An Investigation into the Functional Changes Brought about by Full Body Lycra Suits in Children with Cerebral Palsy

by

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ABSTRACT

Background: The use of Lycra Suits in the management of cerebral palsy (CP) is extremely commonplace though little research has being carried out on them and their effect on lower limbs in walking. Using 3D motion analysis techniques the movement of the limbs may be quantified with far greater accuracy in all three planes. The aim of this project was to evaluate the effectiveness of Lycra Suits in children with Cerebral Palsy during walking.

Methods: Eleven children (nine male and two female) aged 2yrs to 9yrs old, with Cerebral Palsy or similar neurological disorders were recruited to participate in the study. The patients were initially tested without the Lycra Suit (NIni) then again when wearing the Lycra Suit for the first time (SIni). The participants then wore the suit daily for twelve weeks, whilst continuing their usