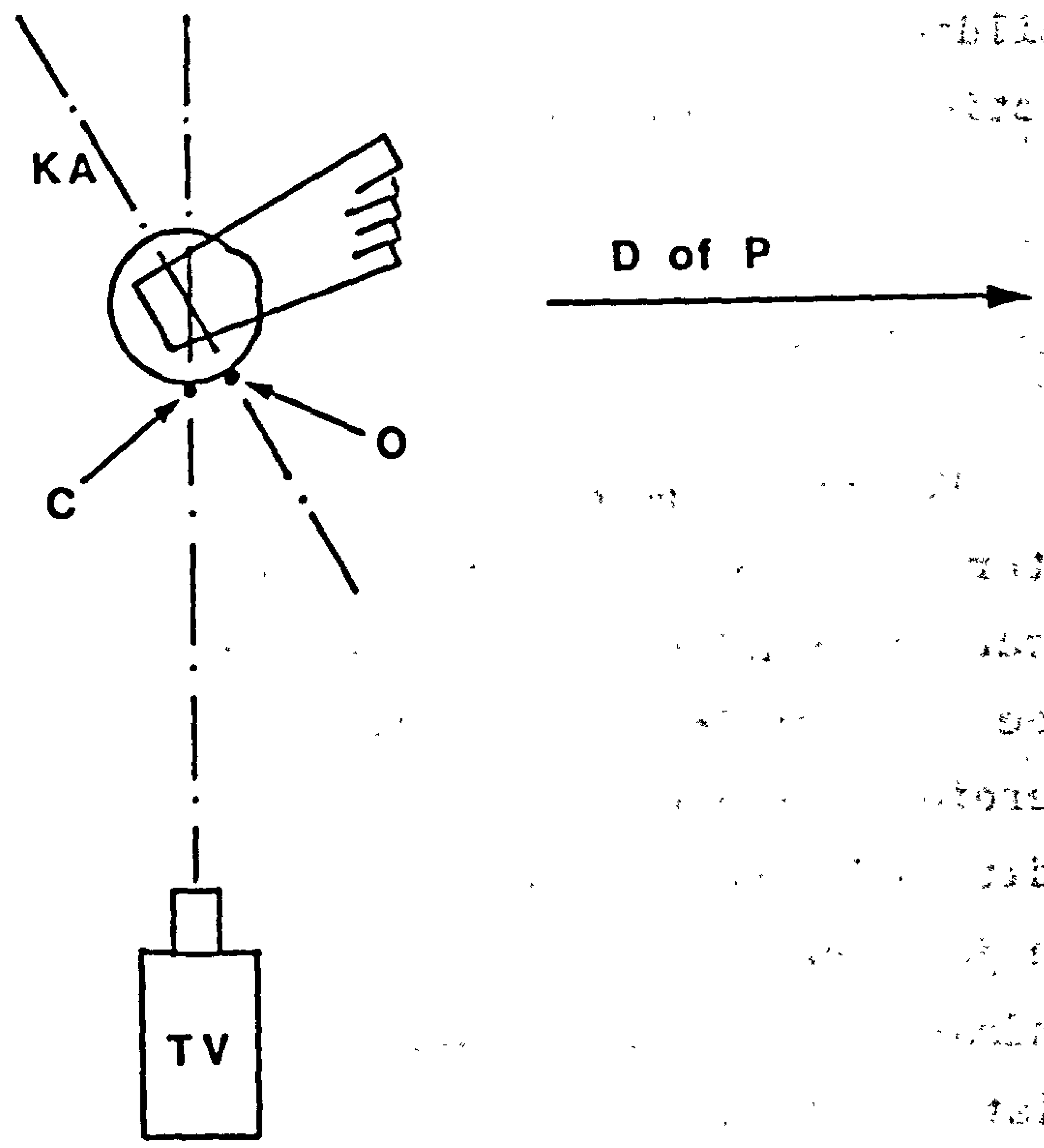


Fig. 4.2

Knee marker location to compensate for internal rotation.

O	original location
C	correct location
KA	knee joint axis (flexion-extension)
D of P	direction of progression
TV	television camera

anteversion, femoral or tibial torsion, or over-activity of the internal rotator muscles. If this resulted in internal rotation of the knee joint during gait, errors in the measured location of the knee joint centre and the computed knee angle would result.

These errors resulted because a single TV camera was used to produce the 2-D analysis. Internal rotation of the knee caused forward movement of the laterally placed knee marker, (Fig. 4.2). This, therefore, caused an apparent knee flexion. In addition, the relationship between the indicated apparent knee joint centre and the line of action of the ground-to-foot force would be inaccurate resulting in an error in the computed external knee moment. These would not have been problems if a multi-camera 3-D analysis had been possible which would have given a true value of the knee centre position.

It was decided, therefore, that an attempt should be made to minimise these errors. The child's gait was observed clinically to determine the extent to which internal rotation of the knee was a problem. As the amount of rotation varied throughout the stance phase particular attention was paid to estimating the magnitude of rotation at mid-stance. Once this had been determined the skin marker was then moved posteriorly from its original location, but in the same horizontal plane. A correct position of the marker was obtained when, in mid stance, the marker would lie on the line joining the centre of the knee axis and the camera lens.

The marker for the ankle joint was placed on the lateral malleolus. The pelvic marker was placed on the iliac crest so that the line joining it and the hip marker was parallel to the lower end of the spine. The forefoot marker was placed on the lateral aspect of the fifth metatarsal head.

The distances between the five markers themselves and the height off the ground of ankle and forefoot markers were determined by tape measure and noted on the appropriate record sheet. In addition the distance to the ground from the hip marker was recorded with the child standing as erect as any joint contractures would allow. This value was considered to be "leg length" and was recorded to make the biomechanical data non-dimensional in subsequent calculations.

A Polaroid photograph was then taken of the child with the camera lens placed at knee height to minimise parallax. This was a lateral view, particular care being taken to ensure that the ankle axis was perpendicular to the plane of the photograph. If necessary if the foot was markedly internally or externally rotated, two photographs were taken. One was taken with the camera perpendicular to the sagittal plane of the body and the other perpendicular to the plane containing the shank and foot, i.e., parallel to the ankle axis.

The Polaroid photographs and tape measurements were used to aid the replacement of the markers in identical locations. This was either for tests on different days or test with and without AFOs on the same day. They were also used to assist measurement of the AFO and footwear characteristics.

Finally, the child's body mass was measured using a set of scales and recorded on the documentation.

4.2.3 Locomotion Data Acquisition

The principal objective was to get the child to traverse the laboratory in a straight line coincident with the centre line of the force plate with the leg to be measured nearest the camera. In addition the foot on the side measured had to strike the force plate "cleanly", i.e. completely on the plate surface, without overhanging the edges and preferably as near to the centre as

Fig. 4.3

Child walking over the force plate
showing the difficulty of striking the plate correctly.

possible. It was also necessary that the contralateral foot did not contact the plate either with the toe on the preceding stance phase or the heel on the following stance phase - "double contact". This implied, therefore, that to avoid double contact the child's stride length, less the foot length, had to be greater than the dimension of the plate in the direction of progression, (Fig. 4.3). If this distance was not significantly greater than the force plate, or less than it, it was unlikely, or impossible, that single contact would be obtained. In these cases the child's line of progression was moved sideways away from the camera so that the tracking line of contralateral foot was beyond the far edge of the force plate.

Once the child's line of progression had been determined it was then necessary to determine the starting point. This was critical if the force plate was to be hit "cleanly". This position was determined by trial and error similar to the process used by a long-jumper, and a chalk starting line drawn. The distance to the force plate varied between 1m and 3m depending on the child's age or the severity of the disability.

Even once this point had been determined problems could still arise either from the variable stride lengths between test runs or by the child starting with a different foot. To eliminate the latter problem the child was observed to see if there tended to be a preferred side. This was noted if it did occur and if not an arbitrary side was chosen. The starting point was then marked on the floor by drawing two chalk foot-prints with the chosen starting foot about 50mm behind the other. In this way the child would start with the trailing foot.

To assist the tests the child would be asked to walk from the starting point to a seat placed beyond the force plate. If the child had been brought to the laboratory by a person such as the mother, she would be asked to sit on the seat to encourage the child. This was particularly useful for the younger children. The person conducting the test would sit behind the starting point so that he could assist the child to place his feet correctly and maintain the child's balance by holding his pelvis. The child would then be instructed to walk and if necessary could be guided for the first pace in the appropriate direction to avoid the initial sidesway experienced by the more severely affected children before gaining their forward momentum. The tone of voice used could also influence the child's walking speed, a soft, gentle instruction resulting in a slow speed, a louder, urgent instruction increasing the speed. This could help to obtain repeatability between tests or, by varying the cadence, influence the ability to strike the force plate "cleanly".

It was important for the person conducting the tests to be able to communicate easily with the computer operator. This was necessary for the purposes of timing the start of the test run to coincide with the state of readiness of the program, and to indicate, after a test run, if the data obtained from the run was of adequate quality to warrant it being stored.

Documentation was used to record the approximate position of the foot on the plate and to indicate if there was some doubt as to whether double stance had occurred, (Appendix IV). In addition there was a space for comment on the quality of the observed gait, e.g., could it be considered typical of that child's gait, was it quicker or slower than normal, did the child stumble or was he distracted? The information obtained was thus available for reference while the data outputs were being scrutinised. If the data appeared to be atypical then reference could be made to the documentation to see if the gait had been considered to be unusual on acquisition. If this was indeed the case then this might influence whether the data would be included for further analysis or discarded at this stage. This is discussed further on page 92.

The child would be permitted to walk with the minimum of instruction so that the influence on his gait was minimal. Obviously it would be likely that the child would be less at ease initially and, therefore, it was of less value taking data right away. A period of familiarisation was usually necessary especially with the young children who might be less familiar with the laboratory situation.

A problem sometimes encountered was obscuring of the pelvic and hip markers by the arm and hand. This could either be for a relatively short period during the gait cycle or for significant periods with a child whose arm motion was limited. This was often the case with the more severe diplegics. The hemiplegics, however, frequently walked with the affected arm raised which thus avoided the problem.

While the child was walking during the initial familiarisation period the TV monitor would be observed to see to what extent obscuring of the markers would present a problem. If this was considered to be sufficiently severe to prevent adequate plotting of the marker trajectories during subsequent data analysis then steps had to be taken to overcome this problem.

The first two or three runs would be achieved allowing the child to adopt the arm motion that came naturally. These were for the purpose of obtaining baseline data on the nature of the ground-to-foot force vector and the motions of ankle and knee joints, the motion of the hip joint being unreliable. The child was then asked to walk with his arms held across his abdomen or behind his back, whichever was determined to be easiest or most natural for a given child. Once this had become familiar the main data acquisition would then take place. The placement of the arms would be recorded on the documentation.

The data obtained initially with the arms free would then be compared with the data obtained subsequently. In this way it could be confirmed whether or not the necessity to restrict the arm motion had unduly influenced the child's gait.

After the first few runs had been obtained it was necessary to examine the quality of the TV data obtained. This was because problems could be encountered with the TV-computer system relating to the amount of light received from the reflective markers. If insufficient light was received the occurrence of the marker in a given TV frame would not be registered. Gaps in the trajectory of the marker would then result where this problem had occurred. Conversely if too much light was received a "comet and tail" effect could result. The averaging process conducted by the program might produce two spots for a given marker which could cause severe problems in obtaining the marker trajectories during later data processing.

The amount of light entering the TV tube was a function of the size of the reflective marker, the velocity at which it was travelling and the aperture of lens. The marker size was fixed by its design. The marker velocity was, however, highly variable depending on the manner of the child's gait. This was particularly so with the smaller and more severely affected children. While the the pelvic and hip markers might travel forwards with a relatively constant velocity, the markers on the foot alternated between maximum during swing and zero during stance, with only a few 1/50 second samples separating these two states.

It was therefore necessary to optimise the aperture setting on the TV camera to accommodate the varying velocities. The initial tests would be conducted with the aperture set mid-way between f11 and f16. It was sometimes necessary to adjust the aperture in increments of 1/8 of the difference between f11 and f16.

It is possible that further development of the skin marker geometry might have eased this problem, however, it is considered that further development of the system using stroboscoped infra-red lighting which is underway, will avoid this problem.

The test runs were conducted with the child barefoot or in any configuration of AFOs, or footwear adaptations considered to be appropriate for that particular child. This aspect will be discussed further in Chapter 6. No set order of configuration was adopted, e.g., barefoot first or with AFOs. The chosen order depended largely on the temperament of the child in question and the severity of his disability. Generally the configuration would be chosen with which the child was most familiar. For instance with the more severely affected children who found barefoot walking difficult and consequently did little walking in this condition normally, the test would commence with the AFO being worn. On the other hand, with the less severely affected children who were familiar and competent with barefoot walking the test would generally start in this state, and progress in a logical fashion towards the most complex configuration prescribed for that child.

The total number of test runs would depend on such factors as the severity of the child's condition, the success to which the force plate was struck and the temperament of the child. It was considered desirable to obtain ten successful runs in each configuration so that perhaps seven might result finally once some had been discarded either because of atypical gait or because of failures during subsequent data analysis. Obviously this was not always possible.

The decision to adopt the policy of discarding data from test runs which were considered to be grossly atypical was made in recognition of the complexity and acknowledged variability of the gait of CP children and the influence on it of AFOs. It was expected that considerable intrasubject and intersubject variability would be encountered and that interpretation of the data would be problematic. It was considered that if all successful test runs, i.e., those in which the force plate was struck cleanly, were included in the analysis the data from those runs which were grossly atypical would tend to conceal the nature of the data from those runs which were considered typical. It was felt that the total data were likely to contain variation over and above that due to the normal variation pertaining to the nature of the pathology. It was quite possible that the influence of the AFOs on gait would not therefore be detectable.

Consequently test runs were rejected if the child tripped, stumbled, was distracted, hesitated, deviated grossly from the chosen line of progression or was excessively fast or slow. It is estimated that approximately 10% of test runs in a session were thus rejected. If there was any doubt as to whether the test run was typical or atypical the data were not rejected. This may have contributed to the large variation in the data observed on analysis.

Although the decisions to accept or reject data were made after observation of the gait and its qualitative assessment it must be remembered that this was carried out by the clinic team which was considerably experienced in this subject. While the policy of rejecting atypical test runs may be open to debate it was considered acceptable, and indeed sensible, in order to make any progress towards understanding the nature of the gait of CP children and the influence on it of AFOs.

Once the tests were complete the skin markers were removed and the underlying pen crosses were washed off. The child was rewarded by being allowed to choose something from the sweetie jar. Frequently following the test sessions the children often felt playful. If this was the case they would be allowed to play around in the laboratory. This was considered important so that they would become more familiar with the laboratory surroundings and therefore be more at ease on any subsequent visit. Finally the suggestion of a future visit would be made to the child and hopefully agreed upon.

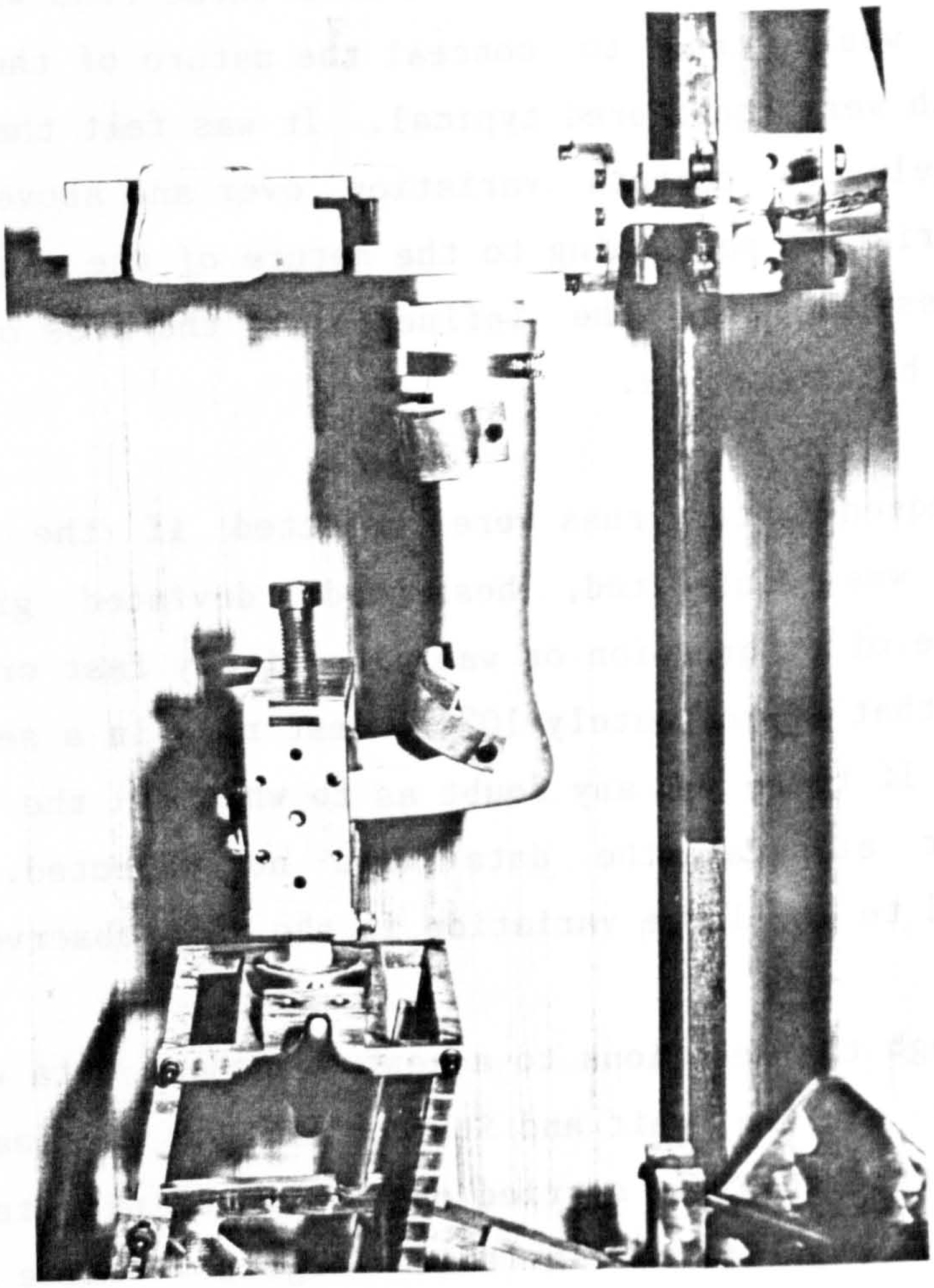


Fig. 4.4

AFO in stiffness measurement rig.

4.3 ANKLE-FOOT ORTHOSES AND FOOTWEAR CHARACTERISTICS

During the latter stages of the gait analysis programme two further forms of measurement were possible. These were concerned with the measurement of the characteristics of the AFO-footwear complex.

4.3.1 Ankle-Foot Orthoses Characteristics

Two principal characteristics of the orthoses were considered to be of primary interest - the angle at which it was set and its stiffness in the sagittal plane.

Angle of Set

The angle at which the AFO was set was obtained from the Polaroid photograph taken previously for the purpose of recording the marker locations. It was not therefore necessary to take additional photographs. The definitions of the axes of the shank and foot sections of the AFO which are required to determine the angle are discussed in Chapter 5.

Stiffness

Measurement of the stiffness characteristics was achieved by the use of the purpose-built test rig originally designed for the measurement of adult sized AFOs, described in Chapter 3. The X-Y plotter, bridge amplifiers and D.V.M. were switched on about thirty minutes before the test to allow the system to stabilise. The bridge amplifiers were then balanced.

The AFO was then clamped in the test rig. The calf section was

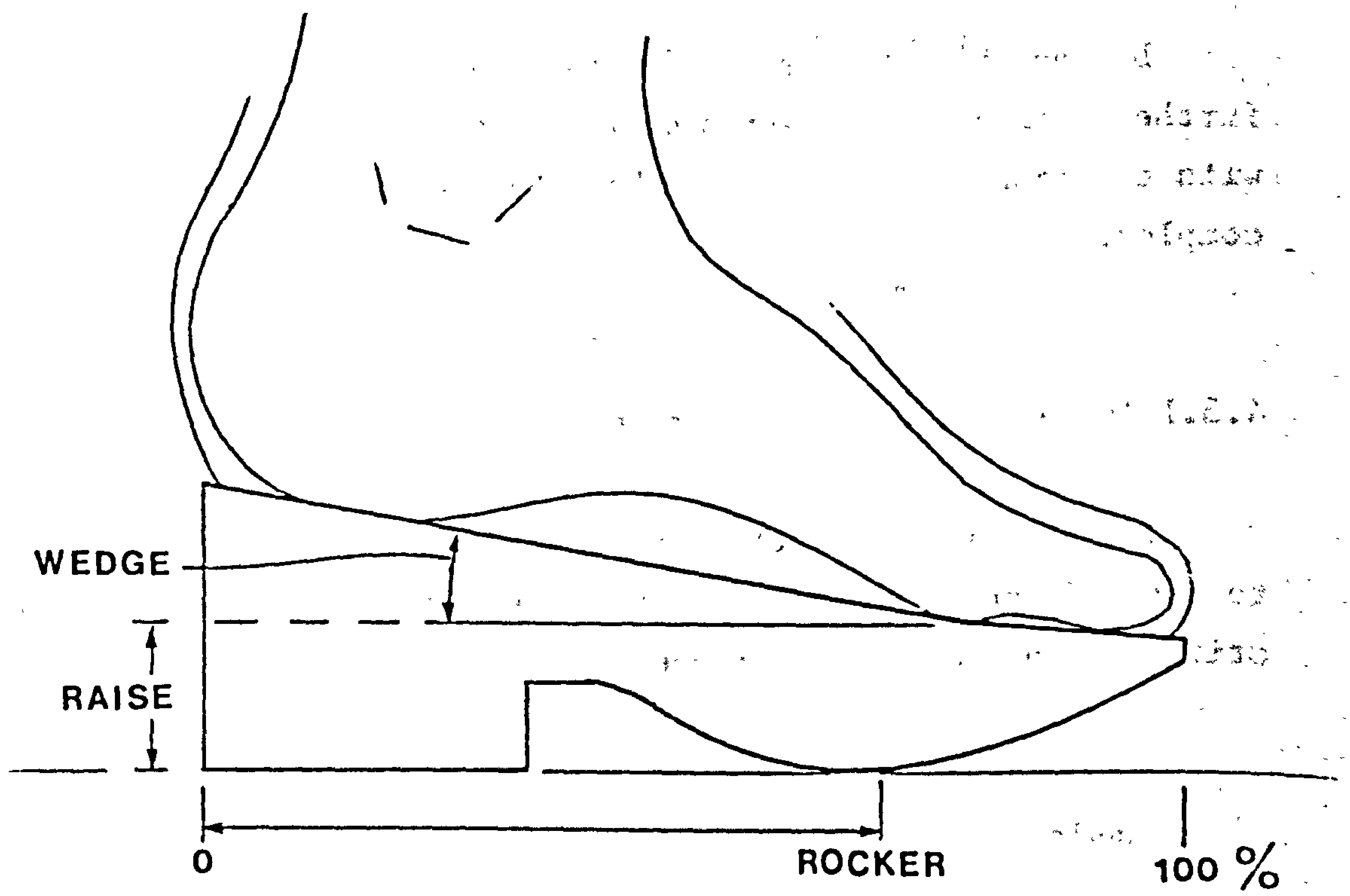


Fig. 4.5

Definitions of footwear characteristics.

clamped using an appropriately sized wooden cylinder and jubilee clip. The foot section was clamped in a powder grip, (Fig. 4.4). If the clamping process had imposed a slight angular deformation on the AFO the relative attitude of clamps would be altered by turning the handle on the machine until the bridge amplifier on the load channel was again balanced indicating a no-load situation. The AFO would thus be at its original angle.

4.3.2 Footwear Characteristics

Three principal characteristics of the footwear were considered of primary importance:– the raise, wedge and rocker effects of the shoe sole, (Fig. 4.5). During the initial gait analysis tests information on these characteristics were obtained from the Polaroid photographs. In the latter stages the purpose built test jig was used.

The properties of the raise, wedge and rocker were identified by their influence on the relationship of the child's foot to the ground. For the purpose of these tests the attitude of the child's foot in the sagittal plane was indicated by the long axis which was considered to join the lowest point of the calcaneus and the lowest point of the fifth metatarsal head. The reasons for this definition will be discussed later, (Chapter 5).

When the AFOs were worn in addition to the footwear the additional thickness of the sole section of the AFO had to be considered in addition to the footwear. This was particularly so if any wedging had to be added to the underside of the AFO at fabrication or if additional temporary packing had been placed under the heel of the AFO during the gait analysis tests. In these cases the combined characteristics of the AFO and footwear were measured.

The locations of the lowest points of the calcaneus and fifth

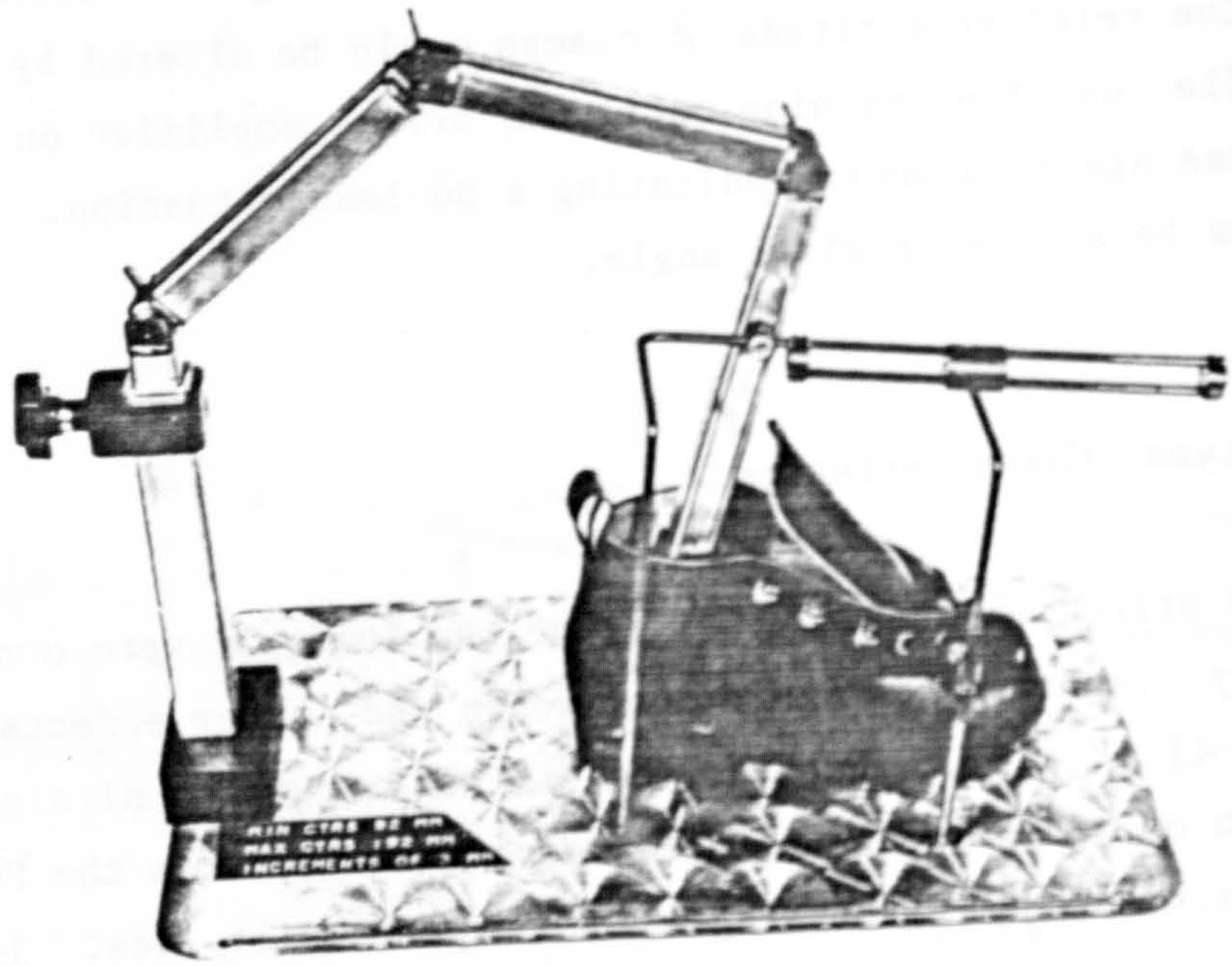


Fig. 4.6

Footwear in measurement rig.
(Protractor has been removed for clarity.)

metatarsal head were identified within the AFO or the footwear as appropriate and their centres marked by felt pen. The distance between the centre spots was measured. The internal needles and discs and external indicators of the test rig were adjusted so that both their distances apart matched this measurement. The footwear, or AFO-footwear combination, was positioned on the rig so that the needles were pressed onto the marked centres. The arm of the rig was then adjusted so that the sole of the shoe was flat onto the base plate. In this situation the external indicators were then identical distances off the surface of the base plate to the internal needles and discs. If the internal curvature of the footwear resulted in an inability to locate both cones because of contact on the arch of the middle section of the telescopic tube the front needle could be dropped downwards to permit clearance to be obtained. In this case the external indicator would also be dropped identically.

Once the rig had been satisfactorily adjusted the measurements were then taken, (Fig. 4.6). Using a ruler the perpendicular distance of the front indicator from the base plate was recorded. This was the value of the raise. The protractor was adjusted so that the arm was aligned through the holes on the indicators. The angle thus measured was the wedge. The total length of the shoe was measured using a ruler. The contact of the sole with the base plate was examined by aligning the eye at the level of the base plate. The point at which the sole left the plate as it started to curve upwards towards the toe was noted. The distance of this point from the rearmost point of the heel was measured by ruler. The ratio of this distance to the total length of the footwear expressed as a percentage was considered to be the rocker index.

Fig. 4.7

Application of ankle strap transducer.

4.4 MUSCLE ACTIVITY MONITORING

A small series of tests were conducted to examine some aspects of the influence on muscle activity of the wearing of AFOs. Two types of monitoring tests were conducted, long term and short term.

4.4.1 Long Term Monitoring

These tests were for the purpose of measuring the ankle strap load for a prolonged period, e.g. during a school day. This was to gain information on the magnitude of this load and its variation over the period selected.

The child to be monitored was seated or placed supine on a couch or the floor. The child would already be wearing the AFO by the time these tests commenced. If necessary the footwear was removed to facilitate the application of the transducer. The velcro ankle strap was unfastened and the child's heel retained within the AFO by gentle thumb pressure on the dorsum. The transducer was then located on the dorsum of the foot and the velcro strap fed through the loops on the transducer outer shell and refastened, (Fig. 4.7). It was important that the straps were tensioned to impose approximately the same retaining force on the dorsum as without the transducer.

The pouch for the Medilog recorder was attached to the child by a harness so that it was located on the front of the chest just above the abdomen. The Medilog recorder with a pre-calibrated tape and power supply unit were inserted into the pouch. The cable from the transducer was fed up the lateral side of the child's leg and underneath all clothing to the waist. The wire was attached to the AFO and the leg with micropore tape.

The transducer was plugged into the recorder. The Medilog

Fig. 4.8

Initial check with monitor unit
to ensure adequate signal.

monitor unit was also attached temporarily to monitor the signal from the transducer. The functioning of the transducer was checked by pressing gently on the outer shell towards the dorsum of the foot.

The shoe was then put on again making sure that it did not interfere with the transducer. If necessary the laces were removed from the top few holes and tied lower down. In this way the effect of the shoe itself on retaining the child's heel into the AFO was kept to a minimum.

The child was then stood up and allowed to walk about, (Fig. 4.8). The signal from the transducer was observed to ensure that its magnitude was adequate for recording purposes. If necessary the amplifiers were adjusted. In an attempt to observe the maximum possible signal and check for overload the child was lifted up and down to stimulate extensor spasm. If the amplifier setting was altered recalibration of the tape was necessary.

Once the system was considered to have been adjusted appropriately the event leads were shorted together momentarily to indicate the start of the test, and the monitor unit detached. The parents or staff concerned with the child were advised that no special action was necessary on their part and that the child was to be allowed to function as during a normal day.

On completion of the tests the event leads were again shorted together. The recorder, transducer and leads were removed. The transducer was reconnected and the recorder allowed to run for approximately five minutes to record the no-load level. The 50N calibration was then switched to ON for five minutes to recalibrate the tape. Finally the recorder was switched off, the plugs removed from the power supply unit and the tape removed from the recorder.

4.4.2 Short Term Monitoring

These tests were for the purpose of examining individual gait cycles to monitor the ankle strap load, the e.m.g. activity of the plantarflexors and the dorsiflexors, and the occurrence of heel strike and toe off.

The ankle strap transducer and the Medilog recorder were attached and connected as described above. In addition the surface e.m.g. electrodes were placed over the bellies of gastrocnemius and tibialis anterior and the leads from these connected to the Medilog recorder. The footswitches were attached to the underside of the shoe at the heel and toe. These were also connected to the recorder. The functioning of these items was checked using the monitor unit as before.

The child was then allowed to walk around for several minutes to become accustomed to the apparatus so that the later gait cycles recorded could be considered typical.

After sufficient data had been collected the AFO and ankle strap transducer were removed. The tests were then repeated to measure the e.m.g. activity of the gastrocnemius and tibialis anterior without the AFO. If necessary an insole was placed within the shoe to compensate for the lack of the AFO and thus ensure a firm fitting of the shoe on the foot. In some instances these tests were conducted barefoot.

Following the tests all the equipment was removed, the load channel recalibrated as described above, the recorder switched off and the plugs removed.

CHAPTER 5

ANALYSIS

CHAPTER 5

ANALYSIS

5.1 INTRODUCTION

This chapter describes the methods adopted to analyse the data obtained from the experiments conducted. These relate to the three main areas of measurement, i.e., gait analysis, AFO-footwear characteristics and muscle activity monitoring. The various sources of error for the gait analysis system are determined.

5.2 GAIT ANALYSIS

The existing software of the TV-computer gait analysis system permitted the acquisition of data relating to the positions in the sagittal plane of the body markers, and the components of the ground-to-foot reaction force. Subsequent processing of the data produced plots of a "stick" representation of the leg with a superimposed ground-to-foot force vector.

Programs existed to calculate the external moments in the sagittal plane caused by the vector at hip, knee and ankle and the angular excursions of these joints in the sagittal plane.

For the purpose of this investigation a convention was adopted whereby external moments at the joints were considered to be positive when tending to extend, and negative when tending to flex. These directions at the ankle joint were plantarflexion and dorsiflexion respectively.

This convention was different from most other conventions adopted for mechanical analysis and gait analysis when moments are considered positive or negative depending on their direction, clockwise or counterclockwise, in the field of view. In this analysis, therefore, when moments at all three joints were positive the anatomical direction of the moments at all three joints was the same, i.e., extension, and vice-versa.

This convention was chosen to assist the identification of the nature of the demand being placed on the muscle groups. Thus if the external moments were all negative, i.e., tending to cause flexion, the muscles required to balance this would be the extensors.

This convention was considered to be more compatible with the clinical presentation of cerebral palsy where reflex activity frequently causes the joints to flex simultaneously or extend simultaneously.

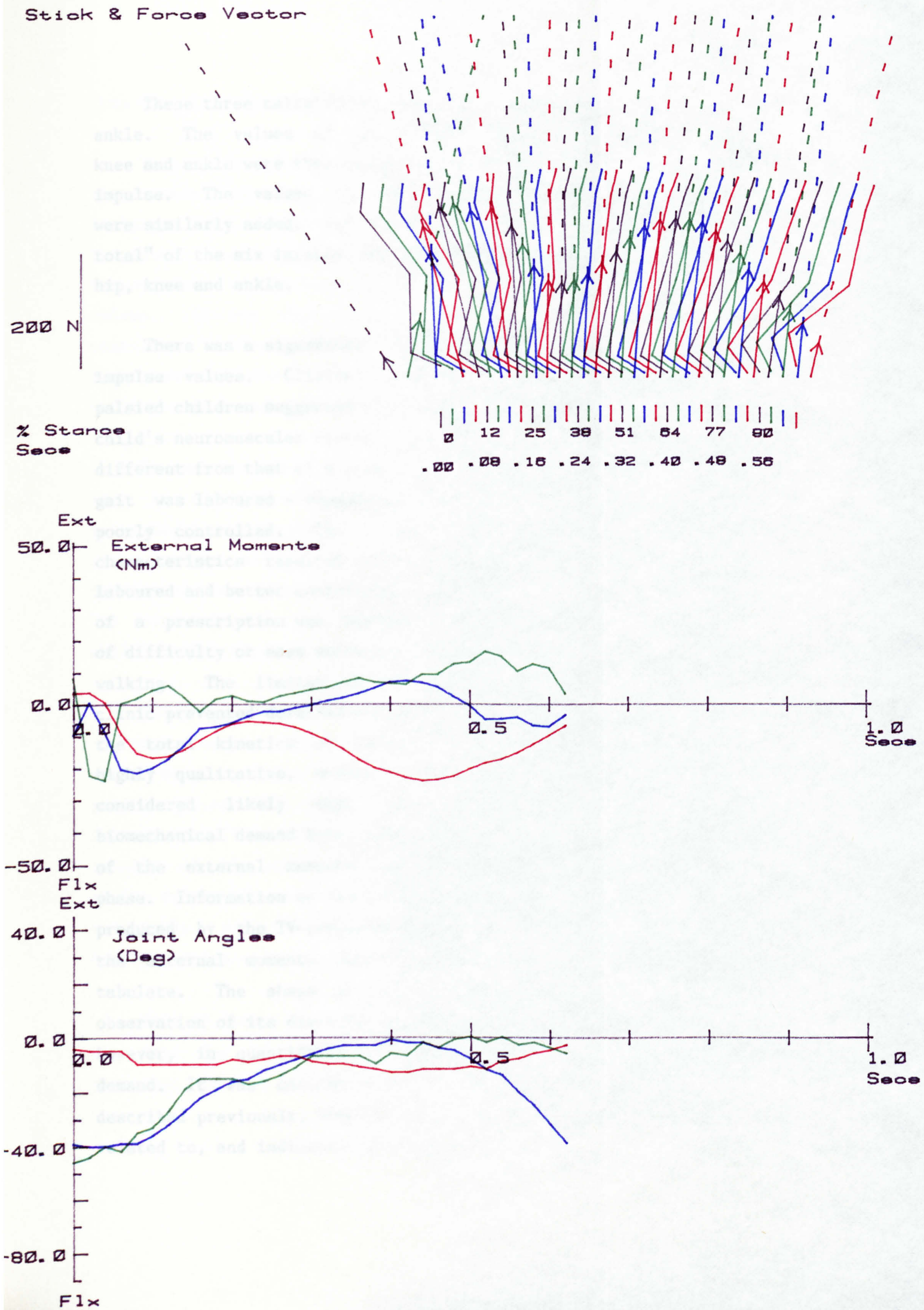
The neurological "positive supporting reaction" is a reflex triggered by stimuli such as contact of the foot with the ground where the net effect of the muscle activity is extension at all three joints. The leg is thus held stable against the negative, flexing moments caused by the reaction force due to body weight in the standing posture.

As mentioned previously, in this convention the external moments were considered positive when in the direction of extension, i.e., when tending to stabilise the leg. The results of the neurological "positive supporting reaction" and the mechanical positive external moments were therefore the same, i.e., the tendency to extend the joints and stabilise the leg.

For the purpose of this investigation additional programs were written with the collaboration of Dr. S. Marlow to further process and present the data, (Fig. 5.1).

The principal additional calculation was that of the "impulse" at the hip, knee and ankle. This was the integral of the product of the magnitude of the external moment and the time for which it acted. It was thus the area bounded by the graph of the external moment and the zero axis throughout the stance phase and had the dimensions of Nms.

If the graph crossed the zero axis this resulted in there being both positive and negative values for the calculated impulse. These two components were calculated separately and their magnitudes added together thus producing a value for the total amount of impulse generated at the joint. All three values were presented in the print-out, namely extension (positive), flexion (negative) and total.



PATIENT DATA

CODE - HBM212
WEIGHT - 240.4 N
LEG LENGTH - 0.63 m

	--L. LEG--	--R. LEG--
FOOTWEAR -	PIEDRO	PIEDRO
SOLE -	RUBBER	RUBBER
AFO ANGLE -	-7	-7
RAISE -	15	15
WEDGE -	5	5
ROCKER -	65%	65%

			HIP	KNEE	ANKLE	HKA
MOMENTS						
	(Max)	Ext	16.6	7.3	3.8	
	(Min)	Flx	-24.1	-21.3	-23.9	
ANGLES						
	(Max)	Ext	0	-1	-3	
	(Min)	Flx	-46	-40	-13	
IMPULSE						
	(Nms)	Ext	3.809	0.829	0.158	4.796
	(Non-D)		0.039	0.009	0.002	0.049
		Flx	-0.975	-3.396	-8.196	-12.567
			-0.010	-0.035	-0.085	-0.130
		Tot	4.784	4.225	8.354	17.363
			0.049	0.044	0.086	0.179

COMMENTS

Fig. 5.1
A3 format printout
of gait analysis data.

These three calculations were performed for the hip, knee and ankle. The values of the extension component of impulse at hip, knee and ankle were then added to give a total value for extension impulse. The values for the flexion component and total impulse were similarly added. This latter value was therefore a "grand total" of the six impulse components, i.e., extension and flexion at hip, knee and ankle.

There was a significant reason for the calculation of the impulse values. Clinical observation of the gait of cerebral palsied children suggested that the demand being placed on the child's neuromuscular system and their response to it appeared to be different from that of a normal child. Typically the CP child's gait was laboured - suggesting the generation of high moments - and poorly controlled. The fitting of an AFO with appropriate characteristics resulted in a gait which appeared to be less laboured and better controlled. Clinical judgement of the efficacy of a prescription was therefore based on an estimate of the degree of difficulty or ease which the child appeared to experience when walking. The limitations of visual observation of gait in the clinic prevented detailed analysis of the relative contributions to the total kinetics of the gait of hip, knee and ankle. Rather, a highly qualitative, average impression was gained. It was considered likely that the significant components of the biomechanical demand being placed on the child were the magnitudes of the external moments and their duration throughout the stance phase. Information on these components were contained in the data produced by the TV-computer system. Maximum and minimum values of the external moments were relatively simple to identify and tabulate. The shape of the graph of external moment permitted observation of its distribution and duration. The difficulty lay, however, in quantifying in a meaningful fashion this biomechanical demand. It was considered that the calculated impulse values described previously, being a function of both moment and time, were related to, and indicated the nature of, the biomechanical demand.

This therefore permitted the comparison of different sets of data.

The impulse values were a function of the external moments and the stance phase duration. Thus a slower gait would tend to result in larger impulse values if the magnitudes of the moment remained the same. Similarly the child's physical dimensions would influence the magnitude of the moments generated and hence also the impulse values. It was therefore probable that a large variation in the calculated impulse values would occur as a result of the different dimensions of the children included in the gait analysis programme and the cadence adopted on a given test run.

To overcome these problems the calculated values of impulse were in addition divided by the stance phase duration, the child's body weight and the length of the leg being analysed, resulting in a dimensionless number. The latter two factors were chosen as it was considered that these were the two most significant influences on the magnitude of the external moments generated, other than the child's clinical condition and prescription.

The programs generated a plot of all the calculated data on an A3 page format, (Fig. 5.1). This consisted of a stick and force vector diagram, drawn at 50Hz. intervals throughout stance phase, graphs of external moment and joint angles during stance phase, patient data (identification code, body weight and leg length), details of the characteristics of the AFO-footwear complex, tables of the values of maximum and minimum moments and angles of hip, knee and ankle, and the calculated impulses. An additional space was delineated for written comment.

This A3 format was chosen to permit observation and analysis of the data for the purpose of this research programme and also as a prototype clinical record.

5.2.1 Error Analysis

There were five principal sources of error in the gait analysis data - the inaccuracies of the instrumentation, the rounding errors of computation, the limitations of the positioning of a single body marker to represent the joint axis, the use of a two-dimensional analysis when "joint axes" are generally inclined to the mean plane of progression, the neglect of gravity and inertial forces and moments.

The instrumentation errors included the accuracies of the TV system and the averaging routines used to reduce the multiple samples to a single value and thus to produce the co-ordinates of the marker positions. An additional factor was the camera parallax error. There were also inaccuracies in the Kistler force plate system. These resulted in errors in the magnitude, direction and point of origin of the ground-to-foot force vector.

The rounding errors in the computations were of very small magnitude and were therefore considered to be negligible.

There were several difficulties relating to the positioning of the skin markers in relation to the anatomical joint axes. There was the problem of the identification (by clinical examination) of the position and orientation of the axis. It was thereafter necessary to estimate the point on the skin, which lay on the axis, and therefore where the marker should be attached.

Particular difficulties were encountered at the knee as a compromise had to be reached when using a single marker to represent the axis which was polycentric and whose instantaneous centre of rotation was dependent on joint angle. In addition many of the CP children walked with internally rotated legs. The knee marker had to be re-located more posteriorly to lie on the line connecting the mid point of the joint axis and the camera lens. This process was

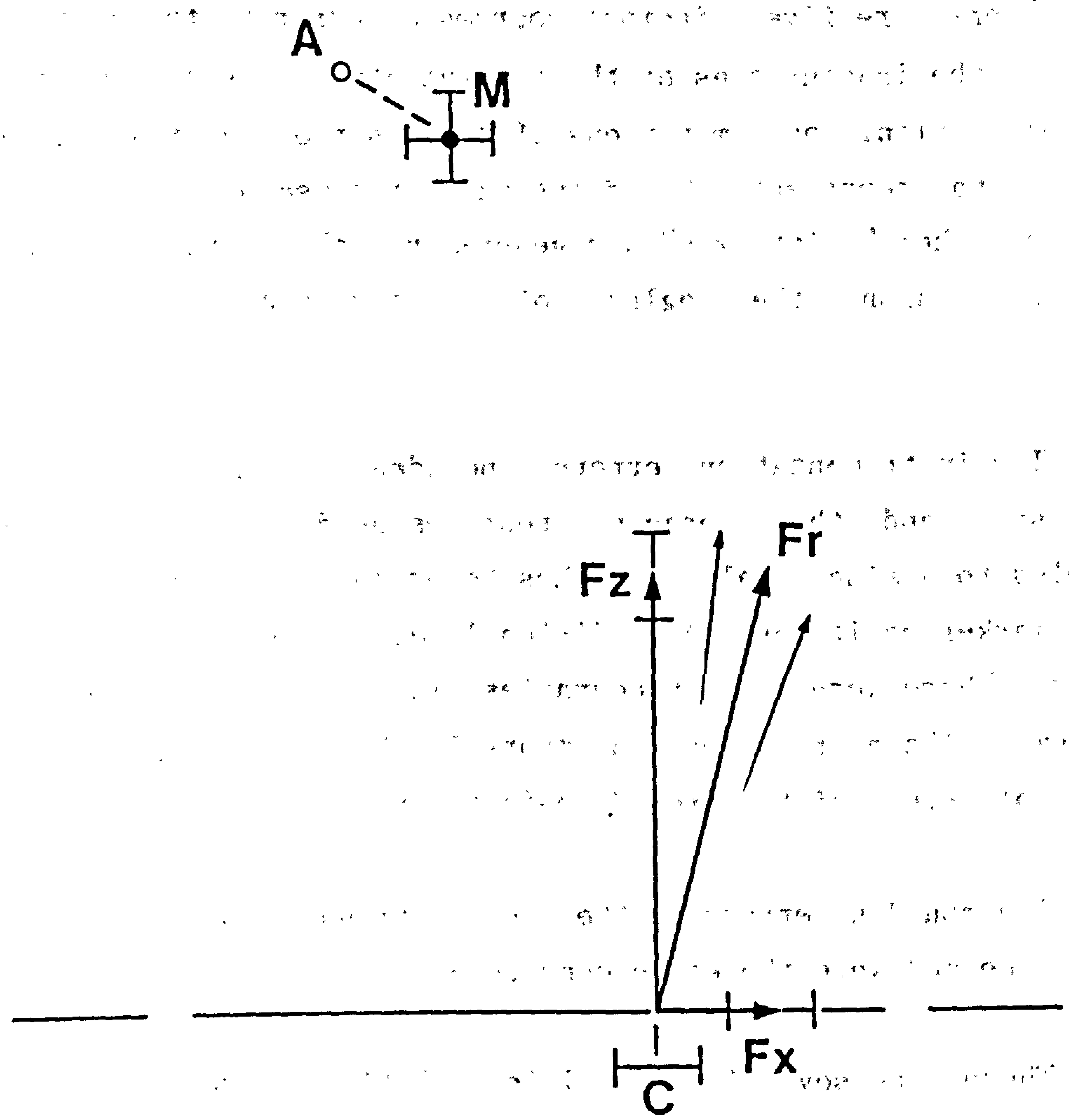


Fig. 5.2

Source of errors of gait analysis data.

Errors in magnitudes of horizontal and vertical components of ground reaction force, Fx & Fz, output from force plate system, produce errors in magnitude and direction of resultant force, Fr. Errors in centre of pressure, C, produce errors in origin of resultant force. Limitations of TV-computer system result in errors in x & z co-ordinates of marker, M. Marker may be offset from true anatomical joint axis, A.

described in Chapter 4. The re-location of the marker was determined by clinical judgment of the amount of internal rotation occurring in mid stance. It was therefore open to some error. In addition the amount of internal rotation was likely to vary throughout the stance phase and therefore re-location of the marker could not compensate accurately for the internal rotation at all stages.

A diagrammatic representation of the sources or errors is contained in Fig. 5.2.

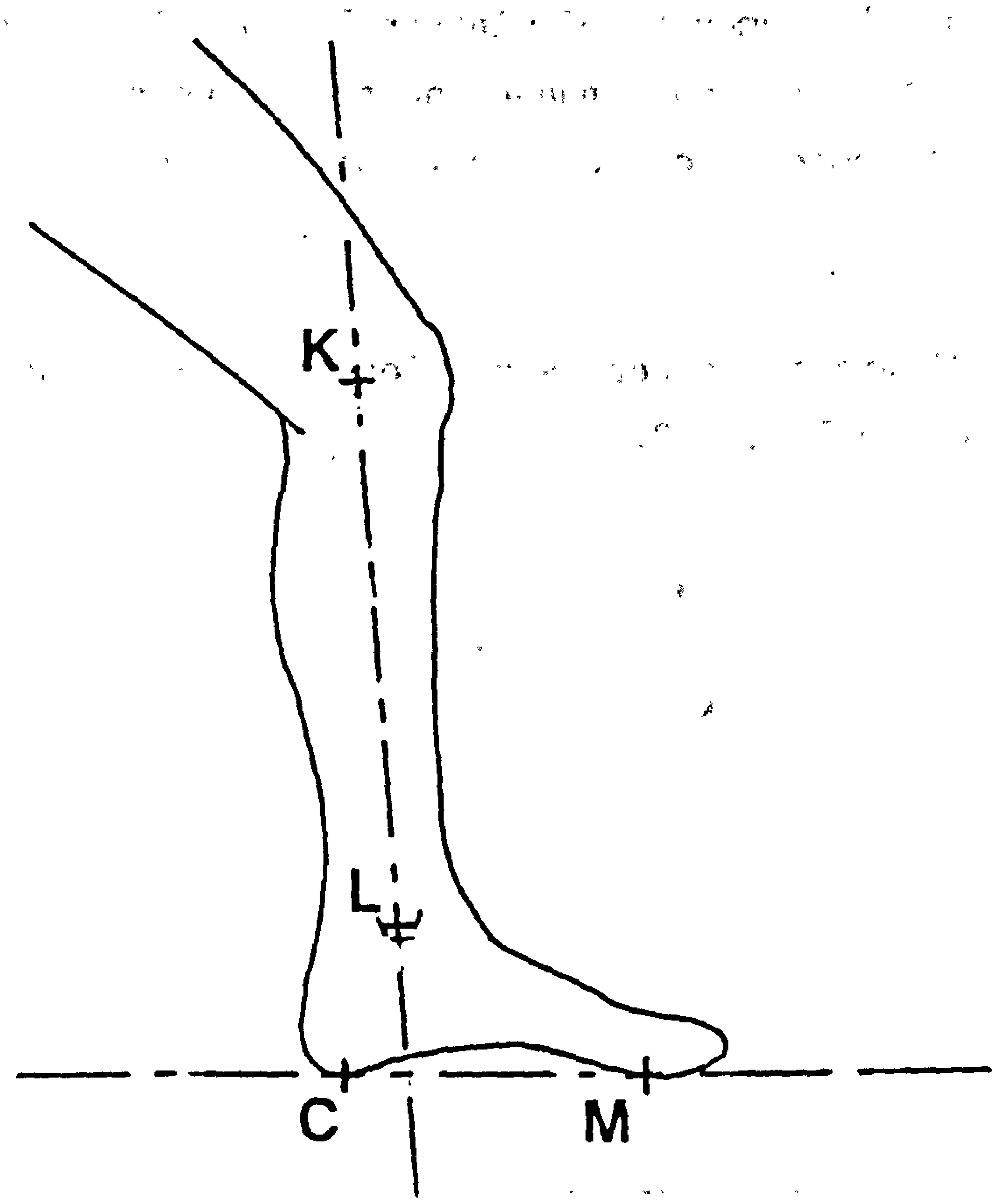


Fig. 5.3

Definitions of long axes of shank and foot.

K knee joint axis (flexion-extension)

L lateral malleolus

C lowest point of calcaneus

M lowest point of fifth metatarsal head

(Axes extended for clarity)

5.3 ANKLE-FOOT ORTHOSIS AND FOOTWEAR CHARACTERISTICS

The data relating to the characteristics of the AFO and footwear were obtained largely by direct measurement. No subsequent calculations were performed. It was necessary in most cases to set up the criteria to define and measure the characteristics.

These data were used to determine the characteristics of individual prescriptions and to measure the changes in these caused by adaptations. It was not therefore used directly in any of the gait analysis computations described in the preceding section.

5.3.1 Ankle-Foot Orthosis Characteristics

The principal characteristic of the AFO which was measured was the angle at which it was set in the sagittal plane. This was equivalent to the angle of dorsiflexion or plantarflexion at which the anatomical ankle joint was held by the AFO.

For the purpose of this research programme it was necessary to define lines which could be considered to be the long axes of the shank and foot and to define the ankle angle as the angle between these lines in the sagittal plane, (Fig. 5.3).

The long axis of the shank was defined as the line joining the point on the lateral aspect of the knee identifying the knee joint axis (flexion-extension), and the lateral malleolus. The long axis of the foot was defined as the line joining the lowest point of the heel below the calcaneus which contacted the ground on normal standing, and the bottom of the fifth metatarsal head which similarly contacted the ground. Thus, in the normal standing posture the ankle angle would be approximately 90 degrees.

The angle of set was measured by protractor from the Polaroid photograph taken of the child in the standing position.

The stiffness of the AFO was defined as the ratio of the moment generated to the angular change in attitude of the shank and foot sections held within the clamps. The graph of moment against deformation was produced directly by the AFO stiffness measurement rig described in Chapter 3. No further measurement or calculation was necessary.

5.3.2 Footwear Characteristics

The three characteristics of the footwear which were measured were the raise, wedge and rocker effects of the sole as described in Chapter 4.

In the initial stages of the programme these characteristics were measured either directly using a ruler for the raise and rocker and from the Polaroid photograph for the wedge effect. In the final stages a measurement rig was completed as described in Chapter 3.

5.4 MUSCLE ACTIVITY MONITORING

The output from the Medelog system was in the form of a graph produced by the U.V. galvanometer recorder. In the case of the long term monitoring tests this was a single channel output from the ankle strap load transducer plotted against time. In the short term monitoring tests there were four channels of data - ankle strap load, heel and toe switches and e.m.g. activity of plantarflexors and dorsiflexors.

Apart from measurement of the peak magnitudes of the ankle strap loads, further analysis was limited to qualitative assessment of the phasic activities of the muscle groups and the profile of the ankle strap loads throughout individual gait cycles.

CHAPTER 6

RESULTS

CHAPTER 6

RESULTS

6.1 INTRODUCTION

This chapter contains the results of the gait analysis tests and muscle activity monitoring tests. A check calculation is carried out on a set of data to confirm the correct operation of the computer program written to calculate external moments. An analysis of errors is performed with discussion on its implications.

6.2 GAIT ANALYSIS

The results of this research programme are based on data obtained from 8 CP children and 6 normal children. The CP children selected for inclusion in the research programme were considered clinically to be good examples of AFO wearers. The normal children were in most cases of similar age and dimensions to the CP children. A total of 215 test runs were obtained from these 14 children and successfully processed to produce the A3 format printouts. Wherever possible the CP children walked barefoot, with AFOs and footwear, and, if necessary, additional adaptations to the prescriptions. The normal children walked barefoot and in one case with shoes also. The details of the test subjects and their prescriptions worn in each series of test runs are given in Tables 6.1 and 6.2.

In parallel to the gait analysis of the children included in the research programme other CP chidren involved in the routine management programme were also subjected to gait analysis. Included in this latter group were some children who were AFO users who were considered by the management team to be problem cases. Others had been referred by clinicians interested in measuring the effects of other forms of treatment, such as drugs, on their gait. These cases did not necessarily contribute directly towards the objectives of this research programme but were considered useful since they provided additional gait analysis experience. An additional 185 sets of data were obtained from this group of children but were not included for analysis in this research programme.

The printouts were analysied to produce a total of 26 items of data from each test run. These were obtained by measurement of the stick and force vector diagrams, the external moment and joint angle graphs, by extracting data from the tables of results or by subsequent further calculation. These items of data are listed in Table 6.3.

Five items of data which were considered to be of special interest were plotted on graphs to aid interpretation, (Figs. 6.1-6.5). These were the grand total of dimensionless angular impulse values in flexion and extension at hip, knee and ankle joints, (HKAI), the maximum external extension moment generated at the knee during the middle period of stance phase, (KMext), the ratio of the maximum vertical component of ground-to-foot force (F2), generated during late stance to body weight (BW), (F2/BW), the external moment at the hip at the instant of occurrence of F2, (HM), and the relative angular velocity at the hip at this instant, (HAV).

Seven random sets of data from a CP child and a normal child were plotted to examine the nature of their distribution, (Fig. 6.6). From this it was concluded that they displayed an approximately normal distribution so that "Student's t" test could be used to determine the level of significance of the differences of means of the sets of test data. It was considered reasonable to assume that all the sets of test data would also display an approximately normal distribution. Consequently tests of significance were carried out. The results of this process are contained in Table 6.4.

The stiffness characteristics of 3 AFOs were measured. These were from subject 001 (left and right) and subject 002 (left). The results of these are shown in Fig. 6.7.

TABLE 6.1 - Details of test subjects

Subject No.	Age on test day (Yrs,Mths)	Sex	Diagnosis
001	8,1	F	Ataxic diplegic
002	6,1	F	L hemiplegic
003	5,8	F	R hemiplegic
004	7,6	F	spastic diplegic
009	6,5	F	spastic diplegic
010	6,5	F	normal (twin of 009)
011	9,3	F	normal
012	7,7	F	normal
015	8,2	M	spastic diplegic
016	7,1	M	spastic diplegic
017	5,11	M	normal
018	7,8	M	L hemiplegic
029	12,4	F	normal
030	12,6	F	normal

TABLE 6.2 - Prescription details

Subject No. /Series No.	AFO Angle (degrees, dorsi -ve)		Raise (mm)		Wedge (degrees)		Rocker (%)	
	L	R	L	R	L	R	L	R
001/1	Barefoot							
2	-7	-7	5	5	10	10		
3 *	-7	-7	5	5	10	10		
4 *	-7	-7	10	10	7	7		
5 *	-7	-7	15	15	5	5	65	65
002/1			5	5	7	7		
2	-3		5	5	7	7		
3	-3		10	5	7	7		
4 **	-3		15	5	7	7		
003/1	Barefoot							
2		-5	10	10	4	4		
004/1	-2	-4	5	5	4	4		
2	-2	-4	5	5	7	7		
3	-2	-4	5	5	9	9		
009/1	Barefoot							
2		-2	10	10	9	9		
015/1	Barefoot							
2	-8	-8	10	10	9	9		
3	-8	-8	15	15	7	7	60	60

* 1 week later than series 1 and 2

** 10 weeks later than series 1,2 and 3

TABLE 6.2 - Prescription details (cont.)

Subject No. /Series No.	AFO Angle (degrees, dorsi -ve)		Raise (mm)		Wedge (degrees)		Rocker (%)	
	L	R	L	R	L	R	L	R
016/1	Barefoot							
2	-6	-6	10	10	1	1		
018/1	Barefoot							
2	-1		10	10	0	0		
3	-1		10	10	3	3		
010/1	Barefoot							
011/1	Barefoot							
012/1	Barefoot							
017/1	Barefoot							
2			10	10	2	2		
029/1	Barefoot							
030/1	Barefoot							

TABLE 6.3 - Gait analysis results

Details of items of data extracted from printouts

Test No.	Subject No./Series No.
BW	Body weight (N)
LL	Leg length - hip marker to ground (m)
SSize	Sample size -no of runs in series (SSize for individual items in [ ] if different)

Values listed are means (standard deviations)

F1	Maximum vertical component of impact force in early stance (N)
F2	Maximum vertical component of push-off force in late stance (N)
%@F2	% of stance phase at which F2 occurs
F1/F2	Ratio of vertical component of maximum impact and push-off forces
F2/BW	Ratio of vertical component of maximum push-off force and body weight
HM	External hip moment at %@F2 (Nm)
HA	Hip angle at %@F2 (degrees)
HAV	Hip angular velocity at %@F2 (degrees/s)
KMext	Maximum external extension moment at knee during mid stance (Nm)
KMflx	Maximum external knee flexion moment (Nm)
KIext	Dimensionless knee extension impulse
KIflx	Dimensionless knee flexion impulse
KIext/KIflx	Ratio of knee extension and knee flexion impulses
KAmdst	Maximum knee extension angle in mid stance (degrees)

TABLE 6.3 - Gait analysis results (cont.)

KM	External knee moment at %@F2 (Nm)
KA	Knee angle at %@F2 (degrees)
KAV	Knee angular velocity at %@F2 (degree/s)
AMearly	Maximum external ankle moment (dorsiflexion or plantarflexion) during early stance (Nm)
AMlate	Maximum external dorsiflexion moment at ankle during late stance (Nm)
AIflx	Dimensionless ankle dorsiflexion impulse
AA	Ankle angle at %@F2 (degrees)
AAV	Ankle angular velocity at %@F2(degree/s)
AAdorsi	Maximum angle of ankle dorsiflexion during stance phase (degrees)
AAplant	Maximum angle of ankle plantarflexion during stance phase (degrees)
AArange	Total range of ankle motion during stance phase (degrees)
HKAI	Grand total of dimensionless angular impulses in flexion and extension at hip, knee and ankle.

TABLE 6.3 - Gait analysis results (cont.)

Test No.	001/1		001/2		001/3	
BW	240		240		240	
LL	0.59		0.63		0.63	
SSize	7		9		3	
F1	376	(37.5)	467	(15.6)	465	(22.9)
F2	217	(16.8)	224	(20.1)	203	(11.6)
%@F2	83	(3.5)	83	(2.3)	83	(2.1)
F1/F2	1.74	(0.21)	2.10	(0.21)	0.85	(0.23)
F2/BW	0.90	(0.07)	0.94	(0.08)	0.85	(0.05)
HM	4.0	(3.73)	-1.6	(3.57)	2.7	(4.04)
HA	-7	(4.9)[6]	-8	(1.5)[8]	-7	(1.7)
HAV	27	(30.4)[6]	44	(39.7)[8]	80	(33.60)
KMext	14.4	(3.73)	10.3	(1.58)	12.4	(1.85)
KMflx	-17.2	(6.31)	-32.3	(5.28)	-36.0	(10.7)
KIext	0.033	(0.0079)	0.020	(0.00048)	0.018	(0.0044)
KIflx	-0.019	(0.0086)	-0.045	(0.0087)	-0.051	(0.0163)
KIext/flx	2.14	(1.208)	0.47	(0.16)	0.41	(0.27)
KAmdst	-2	(2.6)	-8	(1.9)	-10	(0.0)
KM	3.6	(4.91)	6.6	(2.40)	1.7	(3.51)
KA	-9	(5.2)	-15	(3.9)	-17	(4.4)
KAV	-195	(100.7)	-194	(97.0)	-256	(95.9)
AMearly	-20.4	(3.06)	-16.8	(7.00)	-26.7	(3.03)
AMlate	-21.9	(2.36)	-26.4	(2.37)	-24.2	(1.08)
AIflx	-0.108	(0.0099)	-0.075	(0.0091)	-0.094	(0.010)
AA	1	(2.3)	3	(1.1)	-4	(2.0)
AAV	28	(67.3)	48	(25.2)	7	(12.1)
AAdorsi	-8	(1.8)	0	(1.0)	-7	(2.7)
AAplant	12	(2.4)	9	(0.6)	1	(0.6)
AArange	20	(3.8)	9	(1.1)	8	(2.9)
HKAI	0.230	(0.0089)	0.226	(0.0095)	0.232	(0.0093)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	001/4		001/5	
BW	240		240	
LL	0.63		0.63	
SSize	4		14	
F1	415	(21.2)	334	(40.1)
F2	220	(13.5)	244	(18.6)
%@F2	84	(1.6)	76	(5.0)
F1/F2	1.89	(0.15)	1.38	(0.21)
F2/BW	0.92	(0.05)	1.02	(0.08)
HM	9.13	(4.52)	7.4	(5.58)
HA	-5	(2.8)	-6	(2.8)
HAV	100	(51.4)	122	(37.5)
KMext	8.7	(1.35)	5.9	(2.11)
KMflx	-30.9	(1.80)	-22.5	(3.41)
KIext	0.013	(0.0064)	0.008	(0.0047)
KIflx	-0.060	(0.0051)	-0.043	(0.0085)
KIext/flx	0.22	(0.14)	0.20	(0.13)
KAmdst	-10	(1.7)	-7	(4.2)
KM	-5.2	(2.06)	4.1	(3.02)
KA	-19	(4.6)	-8	(4.6)
KAV	-207	(60.3)	-19	(60.1)
AMearly	-29.6	(3.11)	-26.2	(5.79)
AMlate	-25.2	(3.27)	-25.5	(2.68)
AIflx	-0.0107	(0.007)	-0.108	(0.0172)
AA	-9	(1.3)	-11	(1.9)
AAV	44	(9.0)	-2	(16.1)
AAdorsi	-12	(1.6)	-13	(1.0)
AAplant	0	(2.2)	-3	(2.3)
AArange	11	(1.7)	10	(1.3)
HKAI	0.227	(0.0113)	0.207	(0.0275)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	002/1		002/2		002/3	
BW	162		162		162	
LL	0.56		0.56		0.56	
SSize	2		4		5	
F1	210	(0.0)	250	(26.8)	211	(20.4)
F2	158	(31.8)	165	(14.7)	162	(12.0)
%@F2	84	(2.1)	83	(2.1)	75	(4.6)
F1/F2	1.37	(0.28)	1.52	(0.13)	1.31	(0.17)
F2/BW	0.97	(0.20)	1.02	(0.09)	1.00	(0.07)
HM	2.5	(0.71)	1.8	(2.50)	-0.3	(3.35)
HA	11	(0.7)	7	(1.3)	5	(5.2)
HAV	67	(26.9)	70	(34.7)	79	(16.4)
KMext	9.5	(2.33)	10.3	(1.44)	9.6	(1.99)
KMflx	-4.9	(0.14)	-4.7	(3.28)	-4.1	(1.76)
KIext	0.043	(0.0035)	0.047	(0.0105)	0.038	(0.0055)
KIflx	-0.006	(0.0007)	-0.008	(0.0066)	-0.008	(0.0034)
KIext/flx	7.75	(0.35)	13.28	(12.63)	5.50	(2.52)
KAmdst	6	(3.5)	3	(2.6)	3	(5.0)
KM	5.5	(2.12)	6.5	(2.80)	8.2	(2.17)
KA	-1	(3.5)	-5	(5.6)	0	(5.0)
KAV	-141	(27.6)	-176	(49.8)	-116	(35.0)
AMearly	-10.5	(0.78)	1.7	(0.30)	2.4	(0.56)
AMlate	-12.2	(4.53)	-17.5	(1.43)	-15.7	(0.16)
AIflx	-0.091	(0.0092)	-0.084	(0.0071)	-0.074	(0.0053)
AA	4	(5.66)	-6	(1.5)	-4	(1.1)
AAV	19	(19.1)	11	(17.8)	-10	(21.5)
AAdorsi	2	(2.8)	-6	(1.5)	-5	(2.11)
AAplant	21	(1.4)	4	(1.0)	4	(1.3)
AArange	23	(1.4)	10	(0.8)	9	(1.5)
HKAI	0.178	(0.0106)	0.199	(0.0079)	0.175	(0.0137)

TABLE 6.3 – Gait analysis results (cont.)

Test No.	002/4
BW	167
LL	0.56
SSize	10

F1	220	(25.5)
F2	179	(14.1)
%@F2	78	(2.8)
F1/F2	1.23	(0.12)
F2/BW	1.07	(0.08)
HM	0.5	(3.63)
HA	2	(3.6)
HAV	94	(30.8)
KMext	11.9	(1.26)
KMflx	-4.5	(2.28)
KIext	0.045	(0.0105)
KIflx	-0.007	(0.0044)
KIext/flx	8.87	(6.12)
KAmdst	5	(2.1)
KM	10.5	(1.84)
KA	2	(1.9)
KAV	-108	(38.1)
AMearly	1.0	(0.32)
AMlatc	-18.5	(1.14)
AIflx	-0.083	(0.007)
AA	-7	(0.9)
AAV	-27	(22.7)
AAdorsi	-8	(1.2)
AAplant	6	(1.2)
AArange	14	(1.0)
HKAI	0.199	(0.0215)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	003/1		003/2	
BW	206		206	
LL	0.61		0.64	
SSize	9		9	
F1	272	(23.5)	362	(28.6)
F2	177	(14.8)	192	(12.0)
%@F2	80	(7.0)	82	(2.1)
F1/F2	1.55	(0.22)	1.90	(0.24)
F2/BW	0.86	(0.07)	0.93	(0.06)
HM	-1.0	(2.78)	1.4	(4.76)
HA	-10	(4.2)	-11	(2.6)
HAV	65	(21.9)	101	(37.8)
KMext	15.4	(1.61)	12.8	(2.36)
KMflx	-1.3	(1.41)	-7.5	(5.91)
KIext	0.054	(0.0148)	0.043	(0.0133)
KIflx	-0.001	(0.0017)	-0.008	(0.0075)
KIext/flx	82.21	(49.88)	15.95	(17.44)
KAmdst	1	(1.7)	-1	(1.7)
KM	7.6	(2.01)	6.8	(2.88)
KA	-6	(1.6)	-10	(2.0)
KAV	-113	(70.9)	-132	(60.0)
AMearly	-18.6	(1.49)	-16.1	(4.22)
AMlate	-18.1	(2.03)	-22.9	(1.51)
AIflx	-0.112	(0.0058)	-0.095	(0.0052)
AA	5	(2.6)	3	(1.8)
AAV	48	(18.5)	26	(17.2)
AAdorsi	-3	(3.0)	-1	(1.4)
AAplant	19	(2.1)	8	(0.9)
AArange	22	(3.2)	9	(1.8)
HKAI	0.218	(0.0291)	0.214	(0.0237)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	004/1		004/2		004/3	
BW	216		216		216	
LL	0.65		0.65		0.65	
SSize	8		7		5	
F1	375	(31.2)	377	(39.5)	364	(57.3)
F2	239	(16.4)	229	(20.5)	219	(23.0)
%@F2	64	(6.5)	64	(6.2)	69	(2.7)
F1/F2	1.57	(0.19)	1.65	(0.21)	1.66	(0.20)
F2/BW	1.11	(0.08)	1.06	(0.09)	1.01	(0.11)
HM	-6.2	(7.4)	-2.6	(4.29)	-0.9	(3.32)
HA	-12	(3.8)	-8	(4.4) [6]	-5	(4.4)
HAV	75	(21.7)	74	(6.3) [6]	74	(20.3)
KMext	10.9	(1.90)	8.9	(1.58)	8.1	(1.44)
KMflx	-17.9	(4.62)	-20.9	(6.07)	-23.6	(4.58)
KIext	0.028	(0.0129)	0.015	(0.0059)	0.010	(0.0035)
KIflx	-0.028	(0.0135)	-0.043	(0.0120)	-0.059	(0.0153)
KIext/flx	1.33	(0.86)	0.43	(0.38)	0.19	(0.12)
KAmdst	-15	(4.4)	-16	(1.4)	-19	(3.5)
KM	4.1	(6.36)	2.0	(3.42)	-1.2	(3.77)
KA	-16	(4.2)	-17	(1.6)	-22	(4.4)
KAV	-11	(39.9)	-17	(47.8)	-80	(13.2)
AMearly	-13.4	(9.51)	-12.9	(11.02)	-19.6	(6.02)
AMlate	-19.9	(3.47)	-18.3	(2.79)	-17.5	(1.45)
AIflx	-0.083	(0.0227)	-0.071	(0.071)	-0.075	(0.0119)
AA	-5	(1.3)	-4	(2.1)	-1	(1.5)
AAV	-11	(8.0)	24	(9.8)	-2	(21.6)
AAdorsi	-6	(1.9)	-5	(2.3)	-4	(2.8)
AAplant	5	(2.4)	9	(1.1)	11	(1.5)
AArange	12	(2.2)	13	(1.6)	15	(3.4)
HKAI	0.266	(0.0314)	0.240	(0.0346)	0.237	(0.0402)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	009/1		009/2	
BW	186		186	
LL	0.56		0.59	
SSize	4		3	
F1	356	(78.7)	347	(28.9)
F2	175	(16.8)	185	(5.0)
%@F2	80	(2.5)	78	(1.5)
F1/F2	2.08	(0.63)	1.87	(0.16)
F2/BW	0.96	(0.09)	1.01	(0.03)
HM	-4.0	(1.78)	0.0	(4.00)
HA	-10	(1.2)[3]	-14	- [1]
HAV	79	(18.2)[3]	115	- [1]
KMext	5.5	(2.55)	3.6	(0.32)
KMflx	-15.4	(4.49)	-25.4	(1.89)
KIext	0.007	(0.0025)	0.005	(0.0006)
KIflx	-0.035	(0.0118)	-0.067	(0.0047)
KIext≠flx	0.21	(0.09)	0.07	(0.01)
KAmdst	-17	(3.1)	-22	(1.5)
KM	-2.8	(1.32)	-4.0	(1.00)
KA	-25	(2.2)	-27	(4.6)
KAV	-97	(35.8)	-90	(29.1)
AMearly	-13.1	(2.13)	8.2	(1.07)
AMlate	-11.6	(2.25)	-14.2	(1.99)
AIflx	-0.078	(0.0068)	-0.048	(0.0053)
AA	8	(7.4)	1	(1.2)
AAV	28	(32.1)	9	(11.0)
AAdorsi	-6	(1.7)	0	(1.0)
AAplant	15	(4.7)	10	(1.2)
AArange	21	(3.0)	10	(0.6)
HKAI	0.181	(0.0137)	0.210	(0.0071)

TABLE 6.3 – Gait analysis results (cont.)

Test No.	015/1		015/2		015/3	
BW	186		186		186	
LL	0.55		0.58		0.58	
SSize	7		8		9	
F1	314	(29.5)	349	(18.0)	369	(13.6)
F2	174	(9.3)	190	(4.6)	204	(10.4)
%@F2	68	(10.0)	74	(2.2)	68	(4.0)
F1/F2	1.81	(0.19)	1.84	(0.12)	1.81	(0.11)
F2/BW	0.94	(0.05)	1.02	(0.02)	1.10	(0.06)
HM	-1.9	(3.27)	2.5	(3.16)	-2.3	(3.08)
HA	-22	(5.8)[5]	-21	(2.77)	-21	(2.7)[7]
HAV	132	(46.6)[5]	122	(9.03)	119	(8.3)[7]
KMext	8.4	(1.69)	5.1	(1.17)	5.5	(1.69)
KMflx	-16.5	(2.63)	-24.3	(4.03)	-21.0	(4.25)
KIext	0.024	(0.0062)	0.013	(0.0056)	0.014	(0.0060)
KIflx	-0.029	(0.0081)	-0.052	(0.0112)	-1.043	(0.0079)
KIext/flx	0.95	(0.49)	0.27	(0.17)	0.35	(0.20)
KAmdst	-9	(2.0)	-19	(2.2)	-18	(2.9)
KM	4.1	(1.57)	3.2	(2.17)	3.0	(.85)
KA	-10	(1.8)	-19	(2.3)	-18	(2.9)
KAV	-23	(34.6)	-10	(61.1)	10	(18.7)
AMearly	-13.0	(2.13)	-21.7	(4.38)	-19.6	(4.5)
AMlate	-14.3	(0.73)	-20.6	(1.25)	-18.7	(1.4)
AIflx	-0.101	(0.0028)	-0.115	(0.0118)	-0.107	(0.0122)
AA	2	(1.3)	-5	(1.04)	-4	(0.7)
AAV	18	(17.3)	-6	(17.2)	-6	(11.1)
AAdorsi	-9	(2.3)	-8	(1.6)	-7	(1.8)
AAplant	14	(1.8)	2	(0.8)	2	(1.0)
AArange	23	(2.2)	10	(1.3)	9	(1.7)
HKAI	0.219	(0.0084)	0.265	(0.0188)	0.254	(0.0165)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	016/1		016/2	
BW	186		186	
LL	0.53		0.55	
SSize	7		4	
F1	286	(16.2)	326	(11.1)
F2	176	(14.4)	209	(7.5)
%@F2	76	(5.3)	68	(2.6)
F1/F2	1.63	(0.19)	1.56	(0.02)
F2/BW	0.95	(0.08)	1.13	(0.04)
HM	1.4	(5.65)[6]	5.4	(6.16)
HA	-10	(3.8) [6]	-6	(5.25)
HAV	77	(38.9)	82	(28.5)
KMext	1.1	(2.31)	5.6	(1.94)
KMflx	-14.9	(2.97)	-19.0	(2.33)
KIext	0.003	(0.0046)	0.009	(0.0033)
KIflx	-0.068	(0.0228)	-0.078	(0.0174)
KIext≠flx	0.08	(0.11)	0.117	(0.0595)
KAmdst	-33	(3.5)	-29	(4.2)
KM	-9.3	(4.89)	-9.5	(6.46)
KA	-44	(7.1)	-38	(6.14)
KAV	-101	(37.0)	-49	(20.3)
AMearly	-16.2	(1.16)	-16.5	(3.34)
AMlate	-11.5	(2.85)	-16.3	(1.63)
AIflx	-0.092	(0.0093)	-0.1-5	(0.0143)
AA	8	(3.9)	-6	(2.84)
AAV	29	(49.8)	1.3	(17.8)
AAdorsi	-5	(2.7)	-8	(2.2)
AAplant	33	(6.9)	5	(3.9)
AArange	37	(6.2)	13	(2.5)
HKAI	0.236	(0.0166)	0.311	(0.0294)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	018/1		018/2		018/3	
BW	186		186		186	
LL	0.59		0.60		0.63	
SSize	7		7		6	
F1	240	(20.3)	286	(21.3)	261	(4.9)
F2	186	(15.5)	211	(13.5)	213	(8.2)
%@F2	73	(7.3)	77	(3.8)	81	(2.7)
F1/F2	1.29	(0.09)	1.36	(0.09)	1.22	(0.06)
F2/BW	0.91	(0.08)	1.03	(0.07)	1.04	(0.04)
HM	-4.3	(3.90)	0.4	(5.07)	-1.0	(4.56)
HA	-1	(3.3)[4]	0	(3.3)[5]	-4	(0.9)
HAV	62	(29.7)[4]	55	(8.3)[5]	54	(24.2)
KMext	13.4	(2.53)	14.8	(3.19)	10.7	(2.93)
KMflx	-2.0	(2.04)	-6.4	(4.27)	-7.0	(3.09)
KIext	0.062	(0.0092)	0.052	(0.0149)	0.027	(0.0127)
KIflx	0.001	(0.0014)	0.008	(0.0064)	0.011	(0.0066)
KIext/flx	51.93	(22.29)	17.83	(25.81)	6.42	(9.52)
KAmdst	-1	(2.3)	2	(1.9)	-4	(2.4)
KM	11.9	(3.39)	13.0	(3.61)	8.7	(4.18)
KA	-2	(2.4)	0	(2.8)	-7	(5.79)
KAV	-44	(67.8)	-85	(64.7)	-130	(150.4)
AMearly	-11.6	(1.31)	-15.3	(4.11)	-12.3	(4.03)
AMlate	-20.05	(1.64)	-25.2	(2.06)	-24.2	(0.83)
AIflx	-0.116	(0.0046)	-0.116	(0.0097)	-0.089	(0.0096)
AA	-5	(2.6)	-8	(1.4)	-10	(1.8)
AAV	-15	(15.2)	-22	(13.8)	-38	(40.06)
AAdorsi	-7	(2.7)	-9	(1.11)	-13	(1.9)
AAplant	8	(1.7)	3	(1.2)	4	(1.4)
AArange	15	(2.1)	12	(0.8)	17	(1.2)
HKAI	0.273	(0.0325)	0.259	(0.0241)	0.203	(0.0309)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	010/1		011/1		012/1	
BW	191		240		221	
LL	0.56		0.72		0.66	
SSize	4		2		5	
F1	208	(8.7)	270	(28.3)	265	(26.9)
F2	235	(5.8)	270	(0.0)	227	(9.8)
%@F2	76	(1.9)	82	(3.5)	80	(3.2)
F1/F2	0.88	(0.06)	1.00	(0.10)	1.17	(0.15)
F2/BW	1.23	(0.03)	1.13	(0.00)	1.03	(0.05)
HM	0.0	(3.37)	6.0	(5.66)	1.9	(3.54)
HA	-5	(1.3)	7	- [1]	13	(5.2)[4]
HAV	35	(11.2)	92	- [1]	81	(55.6)[4]
KMext	3.4	(2.63)	5.8	(1.77)	7.8	(3.74)
KMflx	-4.5	(1.37)	-15.0	(10.39)	-11.4	(2.97)
KIext	0.013	(0.0112)	0.012	(0.012)	0.019	(0.0103)
KIflx	-0.011	(0.0076)	-0.0815	(0.0191)	-0.016	(0.0032)
KIext/flx	1.97	(1.83)	2.05	(2.76)	1.26	(0.69)
KAmdst	-10	(2.8)	-13	(0.7)	-7	(3.6)
KM	2.5	(2.55)	3.0	(5.66)	7.3	(3.99)
KA	-20	(2.8)	-15	(2.8)	-7	(3.7)
KAV	-52	(36.7)	-79	(43.1)	-55	(43.3)
AMearly	1.2	(0.65)	4.5	(1.91)	3.9	(1.21)
AMlate	-24.4	(1.02)	-33.2	(1.13)	-25.3	(1.50)
AIflx	-0.095	(0.0073)	-0.067	(0.0064)	-0.066	(0.0056)
AA	-8	(7.0)	-16	(2.12)	-7	(3.6)
AAV	35	(34.6)	51	(49.5)	94	(19.8)
AAdorsi	-10	(7.1)	-17	(1.4)	-14	(3.4)
AAplant	7	(3.2)	15	(4.2)	9	(3.4)
AArange	17	(5.3)	32	(2.8)	23	(4.4)
HKAI	0.162	(0.0238)	0.139	(0.0184)	0.159	(0.0203)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	017/1		017/2	
BW	191		191	
LL	0.55		0.58	
SSize	11		9	
F1	238	(9.8)	233	(8.3)
F2	226	(8.7)	237	(10.3)
%@F2	80	(2.0)	79	(1.6)
F1/F2	1.05	(0.05)	0.98	(0.05)
F2/BW	1.19	(0.05)	1.24	(0.06)
HM	5.6	(3.28)	7.8	(3.99)
HA	5	(2.7)	7	(3.1)
HAV	72	(28.5)	57	(31.7)
KMext	6.5	(2.76)	5.1	(1.91)
KMflx	-12.1	(3.10)	-10.1	(3.11)
KIext	0.022	(0.0127)	0.016	(0.0105)
KIflx	-0.029	(0.0107)	-0.024	(0.0103)
KIext/flx	0.94	(0.67)	1.06	(1.34)
KAmdst	-4	(2.6)	-3	(3.1)
KM	3.5	(5.15)	4.0	(2.18)
KA	-9	(4.4)	-8	(3.3)
KAV	-152	(44.6)	-134	(46.2)
AMearly	-0.8	(3.7)	1.5	(0.78)
AMlate	-22.1	(3.0)	-23.7	(1.34)
AIflx	-0.088	(0.0099)	-0.076	(0.0093)
AA	-12	(3.7)	-12	(2.5)
AAV	51	(26.4)	43	(32.0)
AAdorsi	-14	(3.5)	-14	(1.8)
AAplant	8	(2.5)	12	(5.2)
AArange	22	(4.2)	27	(7.2)
HKAI	0.177	(0.0177)	0.156	(0.0215)

TABLE 6.3 - Gait analysis results (cont.)

Test No.	029/1		030/1	
BW	412		461	
LL	0.87		0.82	
SSize	7		5	
F1	451	(20.2)	505	(5.0)
F2	449	(24.2)	469	(25.6)
%@F2	77	(2.1)	81	(1.3)
F1/F2	1.01	(0.08)	1.08	(0.05)
F2/BW	1.09	(0.09)	1.02	(0.05)
HM	11.2	(4.4)	6.6	(7.33)
HA	14	(2.5)	16	(2.9)
HAV	77	(18.0)	68	(17.1)
KMext	11.4	(2.64)	17.9	(7.58)
KMflx	-16.4	(4.23)	-31.1	(7.10)
KIext	0.009	(0.0044)	0.017	(0.0094)
KIflx	-0.010	(0.0022)	-0.019	(0.0045)
KIext/flx	1.03	(0.83)	1.08)	(1.08)
KAmdst	-10	(0.8)	-8	(4.5)
KM	7.6	(3.79)	12.6	(7.40)
KA	-13	(1.80)	-13	(4.0)
KAV	-51	(51.0)	-82	(49.0)
AMearly	3.1	(1.38)	1.4	(1.09)
AMlate	-63.4	(3.83)	-71.6	(4.93)
AIflx	-0.080	(0.0039)	-0.093	(0.0075)
AA	-9	(2.6)	-8	(1.8)
AAV	67	(20.5)	26	(18.5)
AAdorsi	-12	(1.8)	-11	(2.1)
AAplant	12	(5.0)	8	(3.2)
AArange	25	(5.9)	18	(4.8)
HKAI	0.133	(0.0083)	0.163	(0.0214)

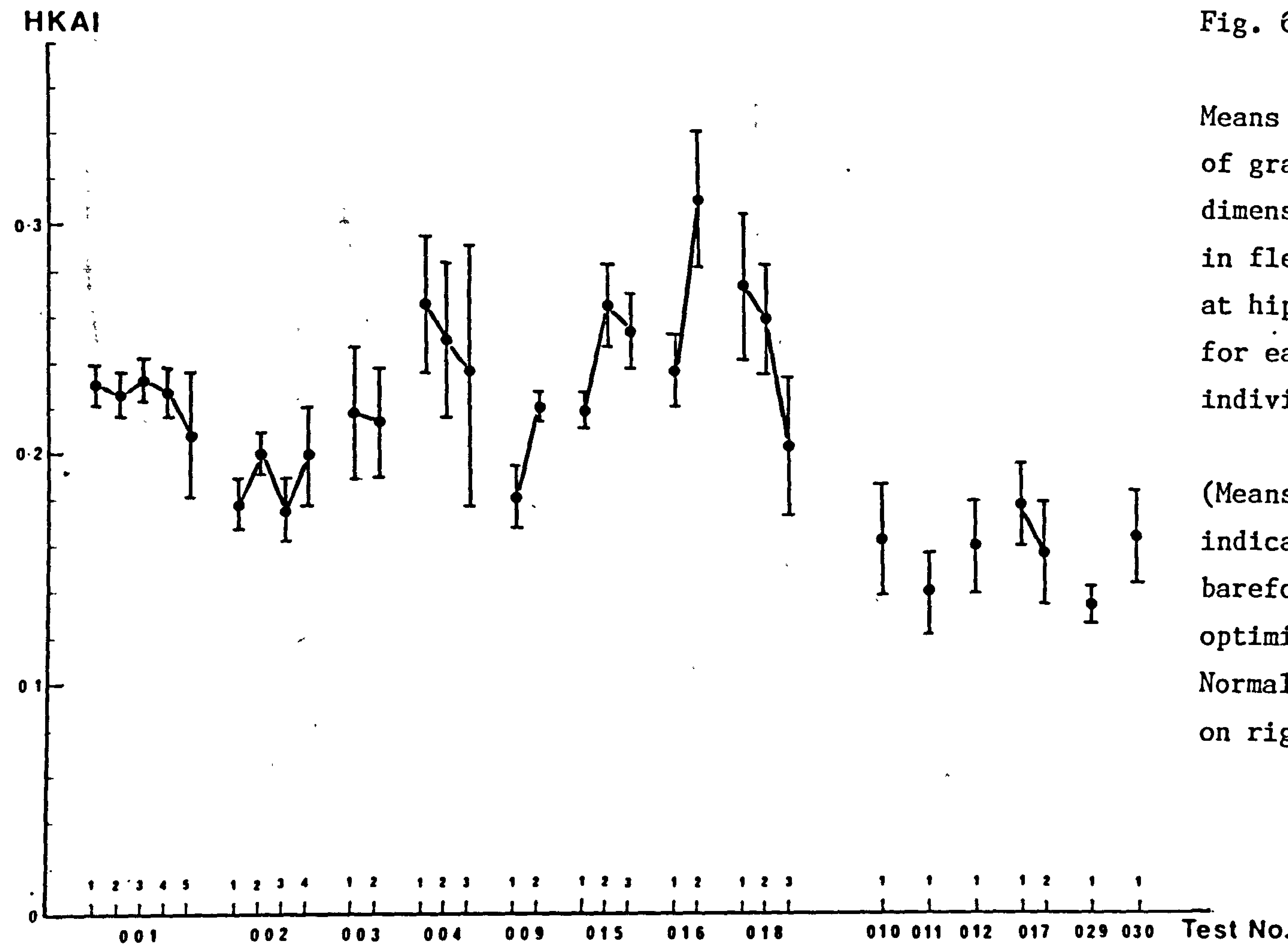


Fig. 6.1

Means and standard deviations of grand total of dimensionless angular impulses in flexion and extension at hip, knee and ankle (HKAI) for each test series with individual subjects (Test No.).

(Means have been linked to indicate trends between walking barefoot and with progressively optimised prescriptions. Normal subjects are grouped on right.)

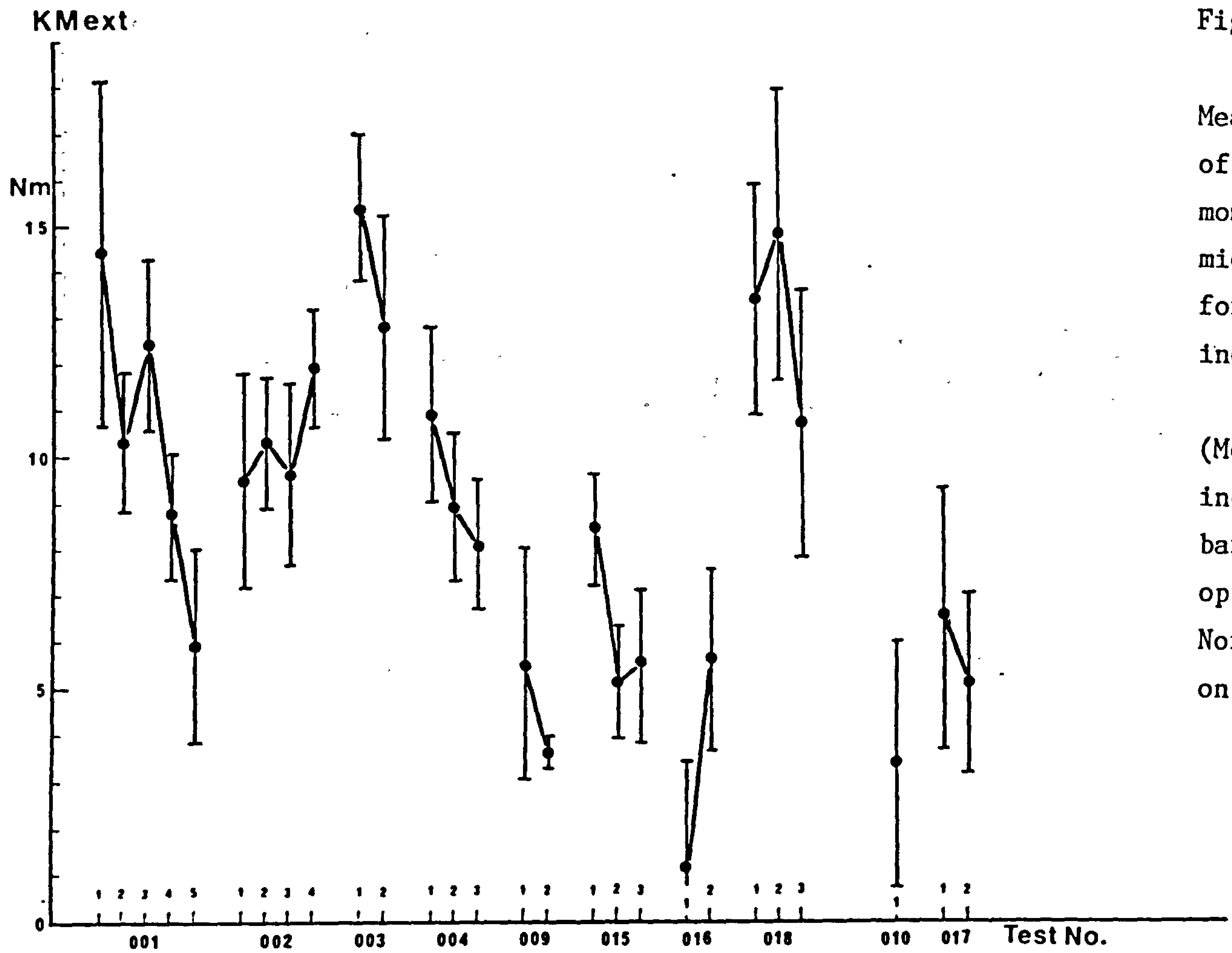


Fig. 6.2

Means and standard deviations of maximum external extension moment at knee during mid stance (KMext) for each test series with individual subjects (Test No.).

(Means have been linked to indicate trends between walking barefoot and with progressively optimised prescriptions. Normal subjects are grouped on right.)

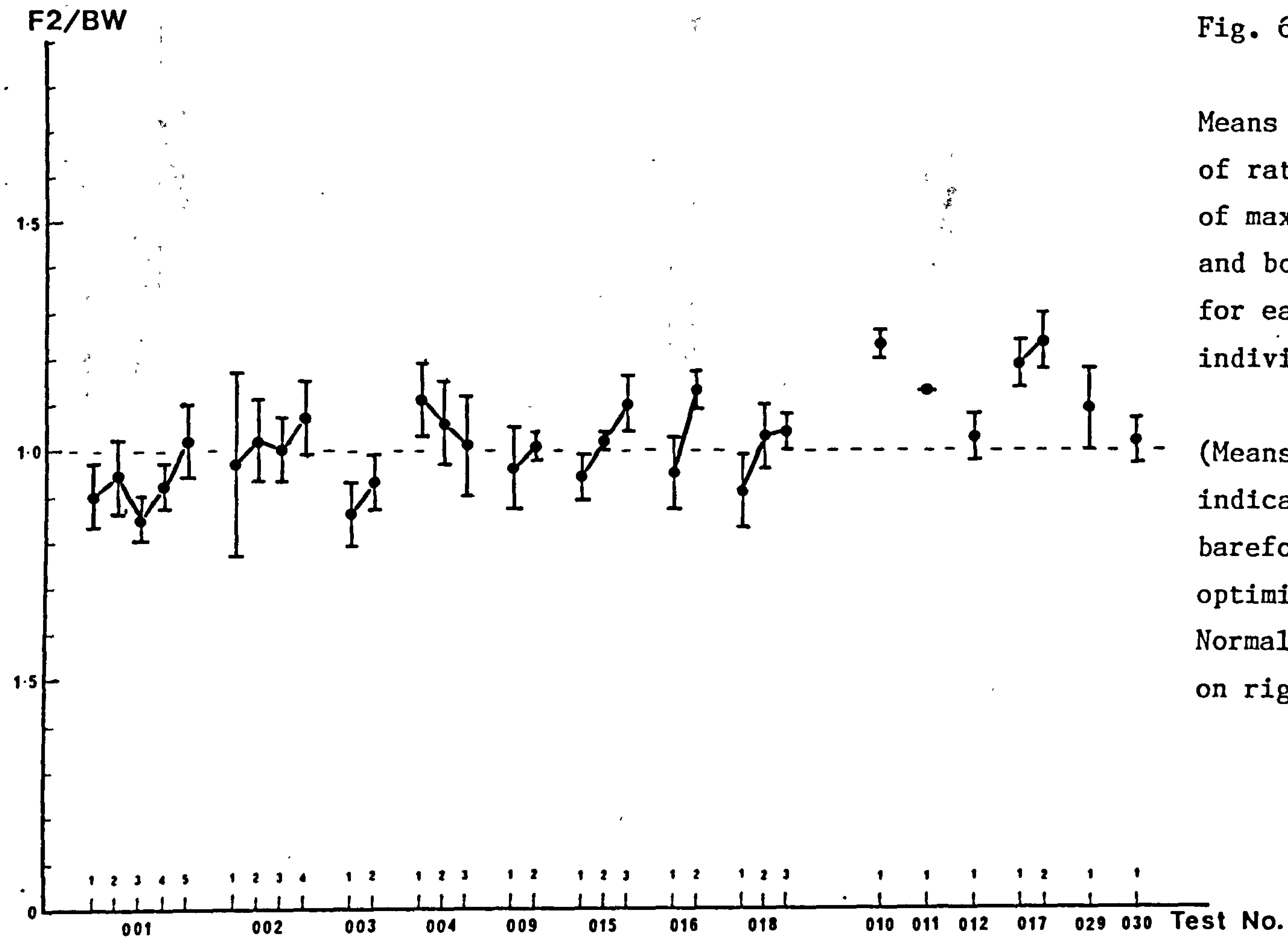


Fig. 6.3

Means and standard deviations of ratio of vertical component of maximum push-off force and body weight (F2/BW) for each test series with individual subjects (Test No.).

(Means have been linked to indicate trends between walking barefoot and with progressively optimised prescriptions. Normal subjects are grouped on right.)

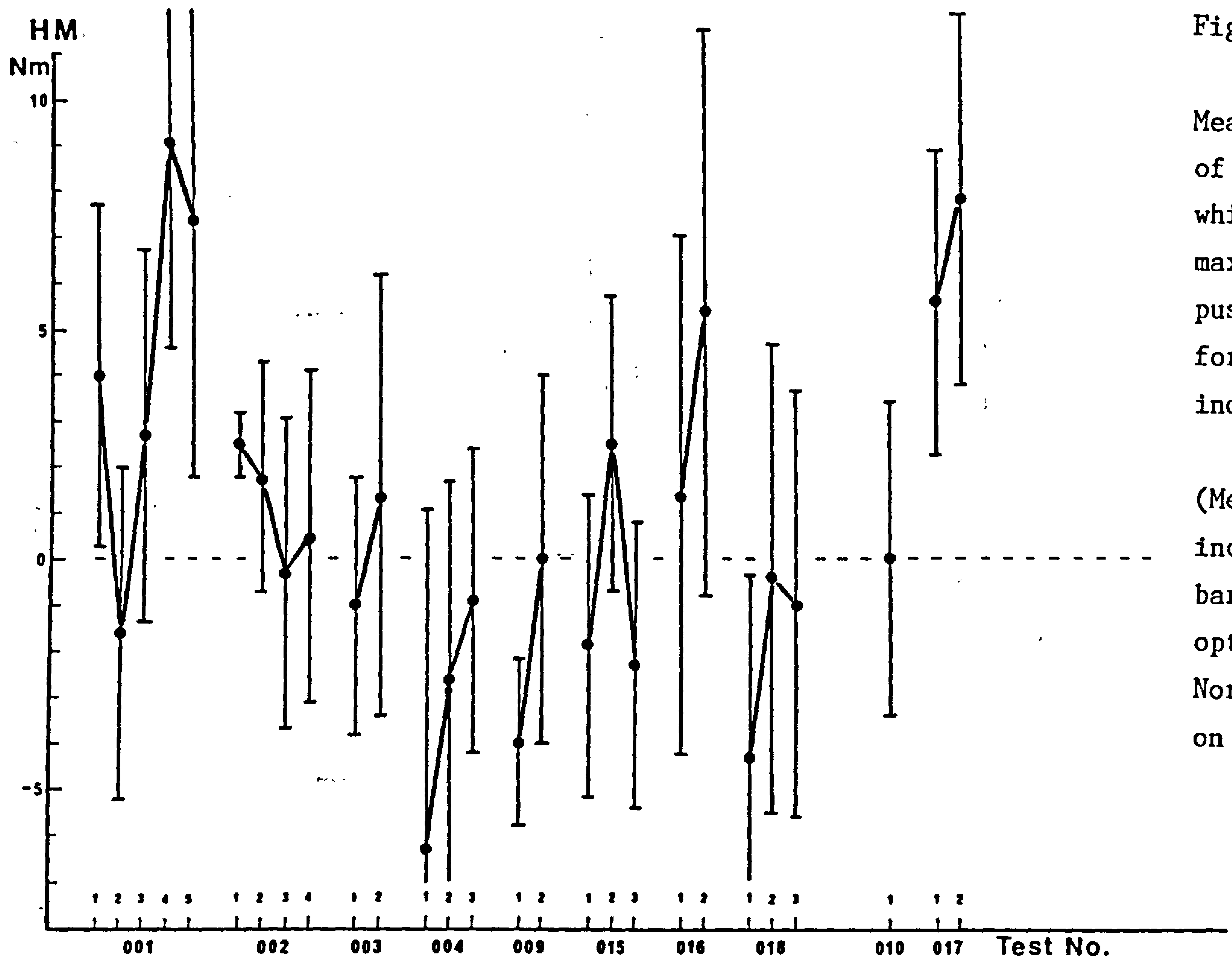


Fig. 6.4

Means and standard deviations of external hip moment (HM) which occurs at instant of maximum vertical component of push-off force in late stance for each test series with individual subjects (Test No.).

(Means have been linked to indicate trends between walking barefoot and with progressively optimised prescriptions. Normal subjects are grouped on right.)

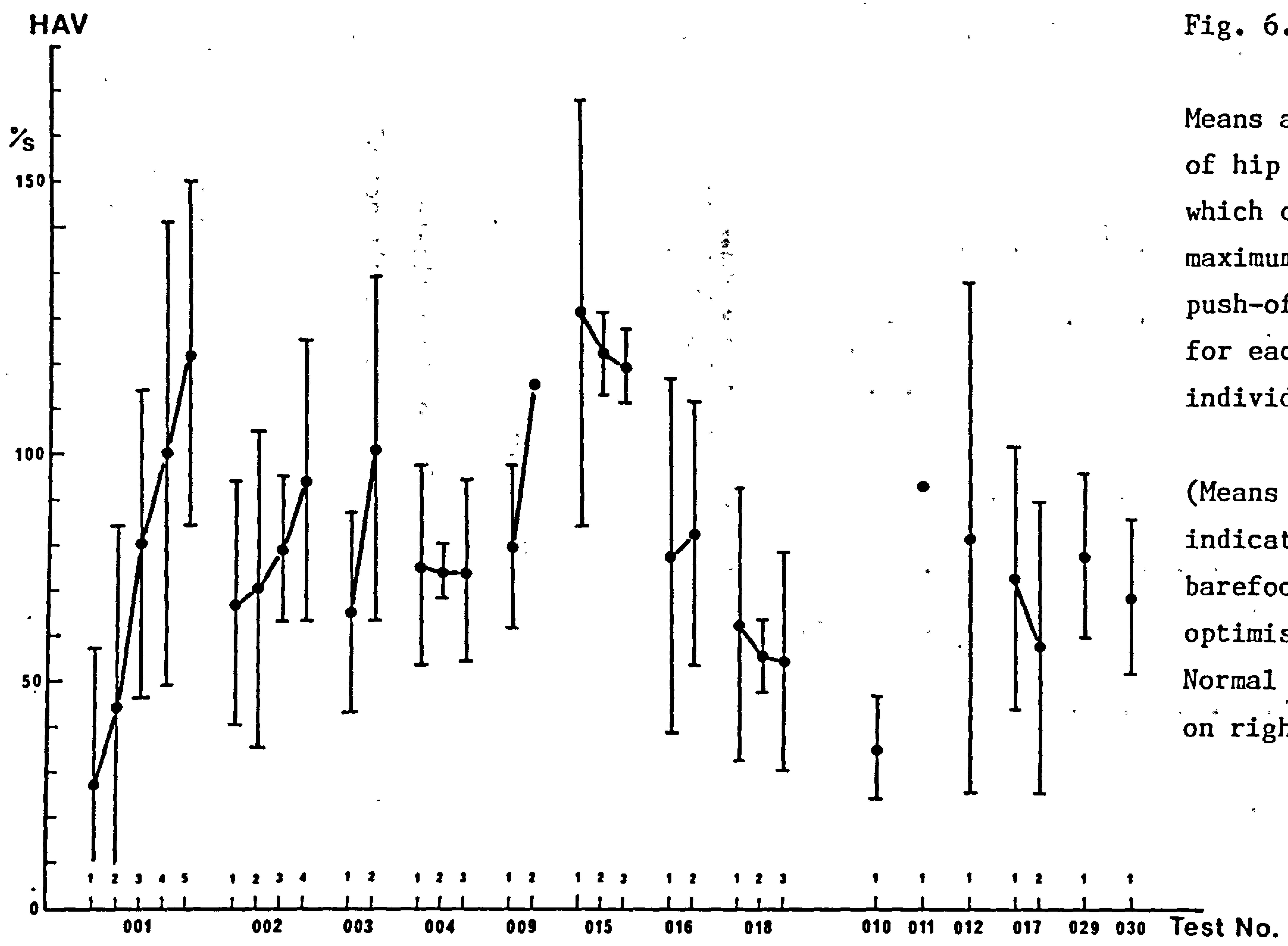


Fig. 6.5

Means and standard deviations of hip angular velocity (HAV) which occurs at instant of maximum vertical component of push-off force in late stance for each test series with individual subjects (Test No.).

(Means have been linked to indicate trends between walking barefoot and with progressively optimised prescriptions. Normal subjects are grouped on right.)

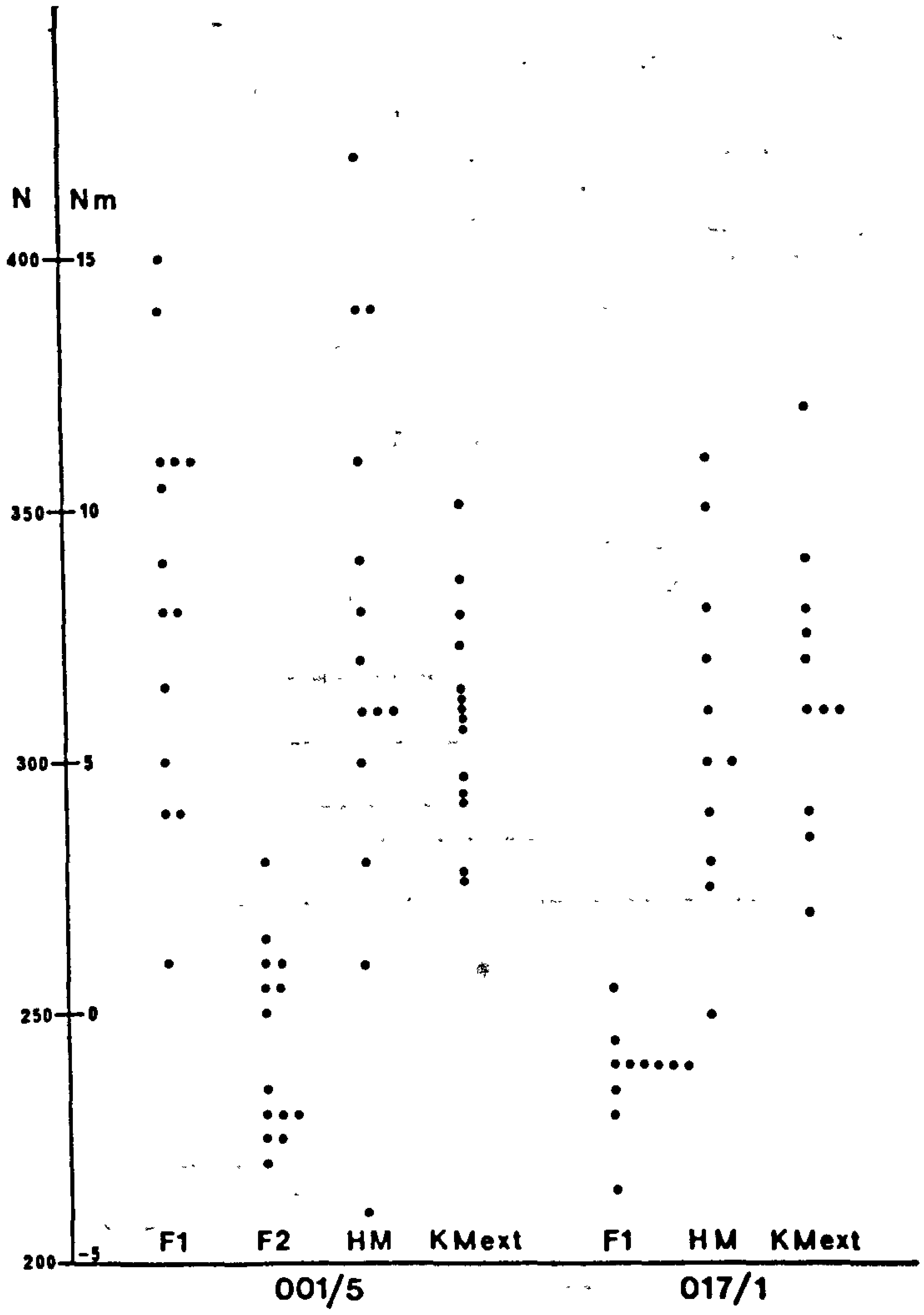


Fig. 6.6

Random sets of data plotted to indicate that their distributions are approximately normal.

TABLE 6.4 - Significance levels of difference of means of items of gait analysis data for different test series with individual subjects

Test Nos.	HKAI	KMext	F2/BW	HM	HAV
001/1-5	SS	SSS	SS	S	SSS
1-2	*	S	*	SS	*
2-3	*	*	S	*	*
3-4	*	S	S	S	*
4-5	S	SS	S	*	*
002/1-4	S	*	*	S	*
003/1-2	*	S	S	*	S
004/1-3	*	SS	S	S	*
009/1-2	S	*	*	*	-
015/1-3	SSS	SS	SSS	*	*
016/1-2	SS	SS	SSS	*	*
018/1-3	SS	S	SS	*	*
017/1-2	S	*	S	*	*

*	Not significant,	>p 0.100
S	Significant,	<p 0.100
SS	Very significant,	<p 0.010
SSS	Highly significant,	<p 0.001
-	Not applicable (single sample)	

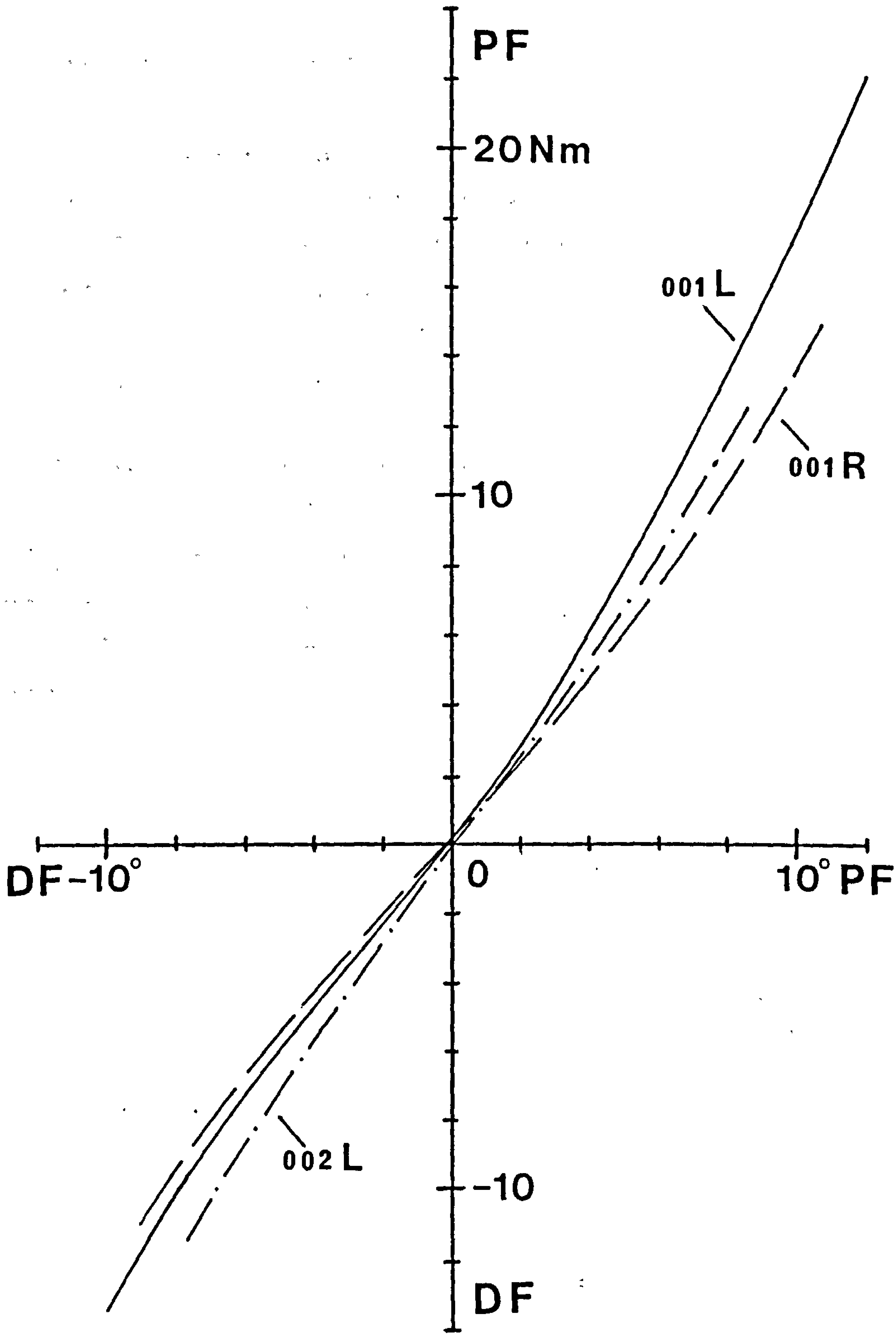


Fig. 6.7

Stiffness characteristics of AFOs
from subjects 001 (left & right) and 002 (left).

6.3 MUSCLE ACTIVITY MONITORING

During the period of this research programme 6 CP children were involved in long term muscle activity monitoring tests. Of these children 3 were involved in short term monitoring. These data were not extensively analysed. Examples of data considered typical and obtained from two spastic diplegic children are shown in Figures 6.8 - 6.10.

Figure 6.8 is an example of the long term monitoring of ankle strap load during a school day of a five year old spastic diplegic. Figures 6.9 and 6.10 illustrate the results of a short term monitoring of a seven year old spastic diplegic, (009 in the gait analysis series - one year later), with and without AFO respectively.

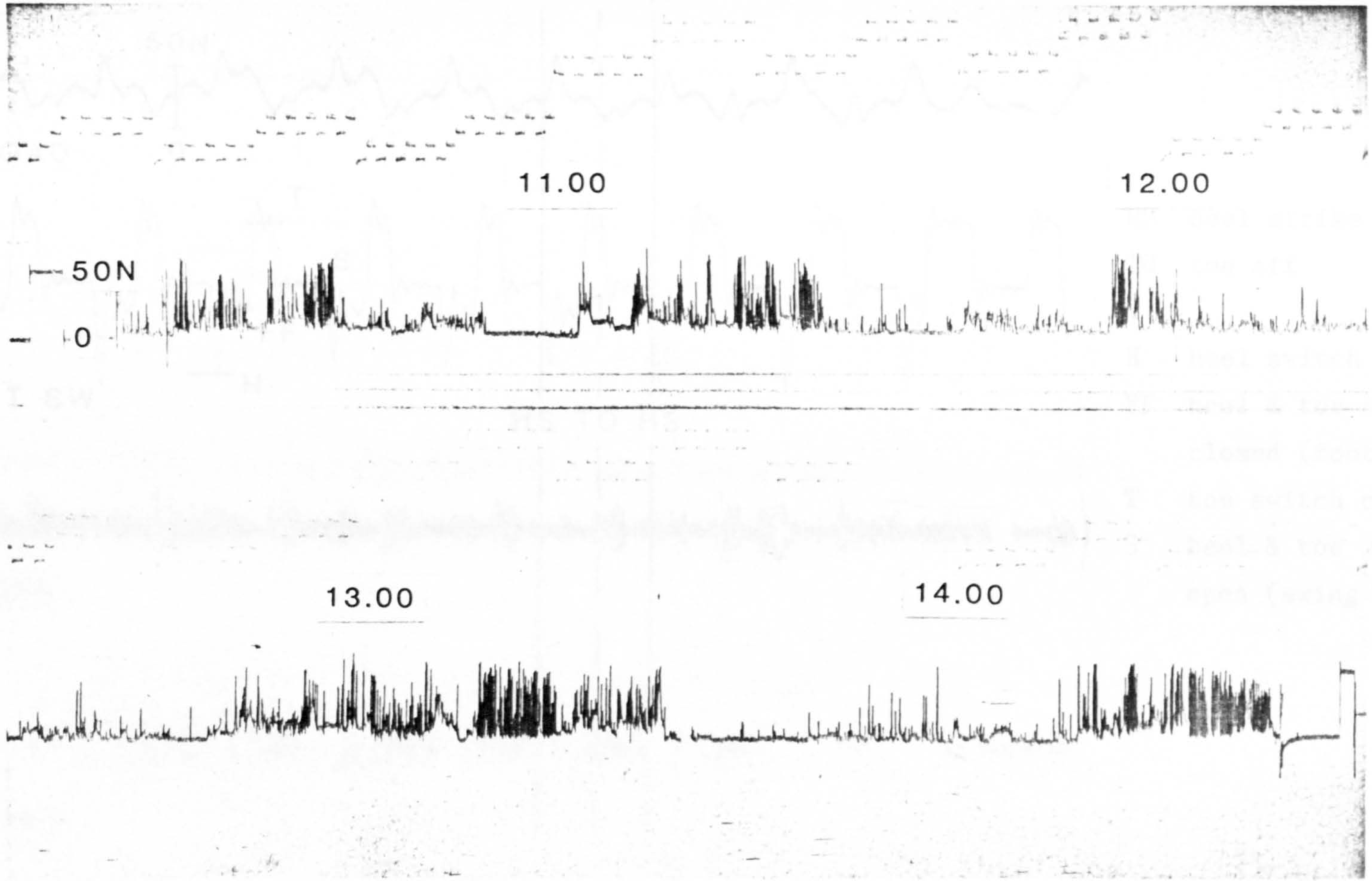
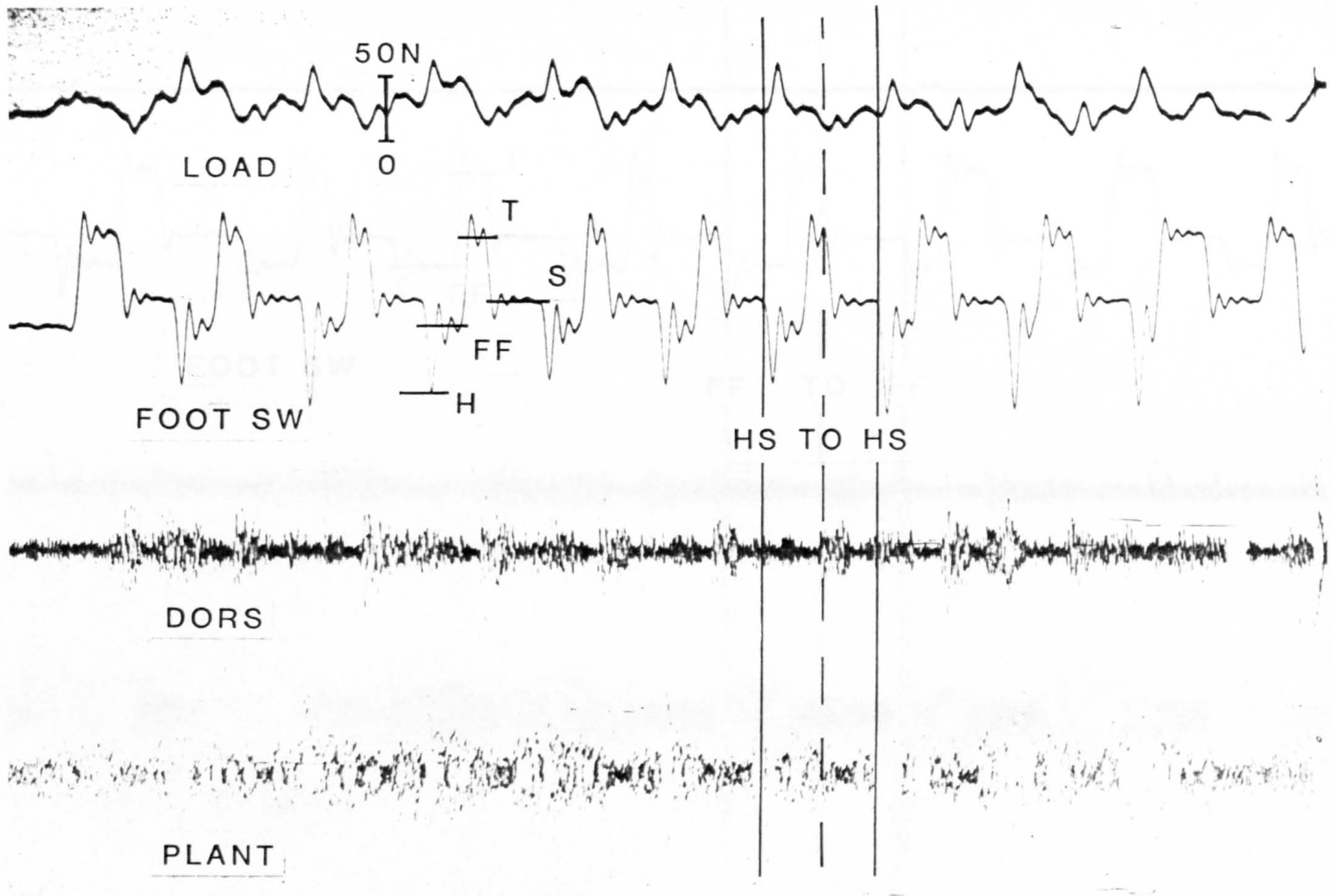


Fig. 6.8

Results of a long term monitoring of ankle strap load during a school day of a five year old spastic diplegic. (Time in hours).



HS	heel strike
TO	toe off
H	heel switch closed
FF	heel & toe switches closed (foot flat)
T	toe switch closed
S	heel & toe switches open (swing phase)

Fig. 6.9

Results of a short term monitoring of ankle strap load, footswitches and emg activity of dorsiflexors & plantarflexors of a seven year old spastic diplegic walking with an AFO.

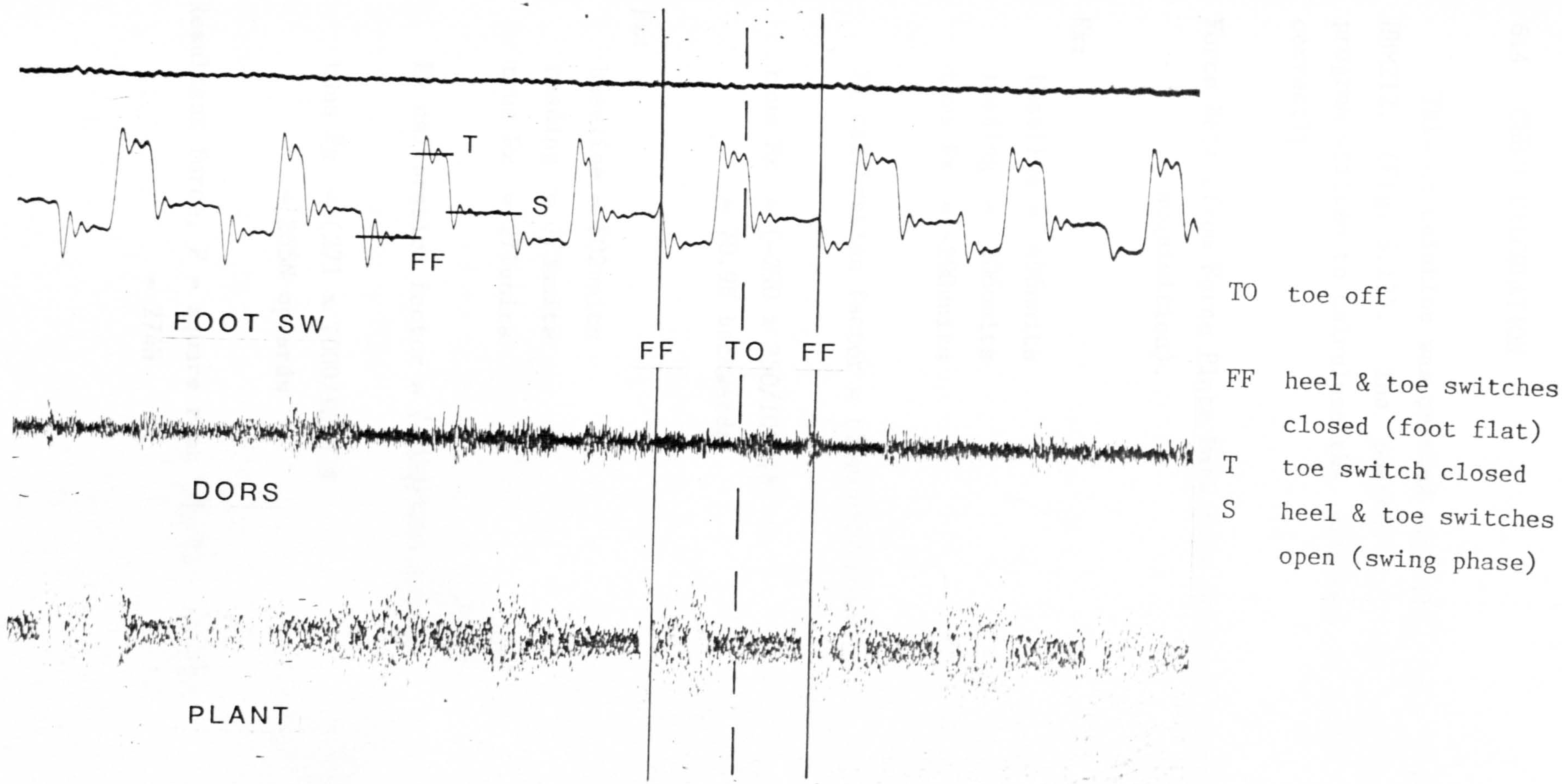


Fig. 6.10
Results of a short term monitoring of footswitches and emg activity of dorsiflexors & plantarflexors of a seven year old spastic diplegic walking barefoot.

6.4 CHECK CALCULATION

This calculation was carried out using data from frame 4 of HBM212, (Fig. 6.11). The purpose of this was to check that the program written to calculate the external moments was performing correctly.

Force Data (from Force Plate Data file obtained on data acquisition).

Fx:

baseline = 496units
reading = 206units
thus Fx = -290units

Fx calibration factor = (250/1023)N/unit

thus Fx = (-290 x 250/1023)N
= 70.9N backwards

Fz:

baseline = 502units
reading = 773units
thus Fz = 271units

Fz calibration factor = (1000/1023)N/unit

thus Fz = (271 x 1000/1023)N
= 265N upwards

Resultant force, F = square root (Fx.Fx + Fz.Fz)
= 274N

From direct measurement from stick and force vector diagram:

Fx = 69N	thus error	= 1.9N = 3%
Fz = 260N	" "	= 5.0N = 2%
F = 270N	" "	= 4.0N = 1.5%

Spatial Data (from direct measurement of stick diagram and patient records)

Distance between hip and knee markers on diagram = 16.5mm
" " " " " " from patient records = 270mm

Thus 16.5mm on diagram represents 270mm in measuring plane
Thus 1mm " " " (270/16.5)mm = 16.4mm

Perpendicular distance of line of action of force vector from knee (measured from diagram) = 4.5mm behind knee

This represents (4.5 x 16.4)mm = 73.6mm in measuring plane

F = 274 from Force Plate Data

Thus moment = (274 x 73.6/1000)Nm
= 20.18Nm in direction of flexion

From graph, moment = 20Nm in direction of flexion

There is, therefore, agreement between the value of the knee moment calculated by hand and that calculated by the program.

Fig. 6.11

Data used for check calculation.

6.5 ANALYSIS OF ERRORS

There were two main sources of instrumentation error – the force plate and amplifiers system, and the TV system. In addition there was the possibility of errors of placement of the skin markers in relation to the true anatomical joint centres. The magnitudes of these errors are listed below.

Force plate and amplifiers system – Kistler specifications

Fx (A-P shear)	less than	+/- 1% FSD = 1.25N	
Fz (vertical)	" "	+/- 1% FSD = 5N	
Centre of pressure	" "	+/- 2.5mm	

The force plate and amplifier system was checked by calibration and found to be within the manufacturers specifications.

TV System

The errors in x (horizontal) and z (vertical) co-ordinates due to non-linearities in the camera were <+/- 1mm if markers were contained within the largest circle which could be drawn in the field of view, (in this system 0.8m diameter).

The errors in x and z co-ordinates were <+/- 3mm if outside this circle. The parallax errors at the edges of the force plate nearest to and furthest from the camera and at extremes of marker trajectories possible towards the edges of the picture in x and z directions were <+/- 25mm.

The above parallax error is the worst possible and was unlikely to occur. In practice the children most frequently walked with their foot placed within the centre half of the force plate, i.e., within 150mm on either side of the short axis of the force plate, (Fig. 6.12). The parallax error then becomes <+/- 13mm. This

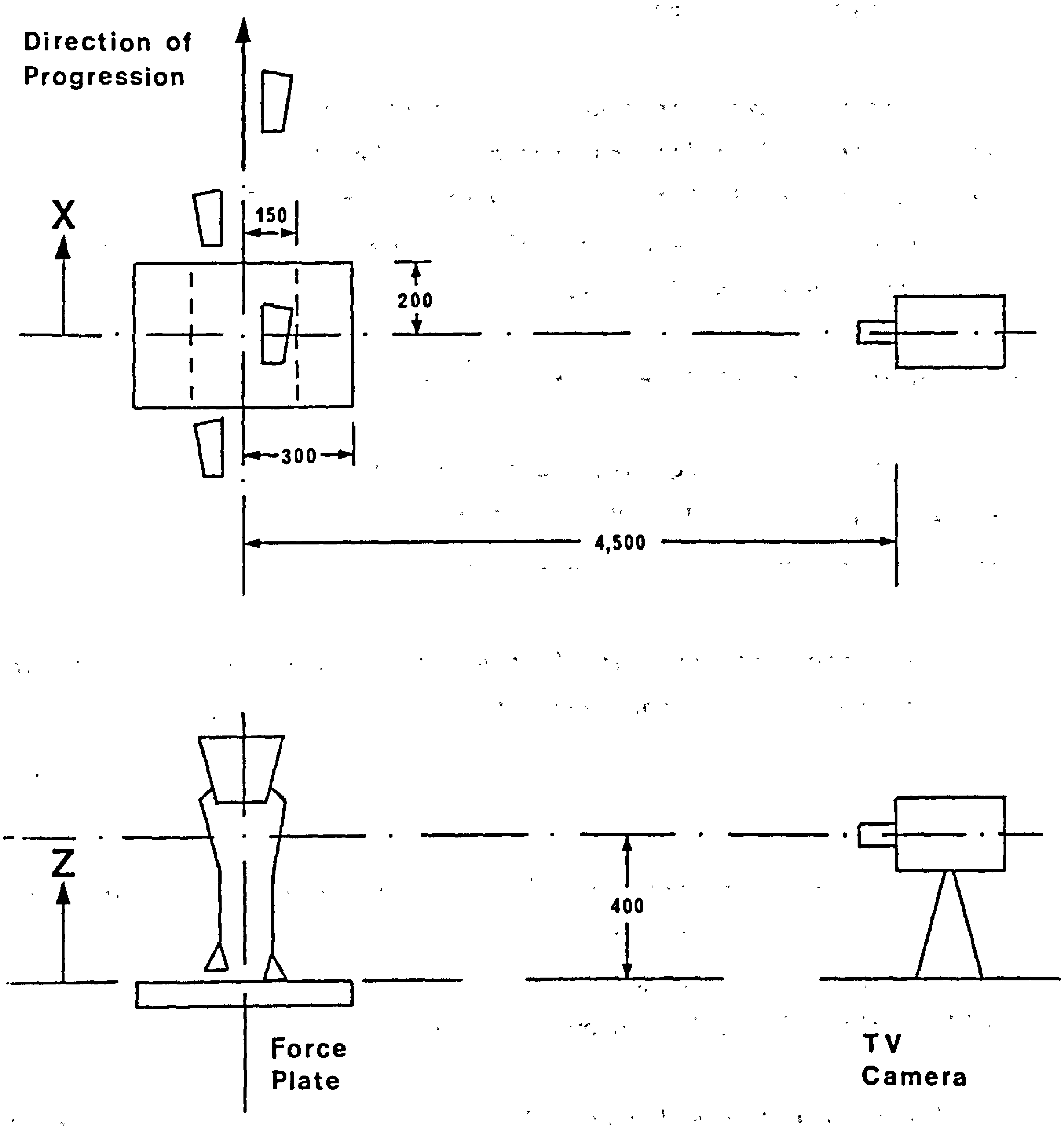


Fig. 6.12

Relative positions of force plate and television camera.

Dimensions in millimetres.

(Not drawn to scale.)

occurs at the extremes of the field of view. This largest error in the z direction would occur at the toe marker when on the ground which was 400mm below the axis of the camera lens. The knee and hip marker trajectories were well within a band whose limits were 200mm above and below the camera lens. Within this band the parallax error in the z direction is <+/- 6.5mm. The x position of the foot markers could never be at a distance greater than 150mm from the long axis because of the relationship of the length of the foot, the length of the short axis of the plate, the distance of markers from the extremes of heel and toe, and the fact that to avoid the possibility of the child not striking the force plate cleanly, i.e., with the toe or heel overhanging the edge, test runs were not accepted unless the extremes of the foot were within 20-30mm of the edge of the plate. In this case the parallax error in the x direction of the foot markers is <+/- 5mm. Larger errors occur at the hip and knee, especially the hip, because of the larger distances in the x direction from the centre line of the field of view. This distance is constrained by the length of the child's leg and the fact that the foot must be on the force plate. Measurement of typical stick diagrams indicate that this would be less than 300mm. The parallax error in the x direction at this point would be <+/- 10mm.

Summary of instrumentation errors likely to occur

Force plate and amplifiers system

Fx	less than +/- 1.25N
Fz	" " +/- 5N
Centre of pressure	" " +/- 2.5mm

TV system

x and z co-ordinates of all markers due to camera less than +/- 1mm

x	co-ordinate	of	hip	due	to	parallax	less	than	+/-	10mm
z	"	"	"	"	"	"	"	"	+/-	6.5mm
x	"	"	knee	"	"	"	"	"	+/-	10mm
z	"	"	"	"	"	"	"	"	+/-	6.5mm
x	"	"	ankle	"	"	"	"	"	+/-	5mm
z	"	"	"	"	"	"	"	"	+/-	13mm

In order to obtain an impression of the effect of the possible errors on the value of the external moments generated, these errors were applied to date obtained from sample 4 of HBM212 relating to the knee joint, (Fig. 6.11).

Error in forces

Components of force obtained from force plate data file

Fx = 70.9N
Fz = 265N
Thus resultant force F = 274N

By trigonometry angle of vector to horizontal = 75degrees

Apply maximum errors, one +ve, one -ve to create maximum change in line of action.

Horizontal force including error, Fxe = (70.9 + 1.25)N = 72.15N
Vertical force including error, Fze = (265 - 5)N = 260N

By trigonometry angle of vector to horizontal = 74.5degrees.
Approximate distance along force vector to intersection with perpendicular line through knee joint centre (obtained by

direct measurement of stick diagram) = 340mm

Thus increase in lever arm at knee = 340mm x tan 0.5degrees
= 3mm approx.

Moment, M, obtained from graph = 20Nm
F = 274N
Thus perpendicular distance,D = (20 x 1000/274)mm = 73mm
" " "
including error, De = (73 + 3)mm = 76mm

Resultant force including error, Fe = 270N

Thus moment including error, Me = (270 x 76/1000)Nm = 20.52Nm
" error = 0.52Nm = 2.6%

Centre of pressure error

Assume centre of pressure displaced by 2.5mm with full effect on perpendicular distance (this would only occur if vector vertical). Calculate effect on original data.

De = (73 + 2.5)mm = 75.5mm
Thus Me = (274 x 75.5/1000)Nm = 20.69Nm
" error = 0.69Nm = 3.5%

Effect of error from TV camera

Assume error is 1mm in x and z direction and that both affect D

Thus De = (73 + 1.4)mm = 74.4mm
" Me = (274 x 74.4/1000)Nm = 20.39Nm
" error = 0.39Nm = 2.0%

Parallax error

Increase in perpendicular distance by error of 10mm in x direction and 6.5mm in z direction to line of action of vector at 75 degrees to horizontal = 12mm

Thus De = (73 + 12)mm = 85mm
" Me = (274 x 85/1000)Nm = 23.29Nm
" error = 3.29Nm = 16.5%

Misplacement of marker

This is unlikely to be more than 10mm because of the relatively small scale of the child's anatomy and is probably about 5 mm.

Assume error is 10mm

Thus De = (73 + 10)mm = 83mm
" Me = (274 x 83/1000)Nm = 22.74Nm
" Error = 2.74Nm = 13.7%

Assume all errors happen maximally, simultaneously and their effects are in the same direction.

Total error = 7.63Nm = 38.2%

To make the error effect more general add all the increases in perpendicular distance caused by the errors.

Increase in De = (3.25 + 1.4 + 12 + 10)mm = 28.9mm
Thus error in moment per N = 0.0289Nm

The error produced in the moment at any joint is directly proportional to the magnitude of the force. Obviously if the perpendicular distance at a given instant is small then the error will be very large if expressed as a percentage of the original moment. However, the shift in the value of the moment caused by the error is a constant for a given force.

Dynamic response of system

The error analysis conducted above considers only static errors. It is possible that additional errors will arise due to the fact that the markers are moving across the field of view and that the ground-to-foot reaction forces are not constant but rapidly changing. These errors are related to the scanning speed of the TV camera, the sensitivity of the tube and the natural frequency of the force plate. Due to the constraints of the sampling rates of the TV-computer system it was not possible to conduct an analysis of the additional errors due to the dynamic response. However, such an analysis has been performed on a very similar TV-computer system in the BioEngineering Unit, University of Strathclyde, (Proctor,1980, Andrews,1982). It is considered that the dynamic responses of the two systems are very similar. In some respects the Dundee system as set up for this research programme is likely to be slightly better.

Two principal errors are possible in relation to the force plate. First, the natural frequency influences its sensitivity in responding to the high-frequency components of the ground-to-foot reaction forces. Analyses by Proctor (1980) showed that at the University of Strathclyde the natural frequency of their Kistler force plate, determined by sampling at 1 KHz, was 112 Hz. The highest significant frequency content of the reaction force during walking is about 5 Hz. The natural frequency of the force plate is therefore more than an order of magnitude higher which is considered to be acceptable for adequate response. Because of the improved force plate mounting system in Dundee the natural frequency is likely to be higher, further improving the response. The value of 5 Hz as the highest significant frequency content of the ground-to-foot reaction force has been obtained by the analysis of adult gait. It is quite possible that in children this value may be higher although it is probable that it is still at least an order of magnitude lower than the force plate natural frequency. Second, the force plate data are not sampled at the same time as the TV data but in between successive TV data samples. The time difference is, of course, extremely small - of the order of a few milliseconds. The error is therefore minimal.

There are three sources of error relating to the TV camera. First, because of the time taken for the scan to travel from the top to the bottom of the screen, markers in different parts of the field of view will not be detected simultaneously. Markers at the bottom will therefore, have travelled further across the field of view by the time they are detected. However, the time taken for a complete scan is 18ms so that the errors between markers, which tend not to lie at the extremes of the field of view, are minimal. Second, if the marker size is small in comparison to the resolution of the TV tube so that it is detected on only one line of the raster at a time the apparent progress of the marker across the field of view will be a series of steps rather than a continuous, smooth movement. If the marker size is sufficiently large so that it is detected simultaneously on more than one line of the TV raster this problem is reduced. With the marker size and field of view used in this research programme the marker could be detected on about 3 lines simultaneously thus avoiding the problem. Third, with very bright markers a comet-and-tail effect can result due to the persistence of the tube. If the direction of movement of the marker across the field of view is the same as the scan of the TV camera the 'tail' will be encountered first, and hence the position calculated, before the actual marker itself is reached. However, in this system, as described in Chapter 4, there was no comet-and tail effect as the aperture of the camera was set with extreme precision. This problem therefore did not exist.

There are thus several sources of error due to the dynamic response of the system. However, from the analysis performed at the University of Strathclyde, (Proctor,1980, Andrews,1983), the magnitudes of these errors are extremely small in comparison to the static errors described earlier. It is, therefore, considered reasonable that these errors may be ignored.

It is interesting to note that the two biggest sources of error are parallax and misplacement of the skin markers. The direction of the parallax error depends on which side of the centre line of the force plate the leg is placed. When several test runs are averaged to produce a mean value for the moment at a joint the negative and positive values of parallax error will tend to balance each other out. While the individual values of moment from each test run may contain relatively large errors the error in the mean value may be considerably reduced. Examination of the records of the position of foot placement on the force plate indicated that indeed there was generally a distribution of positive and negative placements in a typical series of test runs. This may explain why the standard deviations for many of the calculated parameters are large. It is likely, therefore, that the effect of parallax errors on the mean value is considerably reduced but it is difficult to estimate this. The misplacement of the skin marker would give a constant error throughout the series of tests for a given child during one test session. Nearly all the data from the children were obtained in such a single test session. While this would give an error in the measured values, it is important to note that these errors would cancel out when comparing different series of tests, for instance, barefoot tests with test wearing AFOs. Therefore, the trends of the differences between series would be accurate.

While looking, for example, at shifts of moment from flexion to extension, we are therefore left with the true instrumentation errors in De of <+/- 6.9mm and an estimate of the parallax error which may remain after averaging of, say, <+/- 5mm. The total likely error would, therefore, be about <+/- 12mm. In reality it is likey to be less than this because the errors would not necessarily all be in the same direction and, if not, would tend to cancel each other. When comparing the means of different test series it may, therefore, be justifiable to estimate the error in the perpendicular distance to be of the order of, say, <+/- 10mm. It is, however, difficult to be certain of this.

If the above value was adopted this would produce an error in the moments 0.01Nm/N of F. In the example of the knee moment in HBM212 the error would be 2.7Nm.

The errors in the value of F2/BW arise from two sources, the force plate and amplifier system, and the measurement of body mass from the scales. The first, from Kistler specification is <+/- 5N. In addition the measurements from the stick diagrams were taken to the nearest 5N, giving an error of <+/- 2.5N. The total error in F2 is therefore <+/- 7.5N. The body mass was measured to the nearest 0.5kg, the error therefore being <+/- 0.25kg. The scales were calibrated within the range of the children's body mass and adjusted to be accurate to within 0.2kg. The total error likely was therefore <+/- 0.45kg, or 4.5N. The calculated value of F2/BW in test HBM212 was 1.10, the value of Fz measured from the stick diagram being 265N and the body weight 240N. Imposing the maximum errors in opposite direction to combine their effects the value of F2/BW is now 1.16.

These errors in the value of F2/BW are therefore significant when compared with the range of values between test series if they have their maximal effect. It is important to note, however, that the error in the value of body weight is a constant one and therefore does not significantly influence the difference in the values between test series. In the example of HBM212 if only the error in F2 is considered the value of F2/BW is now 1.135, the error being less than 0.04. It is probable that the errors actually occurring are less than those which are the maximum possible, although this cannot be stated definitely.

From this analysis of the errors occurring in F2/BW it can be concluded that the trends observed in change of values between test series can be accepted although the absolute value may contain an error as indicated above.

CHAPTER 7

DISCUSSION

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DISCUSSION

7.1 INTRODUCTION

This chapter discusses the results of the research programme. After comment on the selection of test subjects and their prescriptions, the nature of the results and their interpretation are discussed. The stick and force vector diagrams from a CP child walking barefoot and with a range of prescriptions are presented as typical examples of the variations in the observed kinetic data. These are compared with the results of a normal child walking barefoot. Several of the items of data, presented in graphical form in Chapter 6, are discussed in detail. The results of the muscle activity monitoring tests are discussed. The clinical implications of the results of the research programme are discussed. Finally suggestions for future work are presented.

7.2 GAIT ANALYSIS

It was recognised at the start of this research programme that the subject under investigation, the influence of polypropylene ankle-foot orthoses on the gait of cerebral palsied children, was extremely complex and that compared to this complexity very little relevant information existed. Clinical experience had indicated that although there were similarities between children relating to their gait patterns and to the influence of AFOs there was also no doubt that all children were individuals and that significant differences were likely to exist between them. Clinical experience had shown, for instance, that different children would adopt different compensatory methods to overcome their difficulty with barefoot walking. Some children might adopt, perhaps, a grossly-flexed knee attitude. Others would permit their knees to be forced backwards into hyperextension resulting in great effort being required to "unlock" their knees and initiate flexion in late stance. Some children might alternate between the two options, depending perhaps on their desired velocity. Differences existed between children in the optimum characteristics required for the AFO-footwear complex. In addition, for a given child, very small changes in the characteristics of the AFO-footwear complex could markedly affect the quality of the gait pattern. It was therefore obvious that there was a large number of variables involved. Some of these variables might be controlled, some might be uncontrollable and the existence of others might not even be recognised.

In an attempt to minimise the influence of these variables great care was taken in the choice of children accepted into the gait analysis programme. The eight children whose data is presented in this thesis were all considered by the research team to be good examples of cerebral palsied gait. They displayed typical problems when walking barefoot, and their gait patterns were influenced significantly by the use of AFOs in a manner which again was considered to be typical. While the choice of the research team may be open to some debate it must be remembered that these decisions were made in the light of clinical experience over many years in the use of over 1,000 AFOs with about 150 children.

Most of the children chosen were familiar with the members of the research team and had developed a friendly relationship with them over the years. In addition they were familiar and at ease with the environment of the laboratory, having had routine filming sessions of their gait throughout the period of their management programme. It was considered that there was therefore very little influence on their gait patterns due to the measurement process itself.

It was considered appropriate to conduct gait analysis with the child walking barefoot to obtain baseline information, and walking with the AFOs and footwear whose characteristics were considered clinically to be optimum for that child. It was felt that, apart from being more relevant clinically, this might produce more similar results between children. This was in contrast to adopting the alternative approach of fitting all children with identical prescriptions, perhaps an ordered range of them, and examining the outcome. This latter approach had considerable merit but was rejected for this research programme on logistical grounds.

All children were reviewed regularly as part of their clinical management, enabling the team to confirm that the prescriptions were optimum and that gait analysis should be carried out. In most instances this would be on a separate occasion a few days after the child's latest clinical review. This implied that the child would therefore attend for gait analysis with the optimum prescription. Despite this planning and apparently adequate explanation to the parents in some instances the child attended with different footwear to that which had been matched to the AFO, normally their school shoes. They sometimes attended wearing training shoes or sandals because it was a lovely sunny day, or their best party shoes to look nice for the photographs. Usually the principal difference was the heel height but occasionally the rocker sole profile was different. In these cases gait analysis was usually conducted wearing the shoes they had arrived in if the characteristics were not too inappropriate, and also with temporary adaptations to return the characteristics back to those considered optimum. In most cases this only involved the addition of a heel wedge placed inside the shoe and underneath the AFO. The child was therefore unable to feel the wedge and it did not affect the nature of the walking surface. It was considered likely that the temporarily-adapted footwear was probably more familiar to the child as far as the effect of the characteristics were concerned than the unadapted footwear.

7.2.1 Results

A considerable amount of data was obtained from the gait analysis of the 8 CP and 6 normal children. A total of 215 test runs were successfully processed to produce the A3 format printouts. This involved 31 different test series, i.e. 31 different prescriptions or barefoot measurements. With all but two children these data were obtained during the same test session, i.e. on the same day. With subjects 001 and 002 two test sessions each were involved, 1 week and 10 weeks apart respectively.

Each A3 format printout contained information relating to the ground-to-foot force, the motion of the hip, knee and ankle joints, the external moments generated in flexion and extension and the components of the angular impulses at these joints.

As expected a spread was observed in the data, especially between children, but also within a test series for a given child. There were also, however, some similarities between children apparent on qualitative observation of the data. These occurred when considering the changes in the gait pattern when barefoot or with a bad prescription, and when using the optimum prescription.

Of all the items of data which it was possible to extract from the printouts, 26 were finally selected as being the most relevant and the most likely to permit assessment of the influence of AFOs on gait. These were selected after consideration of clinical experience which had suggested what might be some of the biomechanical changes taking place, and qualitative assessment of the print-outs. These items of data are listed in Table 6.3. The results and implications of some of these items are discussed later including those five from which graphs were drawn and which were presented in Chapter 6.

In order to gain an impression of the nature of the kinetic variations which were observed during the research programme stick and force vector diagrams obtained from two children (010 and 001) are presented, Figs. 7.1-7.7. These data are examples of a normal child walking barefoot, (Fig. 7.1), and an ataxic diplegic CP child walking barefoot and with 3 different prescriptions,(Figs. 7.2-7.7).

Fig. 7.1 illustrates a typical normal gait. Heel strike may be observed by the posterior placement of the first green force vector. There is a smooth "double-hump" shape to the magnitude of the force vector indicating relatively low impact forces in early stance phase and a good push-off in late stance phase. Close alignment of the vector may be observed at the ankle during early stance and at hip and knee, especially in late stance, indicating the imposition of relatively low external moments thus requiring only minimal muscle activity.

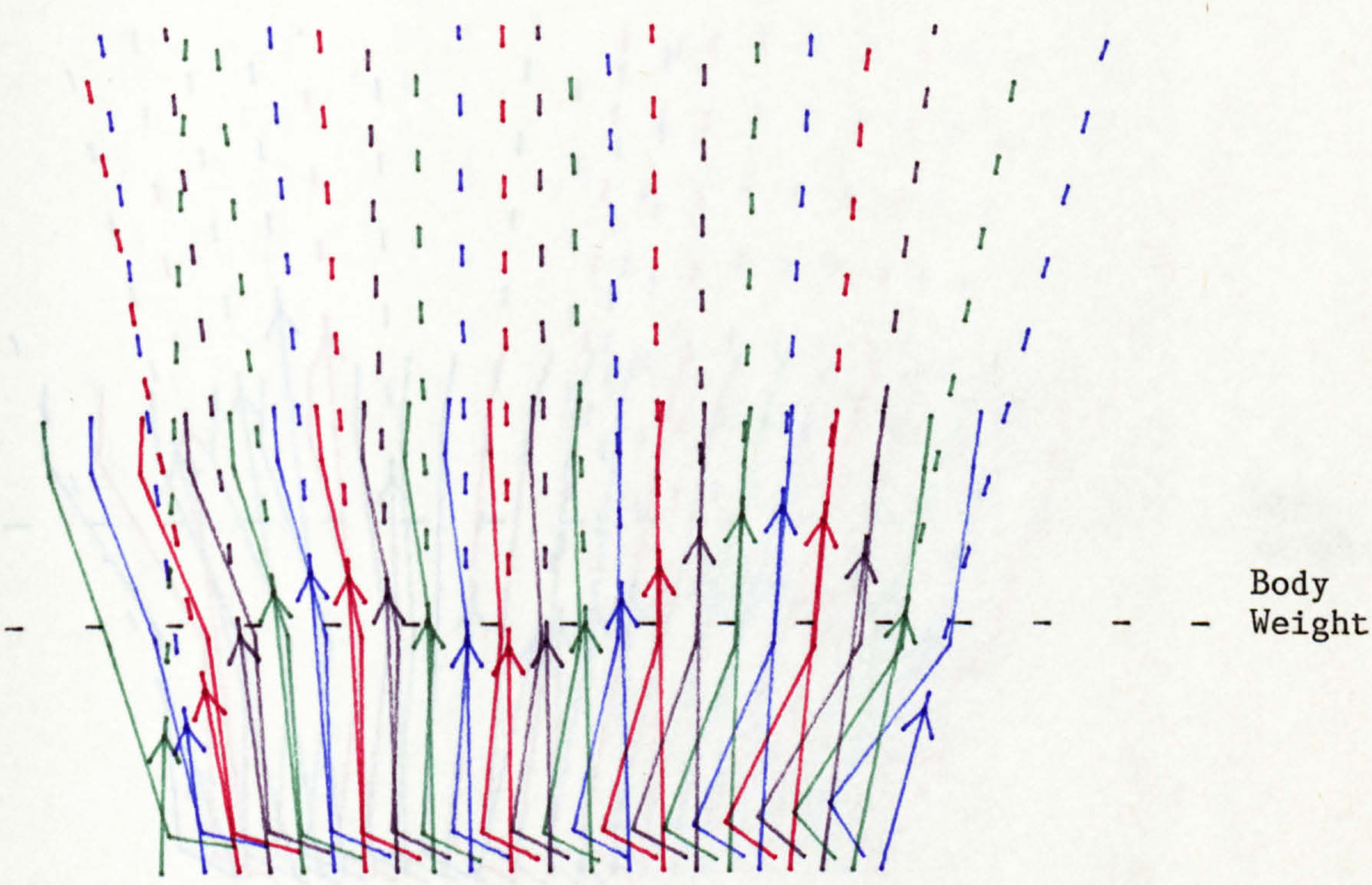

Fig. 7.1

Stick & force vector diagram

of a normal child walking barefoot.

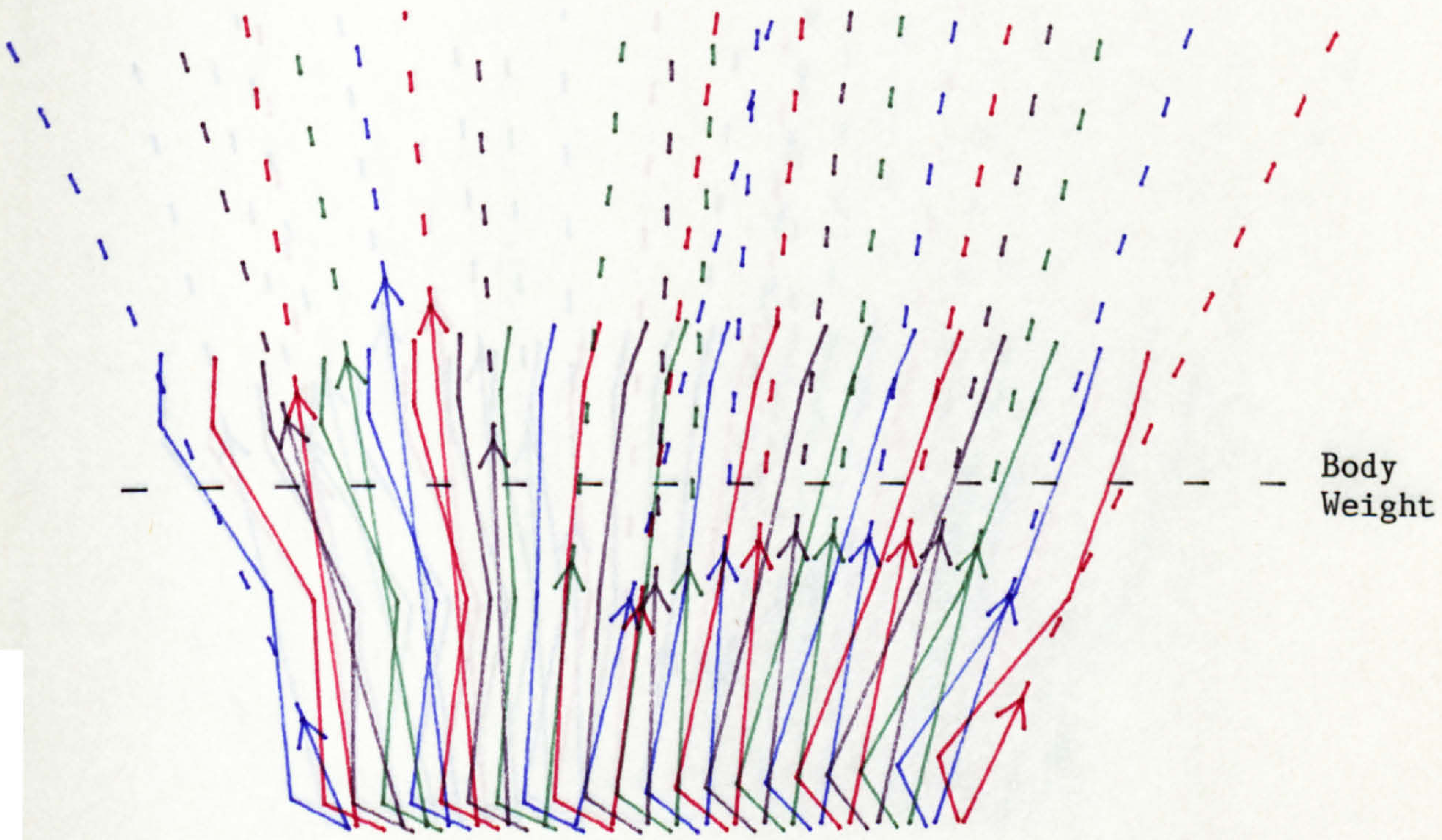

Fig. 7.2

Stick & force vector diagram
of a diplegic CP child walking barefoot.

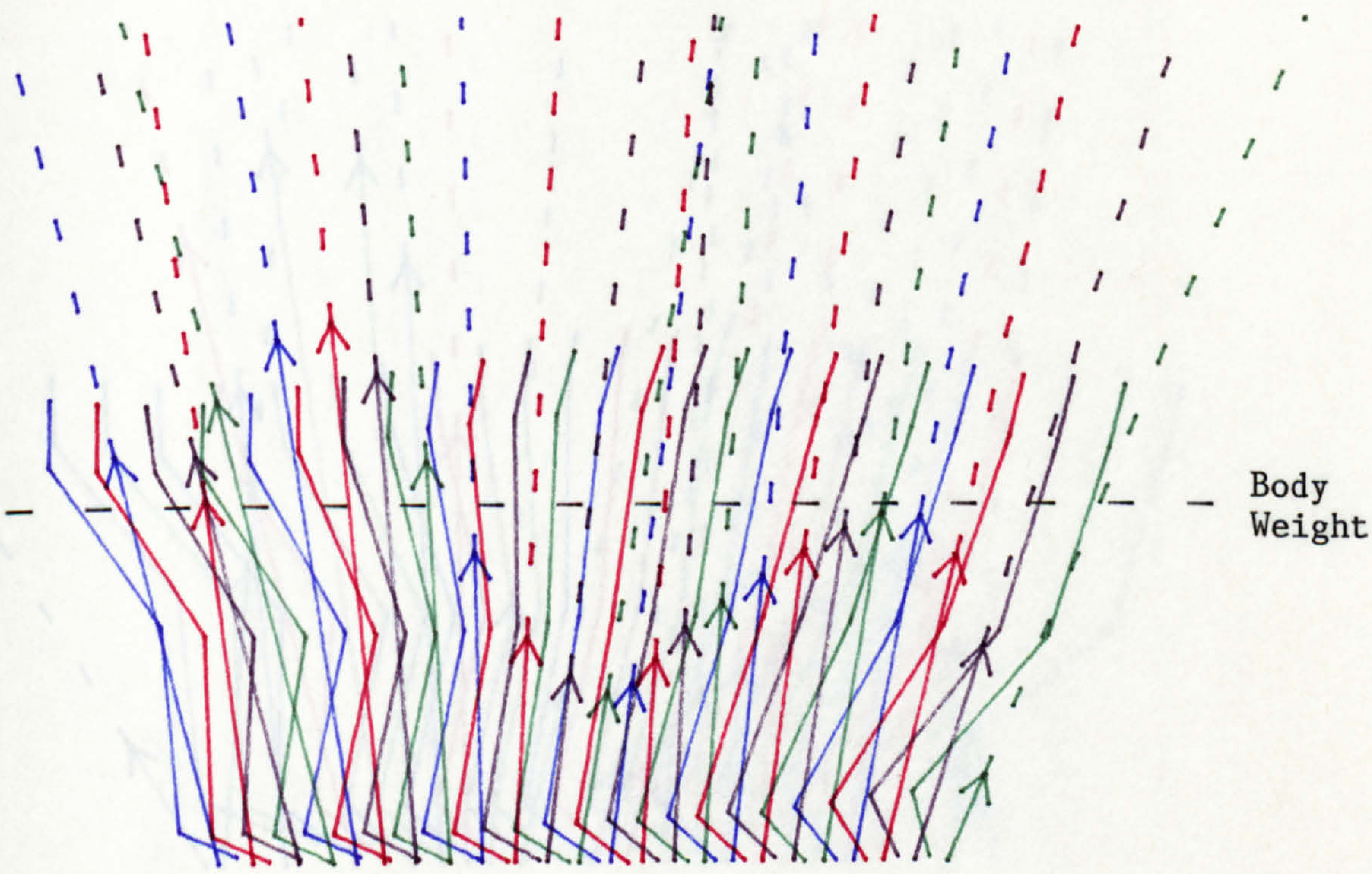

Fig. 7.3

Stick & force vector diagram

of a diplegic child walking barefoot.

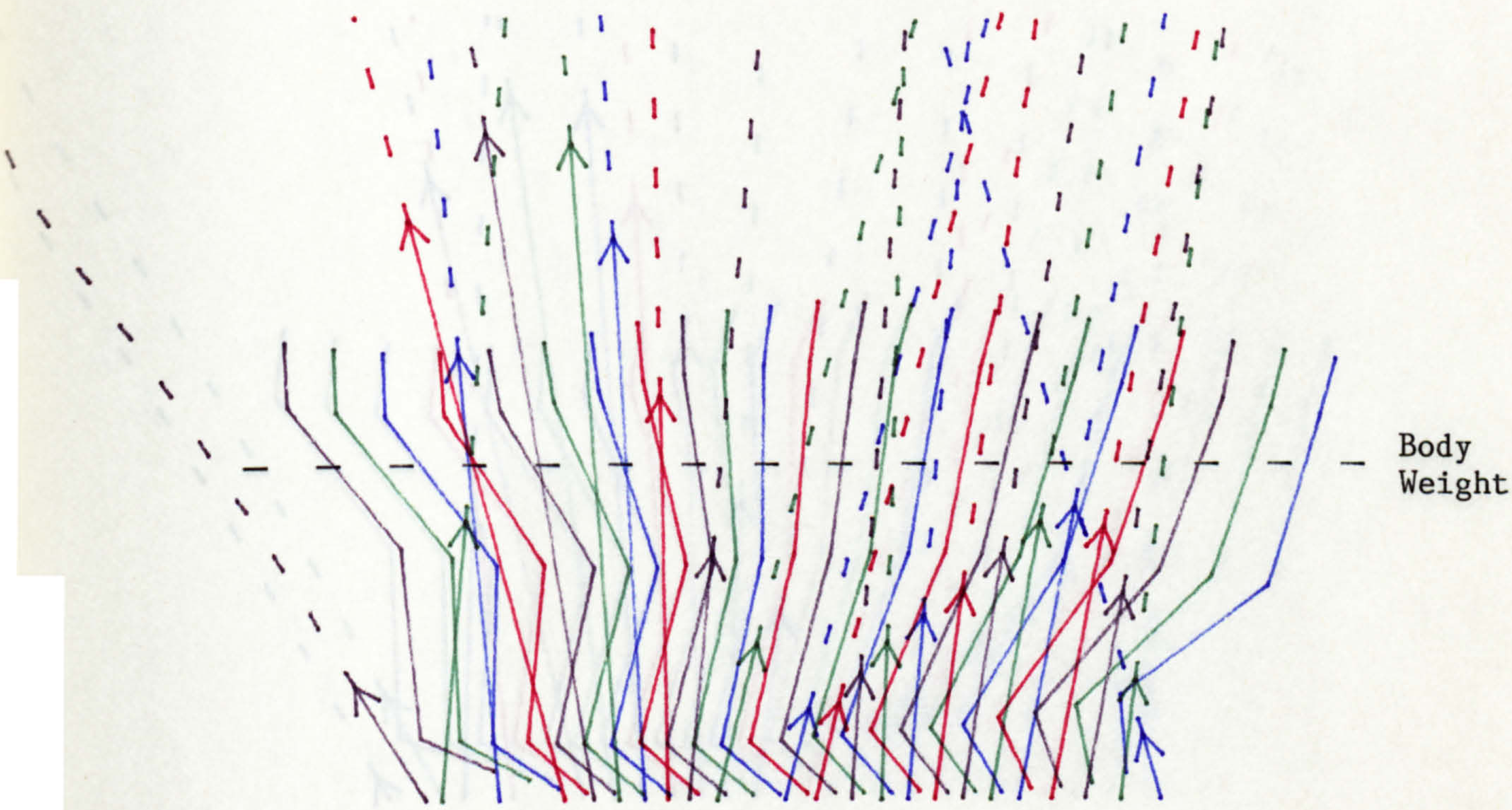

Fig. 7.4
Stick & force vector diagram
of a diplegic CP child walking with
bilateral AFOs & shoes.

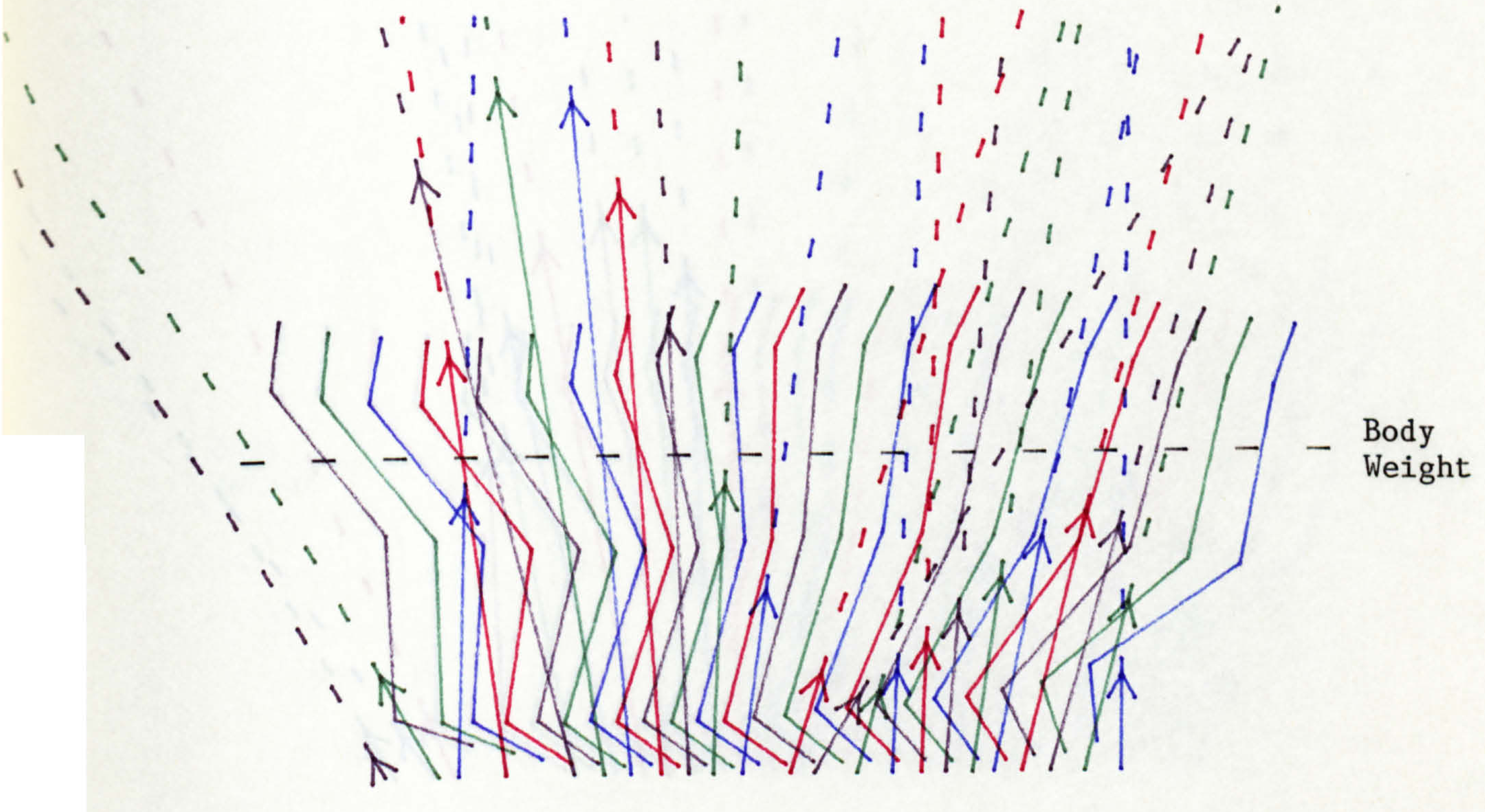

Fig. 7.5

Stick & force vector diagram of a diplegic CP child walking with bilateral AFOs & shoes.

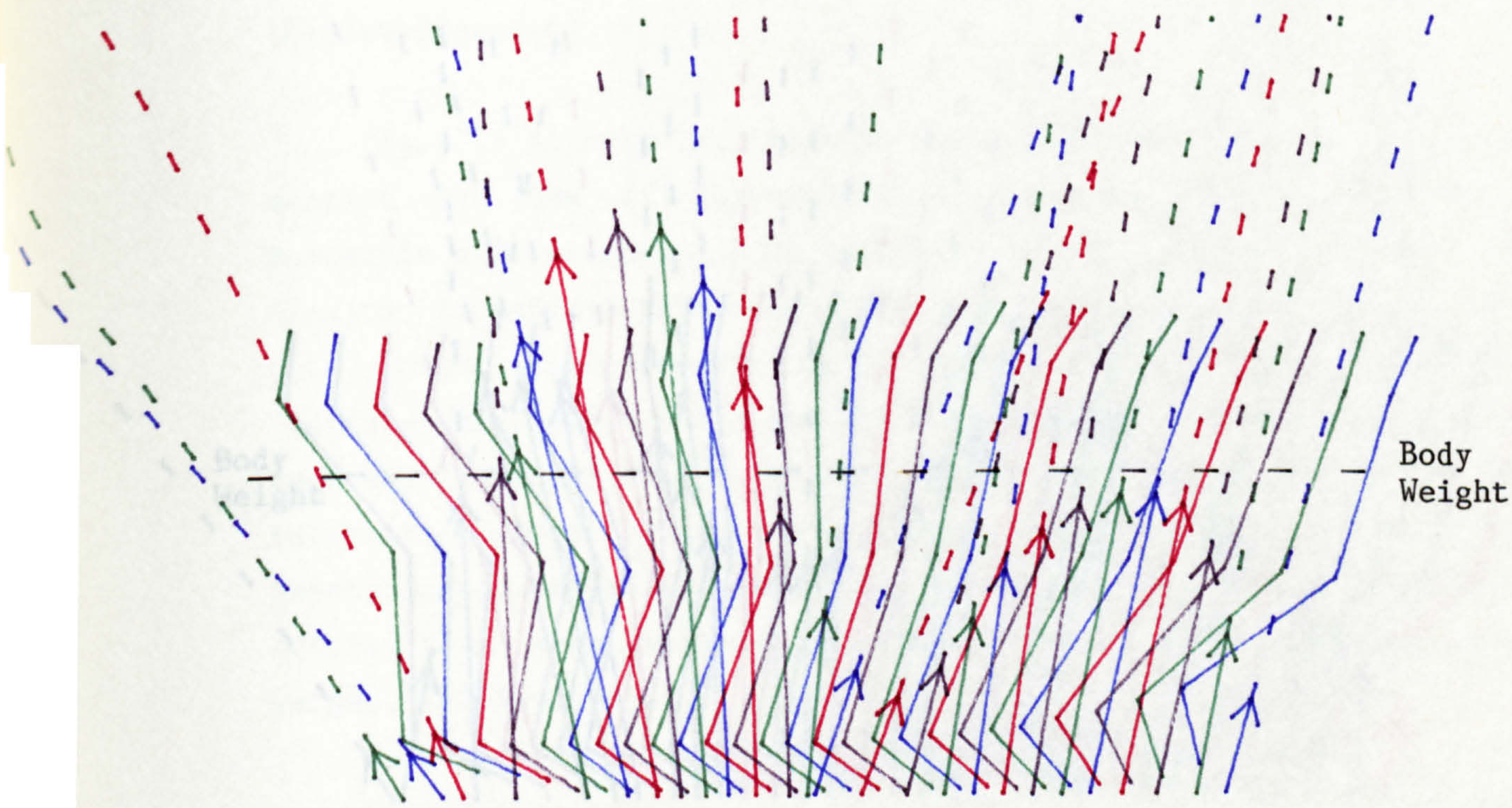

Fig. 7.6

Stick & force vector diagram
of a diplegic CP child walking with
bilateral AFOs & Piedros.

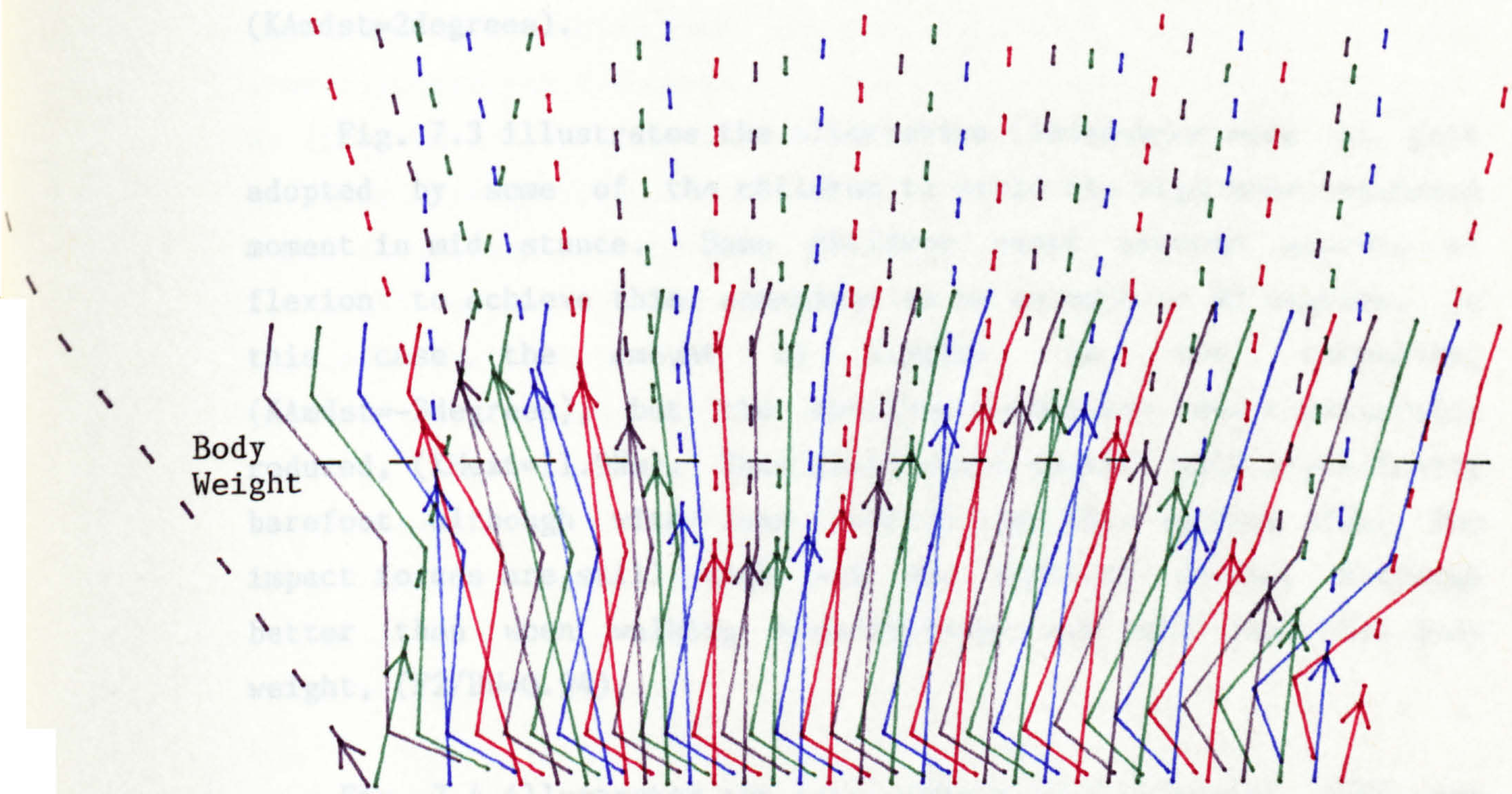

Fig. 7.7

Stick & force vector diagram

of a diplegic CP child walking with

bilateral AFOs, Piedros & rocker soles.

Fig. 7.2 is of an ataxic diplegic CP walking barefoot. The child walks on tip-toe and there is no heel strike. There are very high impact forces and the push-off forces are less than body weight, (F2/BW=0.81). The vector is aligned some distance from all three joints indicating high external moments requiring excessive muscle activity. The vector in mid stance passes far in front of the knee, generating a high extension moment, (KMext=22.5N), and causing the knee to snap backwards into hyperextension, (KAmdst=2degrees).

Fig. 7.3 illustrates the alternative flexed-knee mode of gait adopted by some of the children to avoid the high knee extension moment in mid stance. Some children adopt extreme amounts of flexion to achieve this, sometimes up to as much as 40 degrees. In this case the amount of flexion is not excessive, (KAmdst=-3degrees), but the external moment has been considerably reduced, (KMext=11.9Nm). This child could in fact walk proficiently barefoot although with less control than when wearing AFOs. The impact forces are still high and the push-off forces, although better than when walking hyperextended, are still less than body weight, (F2/BW=0.94).

Fig. 7.4 illustrates the gait pattern with bilateral AFOs set at 7 degrees of dorsiflexion. On the day of gait analysis the child arrived dressed for the occasion with shoes with a much higher heel than those with which the AFOs had been prescribed. She considered that these shoes were justifiable as they were pretty but the research team had other ideas, considering them biomechanically disastrous. The stick and force vector diagram shows that heel strike is now being obtained although the centre of pressure moves rapidly forward. Despite the excessive knee flexion in mid stance, (KAmdst=-8degrees) there is still an extension moment being generated, (KMext=9.0Nm). There are extremely high impact forces, a marked trough in the "double-hump" and a push-off force which is less than body weight,(F2/BW=0.88).

Fig. 7.5 illustrates the gait pattern with the same AFO-footwear combination as Fig. 7.4 but obtained one week later at the second test session. The general form of the stick and force vector diagram, is similar to Fig. 7.4 suggesting a good repeatability of the gait analysis process.

This girl was eventually persuaded to try out a pair of "Piedro" bootees after an explanation that all little Swiss girls wore them when herding their mountain goats. These had a wedge characteristic of 7 degrees, 3 degrees less than the original shoes. An improvement in the stick and force vector diagram can be observed, (Fig. 7.6). The impact force is less and the push-off force is increased although still less than 1, (F2/BW=0.90). There is still a tendency for an extension moment to be generated in mid stance. (KMext=10.5Nm). It is interesting to note that the gait pattern displayed in this figure is in some ways little better than that in Fig. 7.3 when the child is walking barefoot in the flexed-knee mode with which she is proficient. She does, however, have some heel loading and a better push-off. Her standing balance is also better, a fact which should not be overlooked when considering gait alone.

A temporary rocker sole with a characteristic of 65% was added which also reduced the wedge effect by 2 degrees to 5 degrees. The resulting gait pattern is illustrated in Fig. 7.7. A dramatic change in the stick and force vector diagram can be seen. In particular the force vector now displays a smooth "double-hump" shape with relatively low impact forces and a good push-off force, (F2/BW=1.10). The knee extension moment has been reduced, (KMext=7.3Nm).

This series of figures illustrates the conclusions that the gait of the CP children was quite different from that of the normal children and that the use of AFOs influenced these differences. It shows, too, that very small changes in the characteristics of the footwear associated with the AFO had very large effects on the kinetic aspects of the resulting gait pattern. It is also apparent that when dealing with CP children guile is as important an attribute of the clinic team member as a knowledge of biomechanics.

As discussed previously the 26 items of data extracted from the A3 printouts were chosen in the light of clinical experience and initial qualitative inspection of the printouts. Some of these items were analysed in depth and graphs of their results plotted. (Figs. 6.1-6.5). The nature of these results and their clinical implication are discussed below.

Total Impulse

Clinical observation of the influence of AFOs on gait had indicated that when a prescription with appropriate characteristics had been developed for a given child the improvements in gait appeared to be better control of limb motions and a reduction in muscular effort. It was thought that this reduction in muscular effort would be reflected in a reduction of the grand total of angular impulse in flexion and extension at hip, knee and ankle, (HKAI).

Fig. 6.1 indicates that with some of the children there was a reduction in HKAI but this was by no means true of all cases. In some a marked increase was apparent. Table 6.4 indicates that most of these changes were statistically significant, some at a very high level of confidence. It is interesting to note that the values of HKAI for the CP children were much higher than the normal children grouped on the right, indicating a much higher level of muscular activity required by the CP children.

The impulse values were calculated from the external moments being generated by the ground-to-foot force vector and balanced by internal muscle moments. These were, of course, nett internal moments, and reflect the difference in the moments generated by the antagonistic extensor and flexor muscles at any one time. It is known that the gait of CP children is characterised by more antagonistic muscle activity than normal children. It is possible therefore, that the apparent reduction in muscle effort observed clinically was in fact in many cases principally a reduction of antagonistic activity rather than reduction of useful muscular output. The measurement system used in this research programme could not detect antagonistic activity. Further studies using e.m.g. would help to clarify this situation.

It is interesting to observe the reduction in HKAI associated with the wearing of shoes, again statistically significant, of the one normal child (017) who walked with shoes in addition to barefoot.

Ankle Moments and Motion

In normal children the ground-to-foot force vector was usually closely aligned with the ankle joint in early stance only moving to the forefoot during late stance associated with push-off when a high external dorsiflexing moment would be generated. The external moments in early stance were therefore small, sometimes in a plantarflexing direction, especially at heel strike. The CP children typically generated high external moments in early stance when walking barefoot and always in the direction of dorsiflexion placing a high demand on the plantarflexors. There was always similar high dorsiflexing moments at push-off. It was anticipated that the use of AFOs, by maintaining the centre of pressure more posteriorly on the foot, would reduce this intial high external dorsiflexing moment. Surprisingly this very rarely happened. This can be explained by the fact that although the use of AFOs did indeed prevent the centre of pressure being located at the toes as in barefoot walking and delayed its forward progression, the perpendicular distance of the line of action of the vector from the ankle joint was not significantly altered. This was because in toe-walking the ankle was grossly plantarflexed and as the force vector was approximately vertical the perpendicular distance was relatively small. When the ankle was maintained in a more plantigrade attitude by the AFO, even if the centre of pressure was held within the midfoot the perpendicular distance between the line of action of the vector and the ankle joint may not have been reduced and may even have been increased. The demand on the plantarflexors may not therefore have been significantly altered other than by the fact that the stiffness of the AFO itself may have generated some of the balancing plantarflexing moments, thus reducing the demand on the muscles.

The principal effect of the AFO on the angular attitude of the ankle joint was the maintenance of a dorsiflexed attitude and the prevention of the extreme plantarflexion associated with toe-walking. It is interesting to note that the stiffnesses of the AFOs were not sufficiently high to prevent ankle movement, (about 10 degrees of motion being common). This is an encouraging finding and is in contrast to the opinion of the critics of the use of AFOs who maintain that the stiffness of the AFOs prevent the child experiencing ankle motion. Indeed it may be argued that the motion resulting with AFOs was more normal than the motion occurring when barefoot. In the latter case the total range of motion might have been greater but very often this was in extreme plantarflexion with little dorsiflexion occurring at all, especially in early stance.

Observation of the stiffness characteristic of the AFOs, (Fig. 6.7), indicates that a 10Nm dorsiflexion moment was typically required to deform the AFO by 10 degrees of dorsiflexion from the unloaded angle at which it was set. Inspection of the gait analysis data shows that at maximum dorsiflexion the stiffness of the AFO would accounted for between a third and a half of the plantarflexing moment otherwise generated by the muscles to balance the external dorsiflexing moment. This was significant clinically as it was possible that this reduction in demand on the plantarflexors might have reduced the amount of unsettling reflex activity which might otherwise occur.

Because of the problems of internal rotation of the foot with some of the children, mentioned earlier, it was difficult to be certain whether the angles indicated in the graphs were true values or whether they had been distorted by the effect of the rotation. Internal rotation would have increased the apparent plantarflexion of the ankle joint. Since the range of motion at the ankle was small, improvements in the measuring system are therefore necessary to investigate this important subject of the contribution of the AFO to the internal moments.

Knee Moment in Mid Stance

The high external extension moments occurring at the knee in mid stance, (KMext), when the CP children walked barefoot was probably the most obvious feature able to be observed clinically. It was expected that the use of the appropriate AFO-footwear combination would reduce this. This was indeed the case as can be seen in Fig. 6.2. The high extension moments in mid stance are extremely disruptive and can inhibit the smooth flow of motion from early to late stance. The reduction of these high moments is therefore extremely important clinically.

There were two children who did not exhibit this reduction in knee extension moment. Subject 002 showed an increase in the fourth test series. This gait analysis series occurred 10 weeks later than the first session. The AFO was the same one as had been worn in the first session although the left shoe had been raised to compensate for a leg length discrepancy. It is interesting to note that the entry in her clinical records on that day included the comment that it was felt that her condition had changed in the intervening period and that a more dorsiflexed AFO was now necessary. In other respects, however, the AFO seemed satisfactory. The second child, 016, was one who walked with extreme knee flexion and on tip-toe when barefoot. It can be seen from Fig. 6.2 that the external knee extension moment in mid stance was extremely small and that the increase associated with the use of the AFOs, which would otherwise have been considered unusual, brought the moment to a more normal value indicated by the two normal children, 010 and 017, who were of similar height and weight.

Push-off Force

One of the most common observations from the stick and force vector diagrams of the CP children was the low value of push-off force occurring in barefoot walking. This value was increased with the use of AFOs and the optimisation of the characteristics of the associated footwear. It was only on measurement of the vertical component of maximum push-off force, (F2), that the significance of this finding became apparent. In most cases the value of F2 when barefoot was less than the body weight, (BW), the ratio F2/BW being less than 1. With the optimum prescription this ratio was increased, in most cases to greater than 1 as can be seen in Fig. 6.3. The only exceptions to this were two of the diplegics. Subject 003 showed an increase in F2/BW although it remained less than 1. This child had an excellant gait as a result of the use of the AFO. It is therefore surprising that F2/BW was so low. She is a hemiplegic and it is possible that the improvement in her gait observed clinically was principally as a result of alterations in the kinetics of the normal contralateral leg, possibly a reduction in the extra demand placed upon it by the affected leg. Subject 004 was not measured barefoot as she was not proficient at this. She

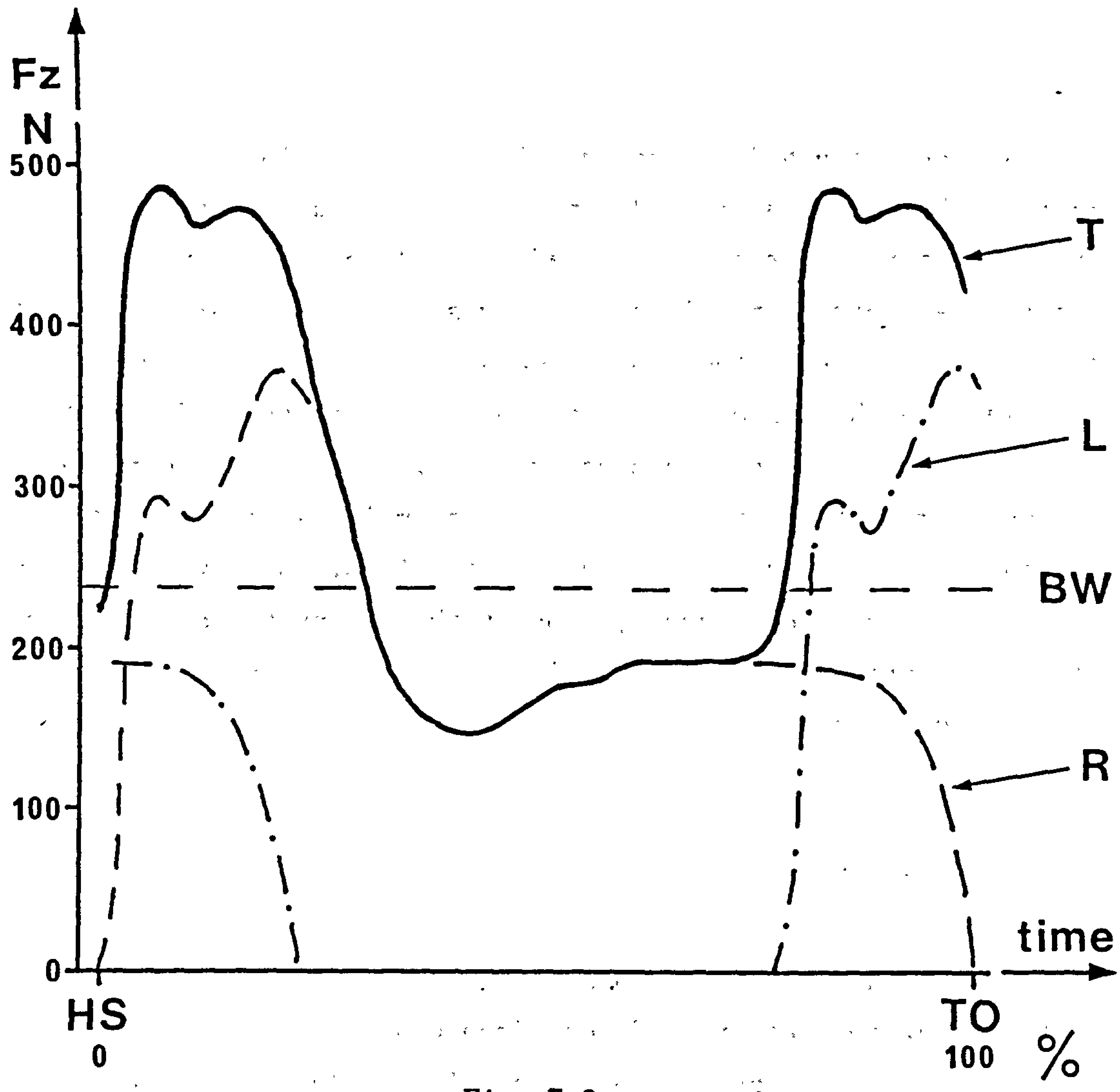

Fig. 7.8

Graph of vertical components of ground reaction force during right stance phase generated by a diplegic CP child walking barefoot.

Fz	vertical component of ground reaction forces (N)
T	total of components generated by both legs
L	component generated by left leg
R	component generated by right leg
BW	body weight
HS	heel strike of right leg
TO	toe off of right leg

The vertical component of ground reaction force of the right leg was obtained from gait analysis data, (cf. Fig. 7.2). The vertical component of the ground reaction force of the left leg was obtained, for discussion purposes, by assuming a symmetrical gait so that it was similar to the right leg. The graph has been drawn with relative phasings of left and right so that heel strike occurs 22% before toe off of the contralateral leg.

It can be seen that the total of left and right components is less than body weight for an excessively long period during mid stance. This suggests that double support is not the reason for the low value of push-off force.

was measured with AFOs and with footwear with progressively increased wedge characteristics which seemed clinically to be appropriate, principally in attempting to gain a heel strike. The value of F2/BW decreased with these changes although inspection of the other graphs indicates improvements in other ways.

There are only two ways in which F2/BW can be less than 1. Either double support is occurring and the leading leg is beginning to off-load the trailing leg which is being measured or the child's body mass is accelerating downwards. The gait analysis process adopted in this research programme did not measure the contralateral leg so that it was not possible to determine the occurrence of double support. However, reports in the literature of temporal studies suggest that although double support times in CP gait are increased in comparison to normal children they are not sufficiently great to explain the low value of push-off force occurring for such a significant period of the stance phase, (Fig. 7.8) Information on double support in the literature is sparse and often not clearly presented. However in those reports where this information is included it is apparent that the contralateral heel strike occurs during the last 1/4 or 1/6 of the stance phase, (Fleiss et al.,1978, Hoffer,1983, Sutherland et al.,1969). The only other explanation, therefore, is that the child is actually in the process of collapsing towards the ground, i.e. the body mass is accelerating downwards. This will occur if the hip and knee are flexing, whereas normally they would extend during the latter stages of push-off to increase the effective leg length and propel the body mass upwards. Alternatively, downward acceleration will also occur if the leg is being held rigidly but is toppling over the foot. If this latter explanation is true and the child is in fact collapsing during late stance-phase then it is obvious that great difficulty will be experienced when walking. The principal effect will be that there will be considerable pressure on the child to complete the swing phase of the contralateral leg and attain double support as soon as possible.

There is obviously a maximum time which the child may sustain single stance before the collapse becomes excessive. This might account for the very hurried appearance of CP gait, in particular the apparently high swing velocity. The very high impact forces during early stance may also be accounted for by the fact that the leading leg will have to recover the collapse of the trailing leg and terminate the downward movement of the body. Walking is, therefore, a series of collapses and recoveries. It is interesting to note the clinical observation that most diplegics do not have the strength to stand stationary on one leg. This is due principally to the fact that flexion contractures of hip and knee prevent the knee being held in a fully-extended attitude. Consequently high external flexion moments are generated which cannot be balanced by the weak knee extensors.

The fact that the use of AFOs with the appropriate footwear characteristics resulted in F2/BW being greater than 1 indicates that for some reason the child was now able to sustain body weight during single stance and even to generate some push-off force. This obviously improved the smooth flow of the gait pattern, reduced the urgency to attain double stance again and reduced the impact forces on heel strike of the leading foot, possibly also reducing reflex activity.

The exact mechanism by which the child achieved this greater push-off capability was not at first understood but qualitative examination suggested that it might have been related to the moments being generated at the hip joint in late stance.

Hip Moment and Motion in Late Stance

The external hip moment, (HM), and the angular velocity of the hip, (HAV), were measured at the instant of maximum vertical push-off force, (%@F2). As can be seen from Fig. 6.4, in many instances HM was negative indicating that the moment was in the direction of flexion. In six cases the effect of the appropriate AFO-footwear combination was to make HM more positive, either decreasing the magnitude of the flexion moment or increasing the magnitude of the extension moment. Few of these changes were, however, statistically significant. In the normal children HM was never negative and in many instances significantly positive. The values of HM for subjects 010 and 017 were included in the graph since these children were of similar stature to the CP children. Subject 010, however, was rather self-conscious during gait analysis and did not walk with her usual sense of purpose which probably indicates the reason for the relatively low value of much of her data.

Inspection of Fig. 6.5 reveals that with five of the CP children the angular velocity at the instant of maximum push-off,(HAV), was increased by the use of AFOs and appropriate footwear, i.e., the hip was extending more rapidly. Only two of these changes were, however, statistically significant. With some children the angular velocity of the knee became more positive, normally reduction of flexion movement rather than a change to extension. There was some doubt as to the accuracy of the measured angular velocities, particularly at the hip. These were obtained by measurement of the slope of the graph of angular position. The graphs plotted were at times rather erratic requiring visual smoothing to obtain a value for the angular velocity. This was probably due to the fact that the distance between the pelvic marker and the hip joint was relatively small so that small errors in the horizontal and vertical co-ordinates of the pelvic marker could produce relatively large angular changes. This resulted in sudden short term increases and decreases in the slope of the graph compared with the probable true values. It was felt, however, that although the absolute values of angular velocity were of doubtful accuracy it was reasonable to accept the trends observed between test series. Angular acceleration of the hip would have been a more relevant factor to measure since this is more directly related to the generation of the push-off force. It was not possible to obtain this information from the gait analysis process used in this research programme. It was considered, however, that observation of angular velocity, by at least showing whether the hip was extending or flexing, gave some indication of the childs ability to effectively elongate the leg.

The increase in vertical forces at push-off in a normal subject is associated with the upwards acceleration of the body mass. This arrests the downwards movement of body mass following mid stance and results in upwards movement in late stance. The arrest of downwards movement is achieved by arresting the flexion movement of the joints. The eventual upwards movement is achieved by effective elongation of the leg, principally by extension of the hip and plantarflexion of the ankle. The knee in many cases tends to flex thus shortening the effective leg length but obviously by a lesser amount than the lengthening effect of hip and ankle. During faster walking the knee may also extend assisting the elongation process. From the gait analysis results it was apparent that the ankle motion of the CP children was reduced. The reasons for this when the AFOs were worn are obvious but are less so when the children were barefoot. Weakness of the plantarflexors may be the reason. Their ankles were not excessively plantarflexed which would otherwise have reduced the possibility of further plantarflexion necessary, as might have been expected. With the CP child, therefore, the principal contribution to elongation of the leg appears to come from the hip.

The muscle group required to act at the hip joint to arrest the flexion movement and to produce extension-movement, thus generating the push-off force, must be the extensors. Obviously if the external moment caused by the ground-to-foot force at the hip is in the direction of flexion the extensor muscles have to overcome this moment. If the CP child has weak extensors, which is common, great

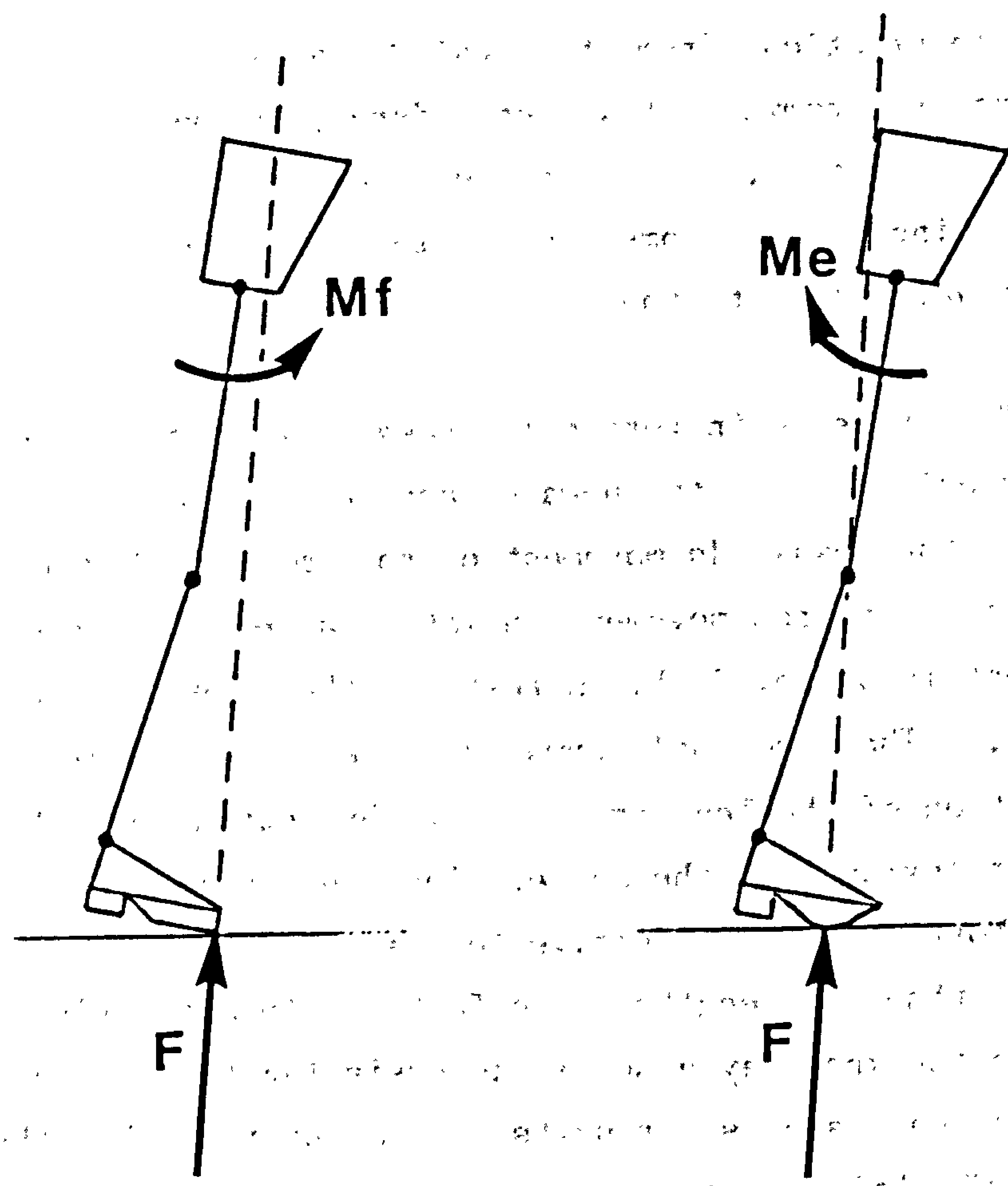

Fig. 7.9

Effect of rocker sole on external hip moment.

Without rocker (left) origin of reaction force, (F), in late stance is on toe of shoe, line of action of force passes in front of hip joint generating an external flexion moment, (Mf). With rocker (right) origin of reaction force is maintained more posteriorly, line of action of force passes behind hip joint generating an external extension moment, (Me).

difficulty may be experienced in achieving this. If the external flexion moment is reduced this would obviously reduce the difficulty. If the line of action of vector is actually re-aligned behind the hip joint an external extension moment would be generated, actually assisting the extensor muscles to create an extension velocity, elongating the leg and generating an improved push-off force.

In the normal subject immediately prior to toe-off the hip flexors are active to arrest the extension movement of the hip. This prevents hyperextension occuring and initiates the hip flexion movement and forward movement of the thigh associated with early swing phase. Most CP children have some contracture of their hip flexors and possibly also of the joint capsule. This prevents the hip from extending fully and may also prevent the thigh from moving behind the hip joint as in the normal situation. It is probable that active hip flexion is not therefore required to arrest the extension movement of the hip prior to toe-off even when the external moment is in the direction of extension.

Inspection of the data reveals that the change in perpendicular distance of the line of action of the force vector to the hip joint between barefoot and with AFO and appropriate footwear was remarkably small, in the order of 20mm or less. This perhaps explains why the use of a rocker sole can have such a dramatic effect on the gait pattern. Assuming for the sake of argument, that the relative magnitudes of horizontal and vertical components, and therefore the direction, of the ground-to-foot force are unchanged when comparing similar instants in the stance phase between barefoot and with AFOs, and that the trajectories of the hip joint are also similar, the only influence on the perpendicular distance is the point of origin of the force vector - the centre of pressure. The use of a rocker can prevent the centre of pressure moving forward to the front edge of the shoe and maintain it, say, under the metatarsal heads, (Fig. 7.9). The distance between these two points in a typical child is at least 50mm which is in excess of the 20mm typically required to influence the external moment generated at the hip joint. A similar argument may relate to the effect of the wedge characteristic of the footwear or the angle at which the AFO is set. This analysis explains why very small changes in the characteristics of the AFO footwear complex may have such a dramatic effect on the gait pattern.

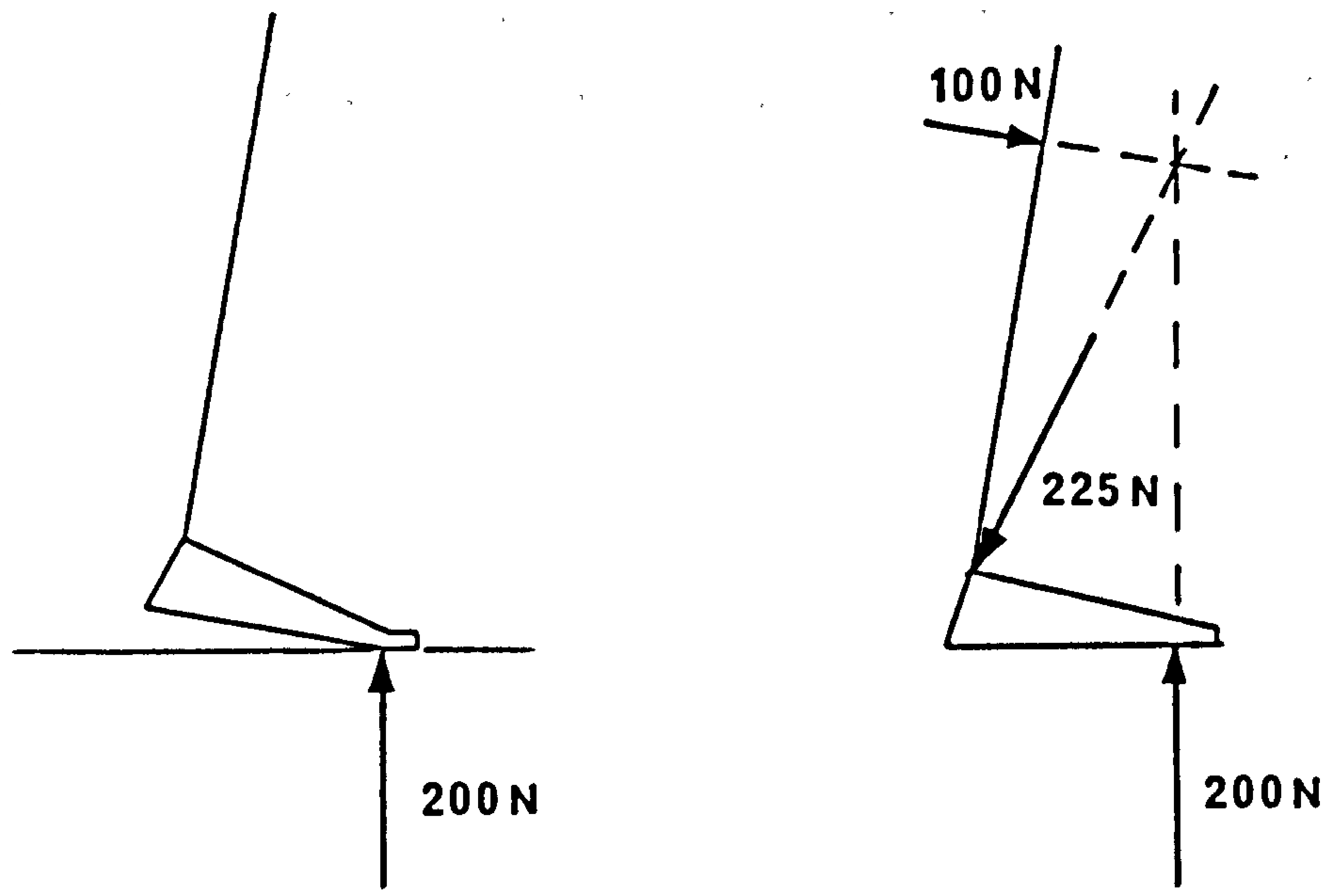

Fig. 7.10

Comparison of forces on leg and foot.

Left - during toe walking, barefoot, ground reaction force on metatarsal heads.
Right - three-point force system applied by AFO.
(AFO not shown.)

7.3 MUSCLE ACTIVITY MONITORING

The data obtained from the long term and short term monitoring tests were not analysed in detail. However, qualitative analysis indicated that there were many common features between the data obtained from different CP children. Typical examples were presented in Chapter 6, (Figs. 6.8-6.10).

7.3.1 Long Term Monitoring

Two important observations emerged from the long term monitoring tests. The first was that the load recorded by the ankle strap transducer was significantly less than that which might have been expected. Maximum loads were typically in the region of 50-60N. The second was that for significant periods the load was virtually zero.

The child whose results are presented in Fig. 6.8 was a 5 year old spastic diplegic who had a body mass of 200N. From analysis of the geometry of the AFO and the approximate positions and lines of action of the 3 point force system being generated between the AFO and the ankle-foot complex when the AFO resists plantarflexor activity, it is possible to estimate the relative magnitudes of these forces, (Fig. 7.10).

If one examines the situation where the child is toe-walking in single-stance, with the centre of pressure under the metatarsal heads, with the assumption that the reaction force is vertical, the plantarflexors which are in spasm will be generating a plantarflexion moment sufficient to lift the heel off the ground, say Mpf. If the child is then fitted with the AFO and when walking tends to generate a similar plantarflexion moment, Mpf, due to spasm, a reaction force will be generated between the sole of the foot and the AFO in the region of the metatarsal heads. If the plantarflexor activity is of the same magnitude as that which occurs during toe-walking the reaction force will also be of the same magnitude as when toe-walking, i.e. 200N.

If one assumes that the relative magnitudes of the lever arms of the reaction forces on the calf and foot are 2:1 the resultant force on the ankle strap is approximately 225N. By comparing the magnitude of the load measured by the ankle strap transducer with 225N it is possible to estimate the magnitude of the plantarflexor activity relative to their activity during toe-walking. In the case of this child the maximum ankle strap forces are between 50 and 60N, approximately 25% of that which might have been expected to resist toe-walking spasm.

There are two possible explanations for this. Either the plantarflexor activity is reduced by the wearing of AFOs or that if significant spasm occurs it does so only in response to load bearing during the stance phase. In the latter case the ankle strap would only have to supply the extra load necessary to attain equilibrium between internal and external moments in the new plantigrade position as opposed to the plantarflexed attitude when barefoot. Either possibility is clinically significant since they show that the loads generated on the dorsum of the foot are not intolerably high, with the potential for discomfort or skin breakdown, and that the presence of the AFO structure on the ankle-foot complex is not in itself stimulating plantarflexion activity continuously throughout the gait cycle. Both are criticisms levelled at the use of AFOs by those schools of thought opposed to the use of orthoses.

It is also interesting to note that for significant periods of the day, probably when the child was seated at her school desk, the load on the ankle strap was minimal. This was a common feature of all the children monitored.

7.3.2 Short Term Monitoring

The example given of a short term monitoring test is data from a seven year old spastic diplegic walking with a right AFO, and walking barefoot, (Figs. 6.9 and 6.10). She was subject 009 in the gait analysis series although her monitoring test was carried out approximately one year later when her body mass had increased to about 200N.

It can be seen again that the ankle strap load is only about 60N at the maximum, occurring shortly after heel strike. It reduces rapidly towards mid stance, and during late stance is virtually zero. This child's gait analysis results had shown that she was one of the children whose use of an AFO prevented the generation of the excessive external dorsiflexion moment during early stance. In fact some initial plantarflexion moments occurred similar to the gait of a normal child. Combining these two sets of observations it suggests that the primary role of the AFO, as far as the ankle-foot complex is concerned, is merely to provide a small external moment necessary in addition to that generated by the ground-to-foot force to maintain equilibrium in the more dorsiflexed attitude than when walking barefoot. However the gait analysis results showed that in mid to late stance the AFO and ankle joint were actually dorsiflexed so that the stiffness of the AFO was assisting the plantarflexors to counteract the external dorsiflexion moment. Since the external moment was approximately the same between walking with an AFO and barefoot the plantarflexing moment caused by the plantarflexors must therefore have been less when wearing the AFO.

One may perhaps conclude that the function of the AFO at the ankle-foot complex is twofold. Firstly, it prevents the ankle from attaining a plantarflexed attitude during the very early part of stance and, secondly, by so doing reduces the moment required to thereafter maintain a plantigrade or even dorsiflexed attitude. This may possibly be achieved by the prevention of any spastic response of the plantarflexors to initial load bearing thus maintaining relaxation throughout the rest of the stance phase.

Fig. 6.10 indicates the result of the short term monitoring with the child walking barefoot. It can be seen from the footswitch output that heel strike is never obtained although the child can maintain a certain amount of foot flat contact before the load is transferred to the toes. Although the e.m.g. traces of plantarflexors and dorsiflexors are variable it can perhaps be seen that the plantarflexor activity is greater when barefoot than with the AFOs in Fig. 6.9.

It is interesting to note that there is good dorsiflexor activity correctly phased when using the AFO which is contrary to the claim of the critics that the AFOs, by providing dorsiflexion assist, will cause disuse of the dorsiflexors. This child had been wearing AFOs for over three years when these tests were conducted. It is interesting to speculate that the activity of both dorsiflexors and plantarflexors are more normal when using AFOs than when walking barefoot. Further work will be necessary before this can definitely be stated, however. At the moment it remains a tantalising possibility.

7.4 CLINICAL IMPLICATIONS

The results of this research programme have shown that the kinetic aspects of the gait of cerebral palsied children may be very different from those of normal children. They have also shown that the use of AFOs and footwear can alter these kinetic aspects. The clinical impression that small alterations to the characteristics of the AFO-footwear complex can result in dramatic changes in function is supported by the significant changes in the kinetic aspects measured by the gait analysis process. These results reinforce the attitude adopted in clinical practice that even if the functional outcome of the fitting of an AFO is not totally satisfactory initially it is worth experimenting with minor adaptations to the footwear, such as the addition of wedges or rockers, since a significant improvement may then occur.

In clinical practice it is customary, if the alterations to footwear are relatively extensive, to consider altering the characteristics of the AFO to achieve a similar functional result without the requirement for the footwear adaptations. Thus if excessive heel wedging is required with the existing AFO a replacement AFO may be produced set in increased dorsiflexion, if this is not prevented by joint contracture. In this way a similar attitude of the shank with respect to the ground is achieved. This would imply that the relationship of the ground-to-foot force vector to the hip and knee would be similar in both cases. This particular situation was not investigated in this research programme but it is considered reasonable to accept the above implication. While the external mechanics at hip and knee may probably be the same in both cases there is however the possibility of a difference at the ankle joint. The alteration in the attitude of this joint implies that the resting length of the associated muscle groups will be different. If the gastrocnemius is tight due to contracture, or even just high tone, it is possible that this will prevent the knee from reaching as much extension as before. This could alter the relationship of the knee to the ground-to-foot force vector. There is also the possibility that alterations to the resting length of the muscle group may alter their neurological activity by inducing relaxation in some groups and increasing the tone in others. This is a very complex situation and needs to be investigated. Meanwhile the fact that alterations to the AFO characteristics to reduce the required footwear adaptations may not result in an identical functional outcome must be borne in mind.

Analysis of the kinetic data has shown that the changes between barefoot walking and walking with AFOs and associated footwear relate to both the nature of the ground-to-foot reaction force and the external moments generated at the joints. These forces and moments generated influence the nature of the loading of the joint structures themselves and the tensions generated by the muscle groups. The response of the body to these loads is obviously complex in the case of cerebral palsy. In addition to the generation of the muscular tension required to stabilise the joints there is the possibility of reflex activity caused by the loading of the muscles themselves and the other structures of the legs and the rest of the body. The large impact forces at heel strike are likely to be significant stimulators of undesirable reflex activity from a number of sources. The nature of these forces is therefore of great interest. From the analysis conducted earlier it has been suggested that these high impact forces are probably a result of the problems relating to the attainment of adequate body support and push-off forces in late stance. These have been shown to be related to the moments generated at the joints during this part of the stance phase. It is of interest therefore to examine the clinical implications of the nature of the external moments generated and the problems of their modification by clinical management.

As discussed in Chapter 1 there are a number of different management methods which are used in cerebral palsy - physiotherapy, orthotics, chemotherapy and orthopaedic surgery. Within each of these methods there are many different approaches. Consequently there are many different stated objectives in the use of these methods with apparently different effects on the child. These objectives relate to the reduction of unwanted high muscle tone, the reduction of joint contracture, the balance of muscular activity around a joint, the facilitation of appropriate voluntary muscle activity to respond to the constant and rapidly changing demands of function, etc. The problems with which the child presents are, of course, independent of, and common to, the various management methods. As mentioned in Chapter 1 there is still considerable controversy in the use of the various management methods. It is maintained by some that aspects of different methods are mutually incompatible. This controversy is exacerbated by the relative lack of real understanding of many of the problems of cerebral palsy and the almost total lack of objective evaluation of the influence on them of the various management methods.

As mentioned in Chapter 1 many of the physiotherapeutic approaches to the treatment of cerebral palsy are based almost entirely on consideration of the neurological aspects of the child's condition. Apparently adequate explanations have been developed concerning the abnormal function observed and the influence on it of particular therapy techniques. No reference is made to the biomechanical factors. Similarly the explanation of any improved function with the use of drugs is limited to the reduction of unwanted hypertonicity and the improvement of voluntary muscle action. The stated objectives of orthopaedic surgery and explanations of the outcome are usually limited to the restoration of more normal ranges of movement or of the creation of balanced muscle action at individual joints. Little attention is paid to the broader biomechanical implications.

This research programme has indicated clearly how changes in the function of the ankle-foot complex can have significant influences on the kinetic aspects at the knee and hip. In the case of this particular investigation these changes were achieved by the use of AFOs and footwear modifications. It is reasonable to assume, however, that changes in ankle-foot function brought about by any of the other methods - physiotherapy, drugs or surgery - will produce similar kinetic changes at hip and knee with consequent changes in the overall function. It is interesting to speculate as to whether these improvements in function are as a result of the primary improvements in the ankle-foot complex itself or largely as a result of the consequent secondary alteration in the demand on the neuromuscular system at the knee and hip. If the latter situation is indeed true it suggests that there are perhaps more similarities than differences in the end effect of the various management methods than was previously believed, even although the primary means of achieving this may differ significantly.

It is recognised that there are many advantages and disadvantages associated with the various management methods, no method being totally ideal. If, however, as this analysis has suggested, the secondary and more important effects of the methods are similar there is perhaps less incompatibility between methods as is believed by many to be the case. It might therefore be possible to develop a management programme consisting of the better elements of all the methods, thus avoiding some of the disadvantages. This idea is of course not new and has to a certain extent been adopted in Dundee and other centres as mentioned in Chapter 1. However, there has traditionally been resistance from those who adopt a neurodevelopmental approach to therapy to accept a programme which includes elements of the other methods, especially orthotics, except where children have presented with severe problems which were not managed acceptably by purely physiotherapeutic means.

The above arguments for the adoption of a management programme with elements of several methods must be considered to be sensible given the magnitude and range of the functional problems of cerebral palsy. Nevertheless there are also arguments to support the adoption of a management approach which is largely orthotic. This research programme has shown that the AFO-footwear complex can have a very significant influence on the nature of the demand on, and the resulting function of, the neuromuscular system. Clinical experience has shown that the effects of the AFOs are virtually instantaneous even although with the initial fitting of a very young child a period of familiarisation may be necessary. The time required of the child and parents to attend for fitting and review of the AFO is minimal in comparison to the regular attendance at a physiotherapy department for treatment. There is therefore more time available for the management of other of the problems such as those related to speech and communication. The function achieved by the AFO and the minimum amount of time required for review also means that the child may be able to lead a relatively normal life interacting with his normal peers in the home environment rather than spending his early formative years as a perpetual patient. The research programme has given some preliminary support to the clinical impression that the AFOs reduce the level of unwanted tone and permit more normal voluntary function, which are also objectives of the physiotherapeutic approaches and the use of drugs. Clinical experience also suggests that AFOs may prevent the occurrence of contractures and has shown that contractures may successfully be reduced by the use of AFOs. The use of AFOs may therefore also achieve some of the objectives of the use of drugs and orthopaedic surgery and, importantly, by less invasive techniques.

Although the above arguments supporting a predominently orthotic management programme are reasonable it is of course likely that a combined approach with the other methods would prove optimum. Nevertheless it is important to recognise that the use of AFOs may complement the effect of the other methods and be compatible with them, perhaps reducing their emphasis so that the undesired side-effects or disadvantages may be selectively minimised.

The gait analysis results have also revealed a previously unrecognised aspect of the kinetics of gait which has broad clinical significance. This relates to the inter-relationship of the joints of the leg and the line of action of the ground-to-foot force vector. The data obtained from barefoot walking and walking with AFOs and footwear have shown that significant changes in the external moments result from relatively small changes in the characteristics of the AFO-footwear complex. These changes are achieved principally by changes in the relative attitudes of the limb segments, i.e., the angular positions of the joints, and changes in the alignment of the force vector rather than necessarily changes in its magnitude. The data have shown that the changes in the inter-relationship of the line of action of the force vector and the joints is frequently of the order of a few millimetres even although the magnitude of the external moments may change dramatically. It can be seen therefore that if joint contractures occur, which is very common in cerebral palsy, and that if these prevent the required joint attitudes being obtained during walking, significant abnormalities in the external moments are likely to occur. This will obviously result in an extremely abnormal demand on the neuromuscular system. If a purely therapeutic approach to management is attempted with the intention of obtaining a "normal" gait pattern with "normal" neuromuscular activity then this cannot succeed. Even minimal contractures of the order of 5 to 10 degrees at the hip and knee may prevent optimum alignment of the vector at both joints simultaneously. Contracture of the ankle joint of course may move the origin of the vector from, say, a midfoot position to the toes with even larger changes in external moments resulting. Surgical reduction of the contractures would therefore be necessary to permit normal alignment of the joints and thus permit the possibility of the generation of "normal" external moments at all joints simultaneously.

It would appear that one of the principal beneficial effects of the use of AFOs and footwear with appropriate characteristics may be to compensate for the influence of joint contractures and to re-align the force vector to obtain the optimum compromise in the external moments at all joints simultaneously. In some cases this may result in a "normal" demand on the neuromuscular system but it is more likely that it is abnormal but more favourably matched to the capabilities of an abnormal neuromuscular system. There are, however, likely to be limits to the compensatory capability of the AFOs and footwear. It is now apparent that additional attention must be paid to the influence of even mild joint contractures and the necessity for their surgical reduction, especially in relation to the successful generation of push-off forces.

The gait analysis data obtained during this research programme was obtained by monitoring the effect of prescriptions whose characteristics were decided by clinical judgement. In retrospect, with the experience of the detailed analysis of the data and interpretation of its significance, it is possible to detect aspects of the kinetics which perhaps could be improved by alteration of the characteristics of the AFO-footwear complex. It is even possible to suggest what these required alterations might be. It is therefore apparent that the gait analysis process itself is functioning as a clinical tool. Ultimately it may be possible to analyse the gait of a child barefoot and estimate from the kinetic data what the required characteristics of the AFO-footwear combination should be. It is considered however that this is perhaps rather unlikely and that a more realistic and effective approach would be to use clinical judgement to determine the approximate characteristics. Gait analysis after initial fitting would then indicate the nature of the required fine-tuning of the characteristics and thereafter the eventual success of the outcome.

7.5 SUGGESTIONS FOR FURTHER WORK

This research programme, while producing many results of clinical significance, has also indicated that much work still needs to be carried out to investigate the influence of AFOs on the gait of CP children.

From the point of view of the measurement systems three-dimensional measurement of the motions of the skin markers would be preferable. This would eliminate the problem of parallax and permit kinetic analysis in the medio-lateral plane which is likely to be as relevant as analysis in the antero-posterior plane. This is particularly so at the hip joint where spastic activity of the adductors and internal rotators is a significant clinical problem.

A 3-D measurement capability would permit the measurement of internal rotation of the leg. It would also permit measurement of the true plantarflexion and dorsiflexion movement of the ankle joint which was distorted using the 2-D analysis adopted in this research programme.

Improved techniques of joint centre identification should be developed to aid accurate placement of skin markers, or the development of a system to compute centres of rotation from motion data of the leg segments during gait.

Electromyography to measure the phasic activity of various muscle groups would assist the interpretation of the phenomena taking place. It would be of great value to combine the gait analysis tests and the short term monitoring tests so that all the necessary information would be obtained together. This would permit the exact influence of the AFO on the ankle-foot complex to be determined.

The long term monitoring tests should be continued, being repeated on the same child several times to look for any variation from day to day.

The influence of the details of the characteristics of the AFO, its angle of set and its stiffness, and the characteristics of the associated footwear should be more thoroughly investigated. This implies a vast range of tests with different permutations and combinations of characteristics.

It would also be interesting to observe the effect of footwear without AFOs to determine their potential for use in the children with only marginal spastic activity. The possibility of tone-reducing night AFOs in combination with appropriately adapted daytime footwear is a new and interesting posibility.

The influence of joint contractures, particularly at hip and knee, should be examined to determine their role in influencing the magnitudes and directions of the external moments generated.

It would be of interest to re-examine the case of the child whose gait with AFOs was considered clinically to be satisfactory but where the kinetic aspects of the gait were shown by the TV-computer system to have retained some anomalies. It is quite possible that fine-tuning of the characteristics of the AFO-footwear complex might result in further significant kinetic improvements, with consequent benefit to the child, even although this still might not be apparent by clinical observation.

CHAPTER 8

CONCLUSIONS

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8.1 CONCLUSIONS

This research programme has demonstrated that the kinetic aspects of the gait patterns of CP children are different from those of normal children. It has shown that the use of polypropylene ankle-foot orthoses and associated footwear influences markedly the resulting gait patterns. It is apparent that very small changes in the characteristics of the footwear result in significant kinetic changes.

While there are variations between children there are also some important common features which are apparent when comparing their gait patterns when walking with an appropriate AFO-footwear combination to their gait patterns when walking barefoot:-

The value of the total of all angular impulses generated at the hip, knee and ankle in flexion and extension is not necessarily reduced.

The external moments at the ankle joint may not necessarily be significantly altered. There is, however, the evidence which shows that the AFO modifies the activity of the plantarflexors necessary to balance the external moment.

The high external knee extension moment frequently encountered in mid stance is reduced.

The ability to develop a push-off force in late stance is improved. This is achieved by alteration of the alignment of the ground-to-foot force vector with the hip resulting in a change in the external moment in the direction of increased extension.

The results of the research programme have many clinical implications:-

The gait analysis data have confirmed the clinical impression, and attitude to management, that the characteristics of the AFO and of the footwear which are selected for a given child are critical.

It is now apparent that further improvement in the kinetic aspects of the gait may be possible by further fine-tuning of these characteristics, with consequent benefit to the child, even although these improvements may not necessarily be detected easily by clinical observation.

It is considered reasonable that alterations to the kinetic aspects of the gait pattern similar to those achieved by the use of AFOs may result from the use of other management methods. It is believed, therefore, that a higher level of compatability may exist between the use of AFOs and the other management methods than was recognised previously. This implies that a broader, and better, management programme may be possible with the selection of elements from different methods to obtain maximum benefit for the child.

The research programme has indicated that further investigation is necessary in a number of areas:-

The gait analysis process should be developed to permit 3-D analysis which would permit kinetic analysis in the medio-lateral plane and eliminate the the errors due to parallax. Improved methods of joint axis identification and skin marker location should be developed.

Electromyography should be utilised during gait analysis to measure the phasic activity of various muscle groups.

The influence of the details of the characteristics of the AFO-footwear complex should be more thoroughly investigated.

The use of the gait analysis data to permit fine-tuning of the characteristics of the AFO-footwear complex, and thus further improvement in gait, should be investigated.

APPENDIX I

REFERENCES

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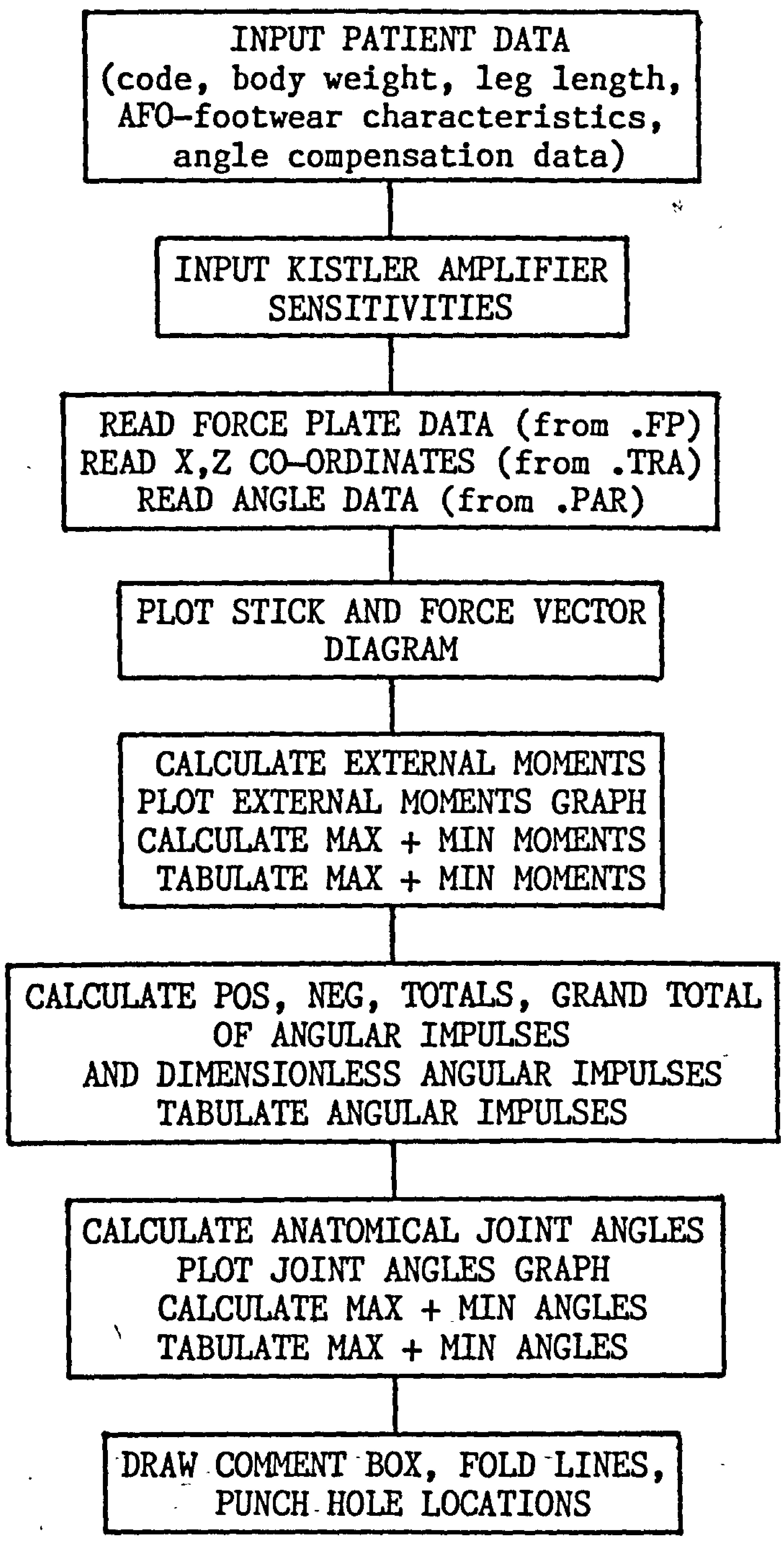
APPENDIX II

COMPUTER PROGRAM FLOW CHART

APPENDIX II

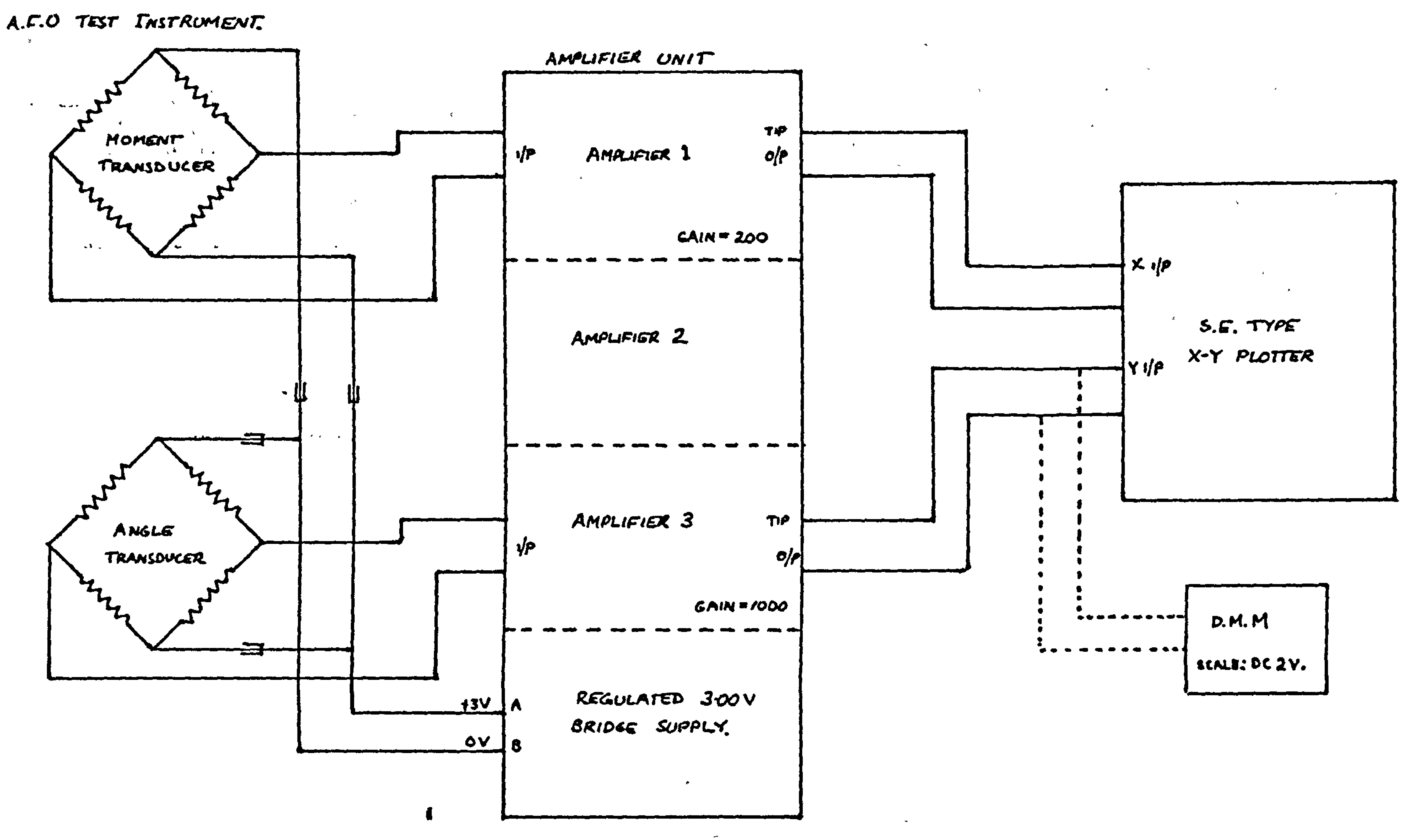
COMPUTER PROGRAM FLOW CHART

This program further processes data obtained from gait analysis data acquisition and reduction programs to produce A3 format printout.



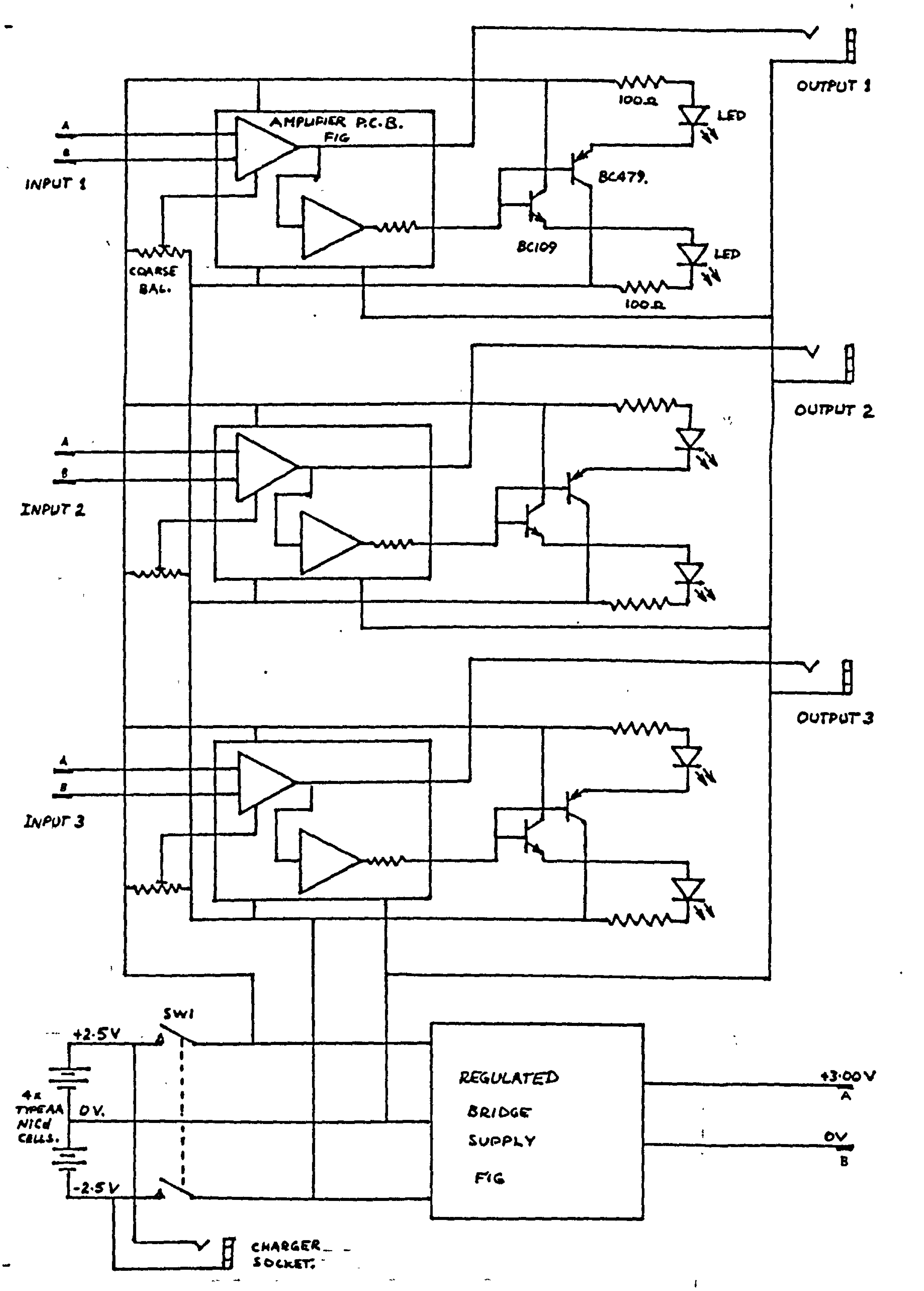
APPENDIX III

CIRCUIT DIAGRAMS

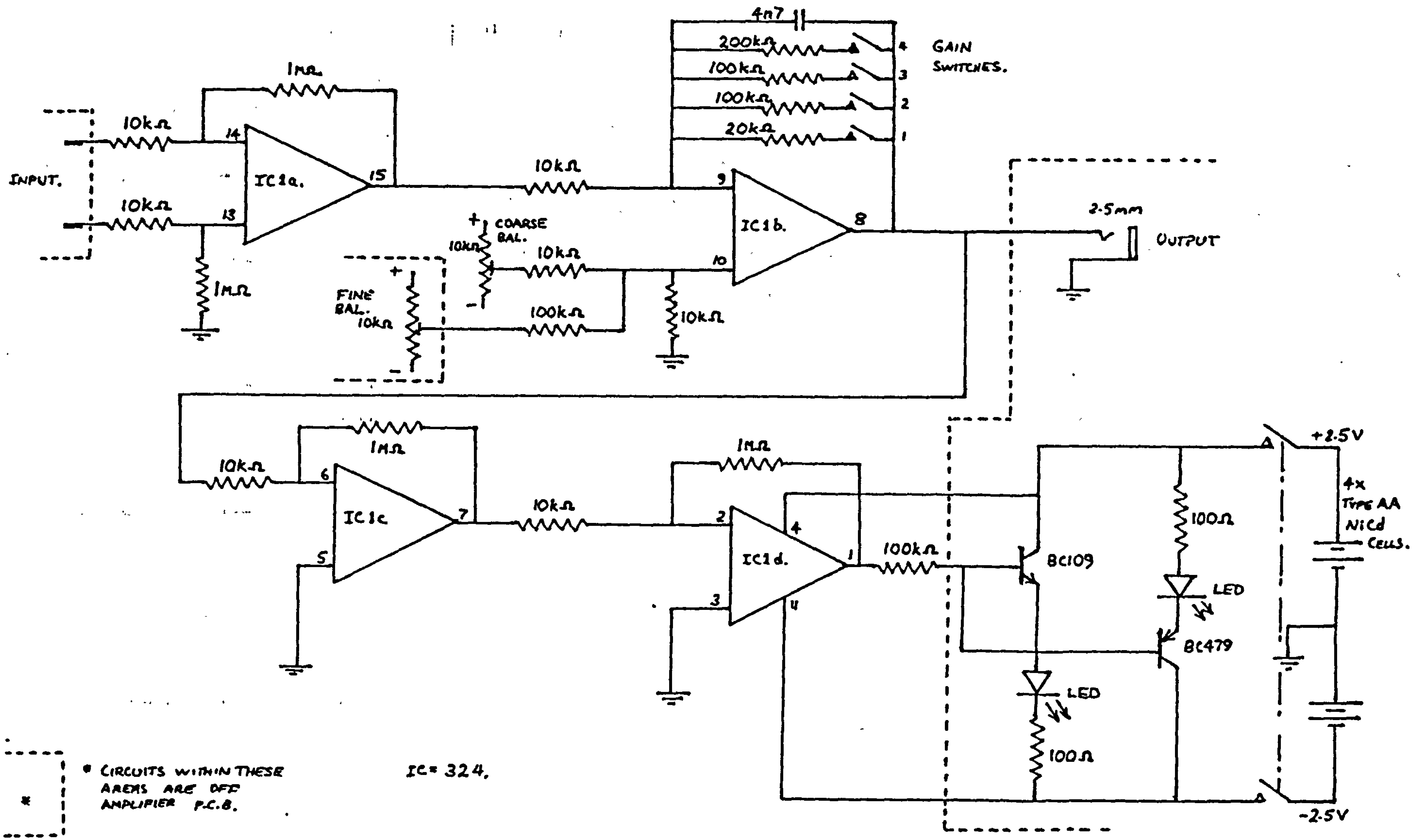


ANKLE-FOOT ORTHOSIS TEST RIG

A.E.TRAPPITT 1983

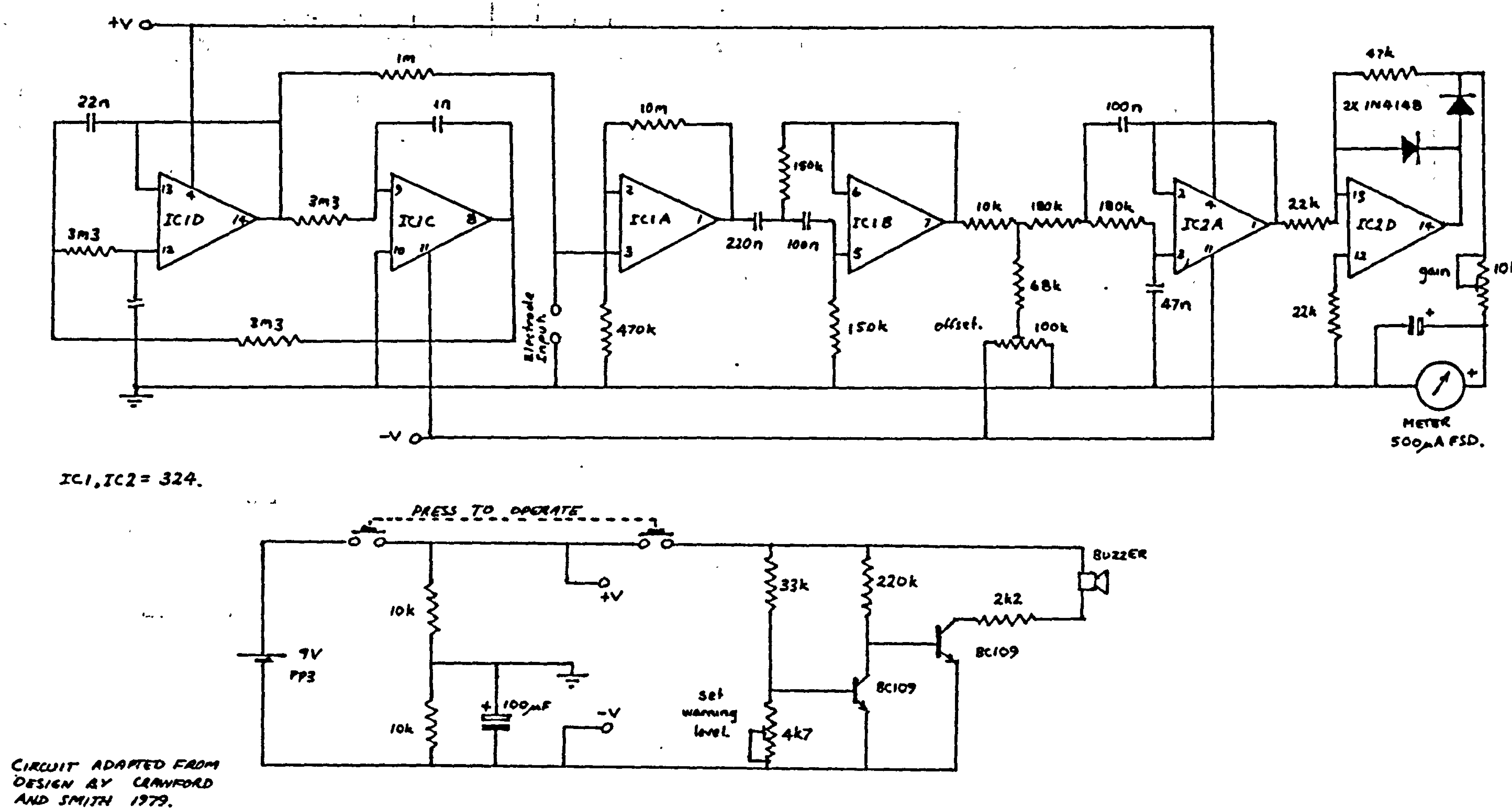


STRAIN GAUGE AMPLIFIER UNIT. A.E.TRAPPITT 1983



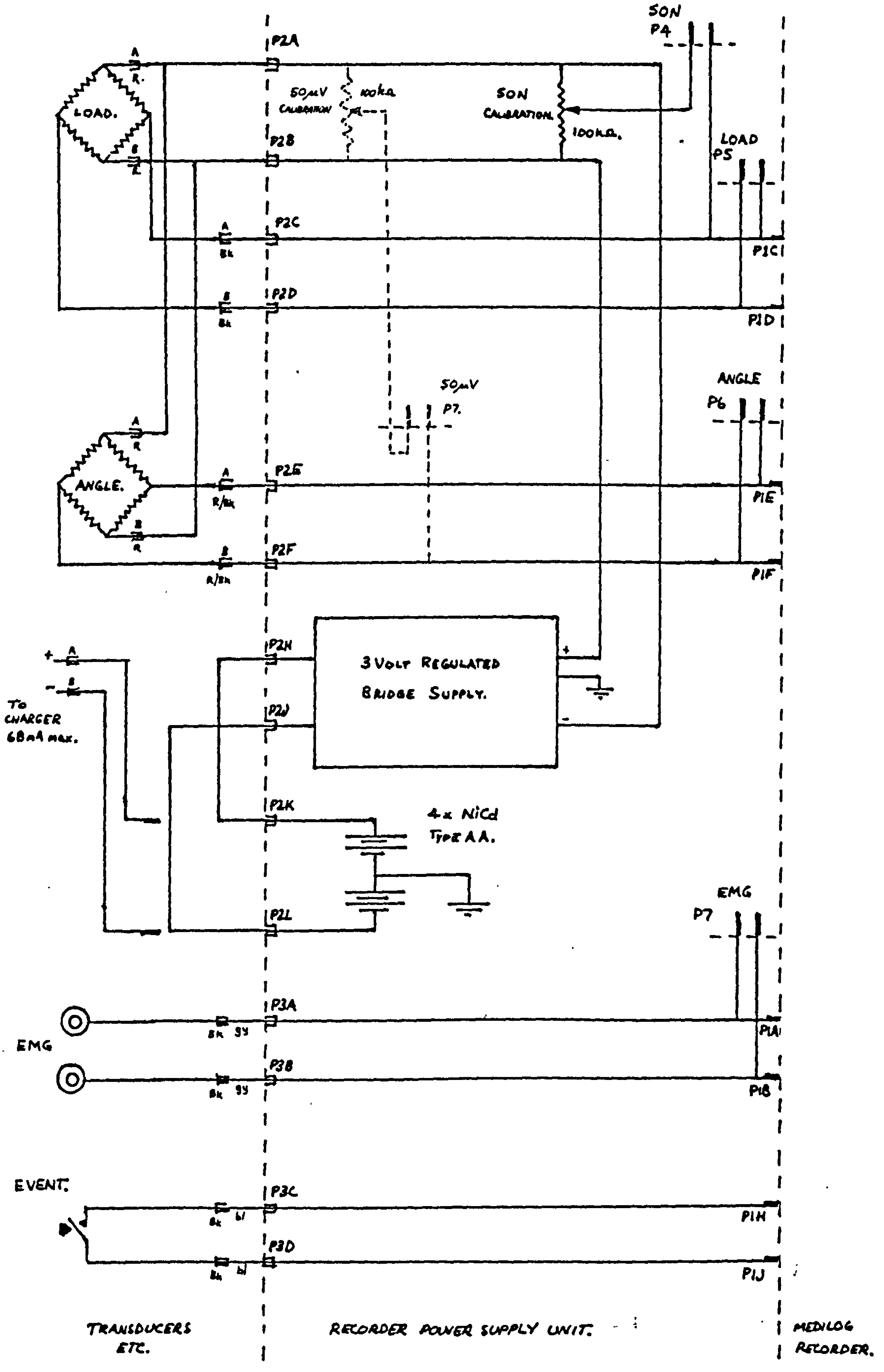
STRAIN GAUGE BRIDGE AMPLIFIER

A.E.TRAPPITT 1983

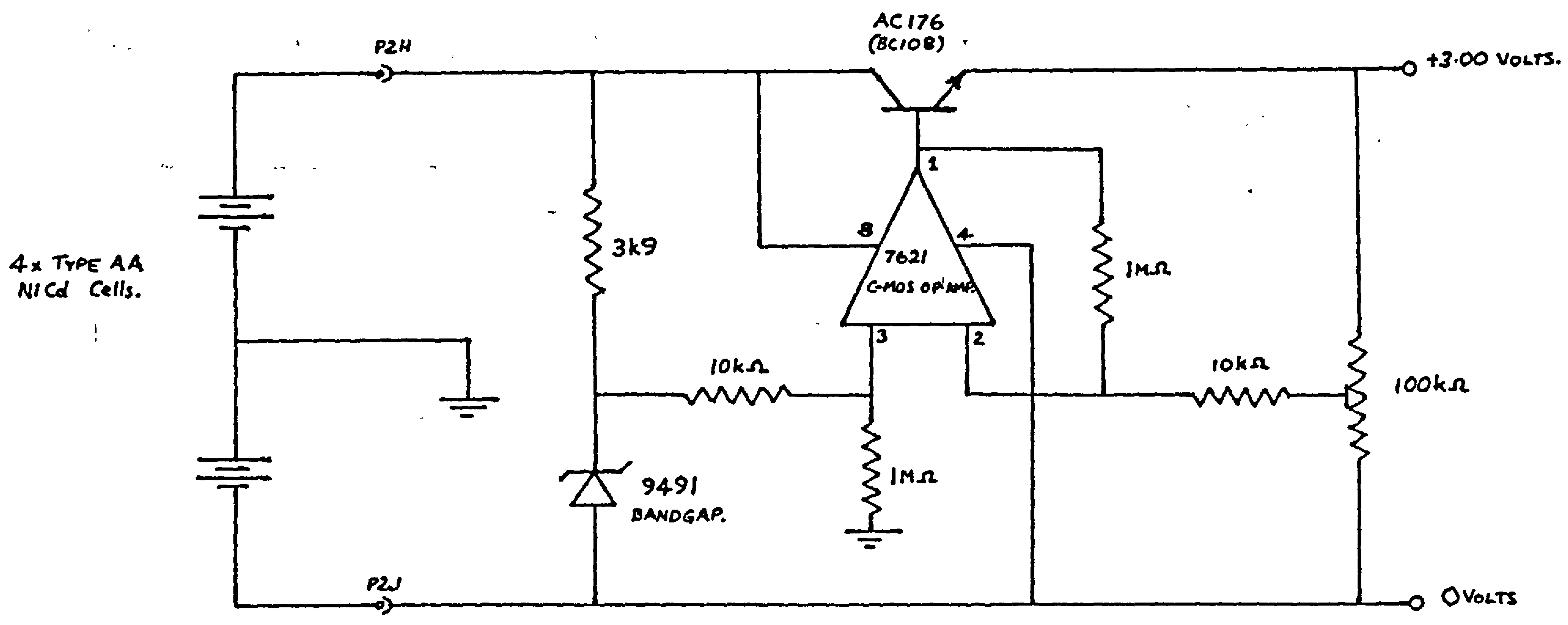


IMPEDANCE METER

A.E.TRAPPITT 1983

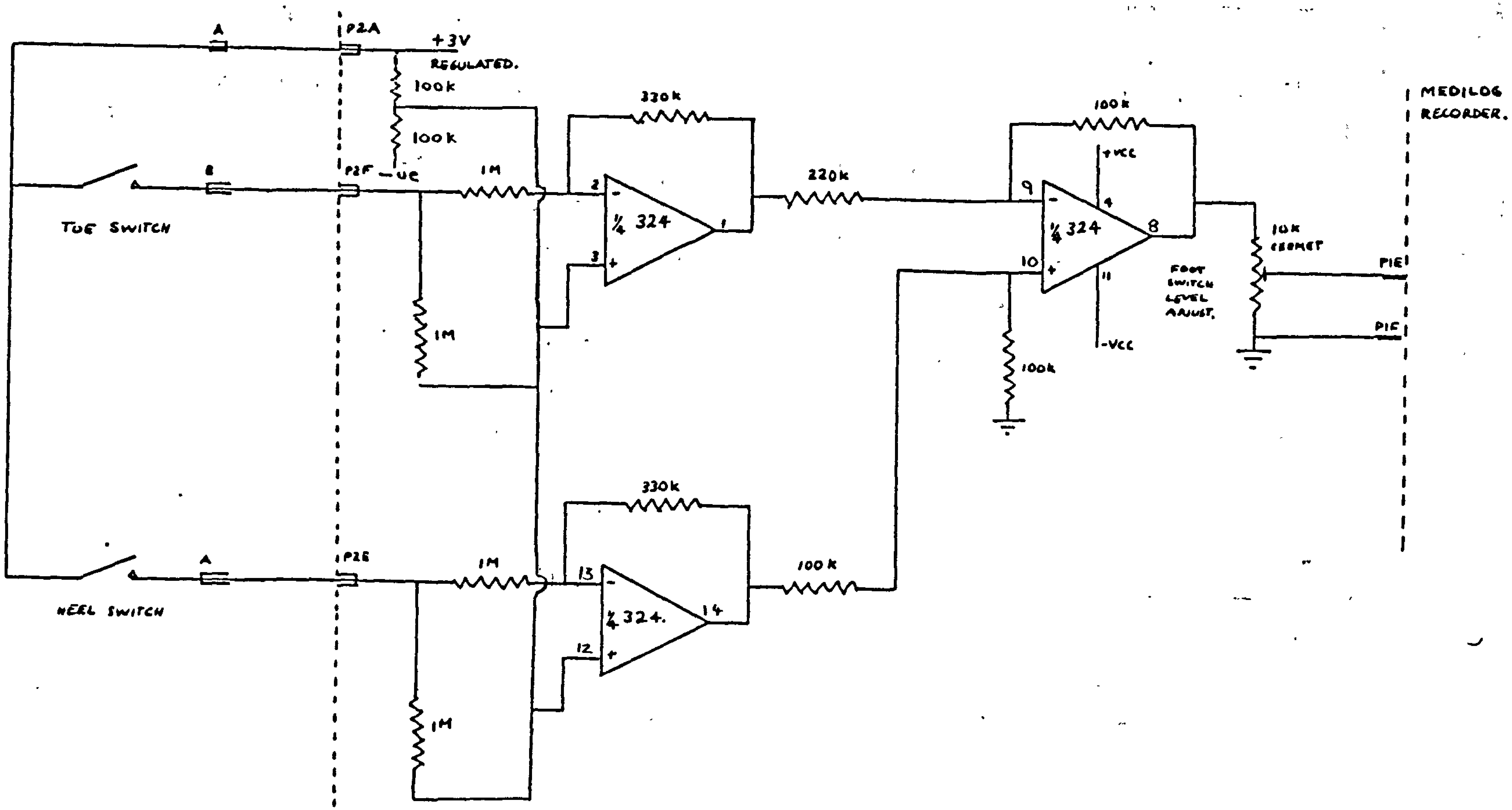


TRANSDUCERS & RECORDER POWER SUPPLY UNIT A.E.TRAPPITT 1983



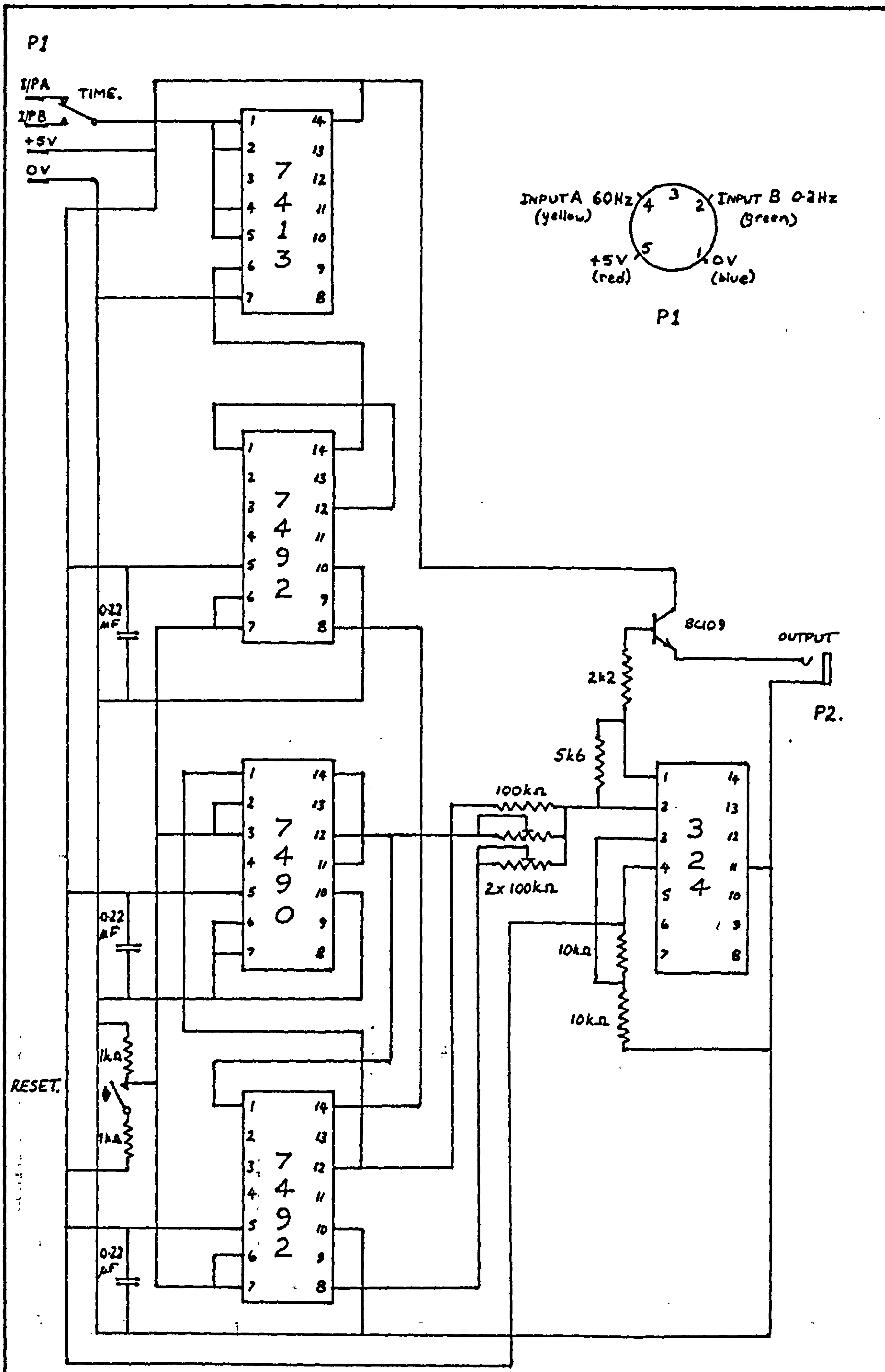
REGULATED BRIDGE SUPPLY

A.E.TRAPPITT 1983



FOOTSWITCH AMPLIFIER-SUBTRACTION UNIT

A.E.TRAPPITT 1983



TIMER UNIT A.E.TRAPPITT 1983

APPENDIX IV

RECORD SHEETS

TAYSIDE REHABILITATION ENGINEERING SERVICES

CEREBRAL PALSY FUNCTIONAL ASSESSMENT

Name	D.o.B.	Unit no.
Address	Telephone no.	DLFC no.
Daytime Location	Telephone no.	Project no.
Constraints on attendance	Other relevant information	

DIAGNOSIS

Associated Problems

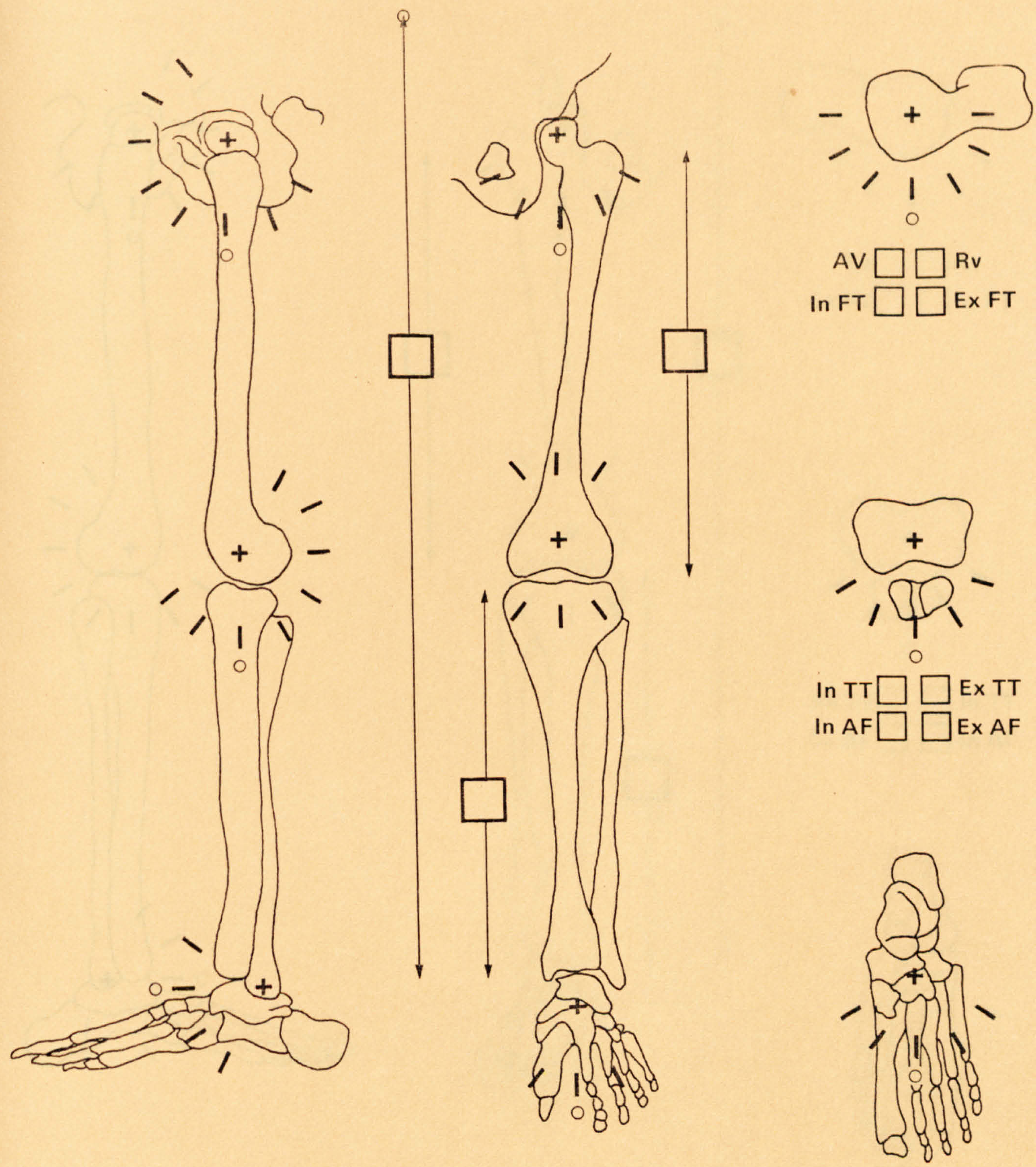
SYNOPSIS OF HISTORY

Date	Medical
	Orthopaedic
	Orthotic

L

Name

Date



PSR

TLR

STNR

ATNR

Back Para

L Para

R Para

Forw Para

Height

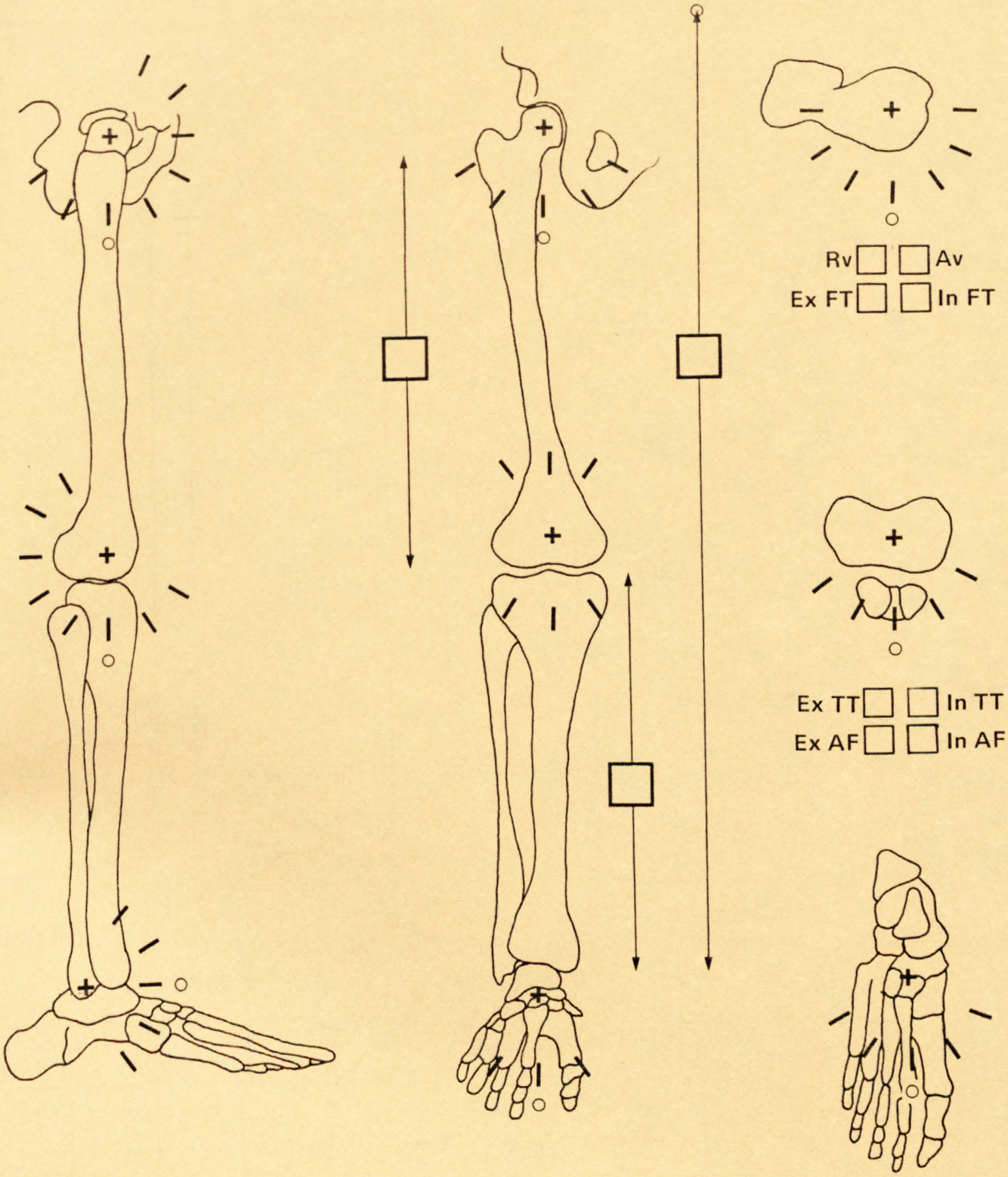
Inter-troch dist

Weight

R

Name

Date



Crawling

Standing balance

Walking

Rising-to-stand

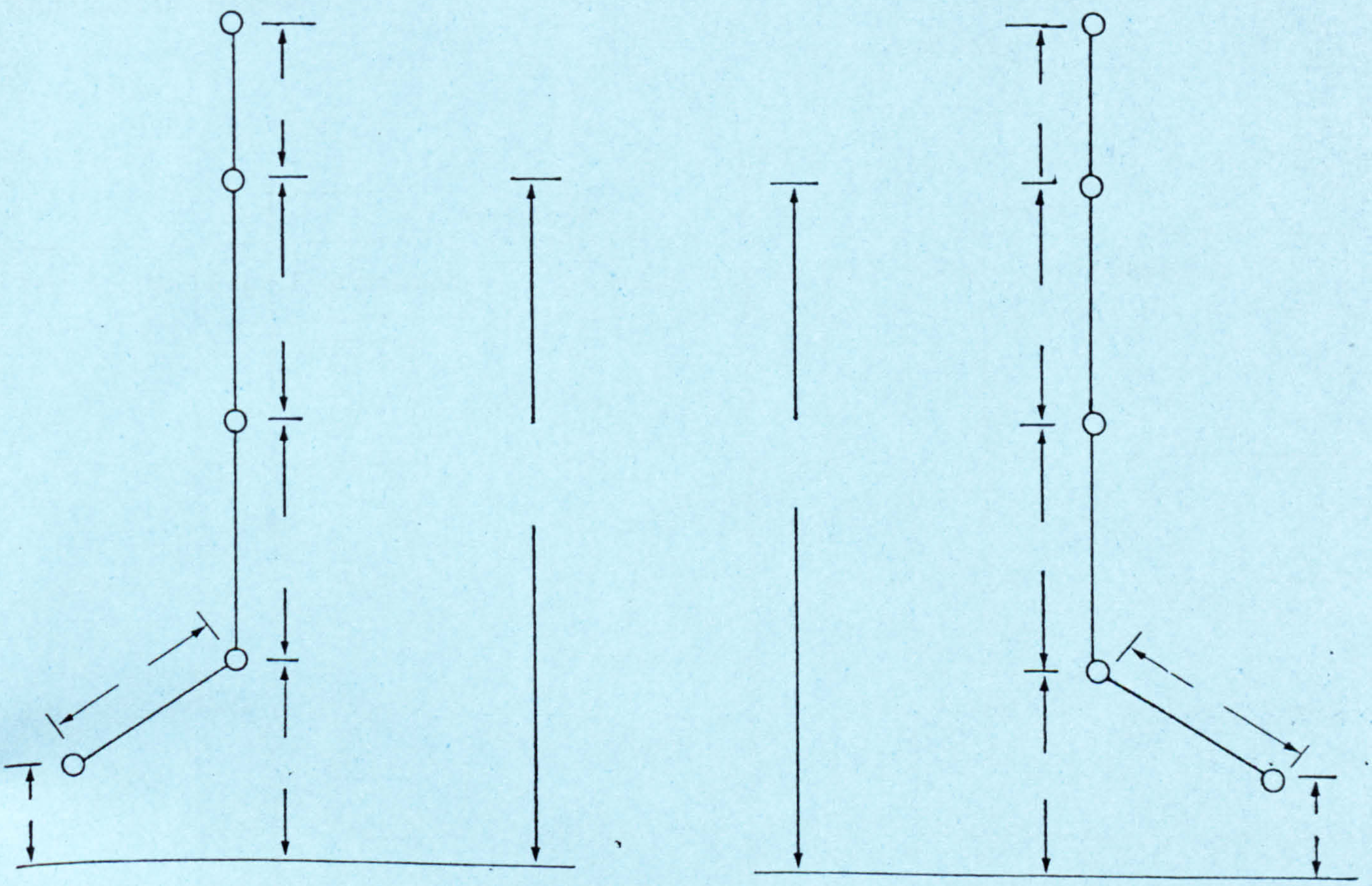
Tested by

CEREBRAL PALSY GAIT ANALYSIS — PATIENT DATA

Name

Date

Code



Weight (kg)

LEFT						RIGHT				
					Run Nos.					
					Shoe					
					Sole					
					AFO					
					Raise					
					Wedge					
					Rocker					
					Ang. Comp.					
					Hip					
					Knee					
					Ankle					

CEREBRAL PALSY GAIT ANALYSIS — TEST RUN DATA

Name

Date

Code

Additional Information

Grid No.

Camera No.

Position

Lens

Aperture

		Acquisition		Analysis			
Test Run No.	Leg	Feet position	Comments	SF	EF	DBS	Comments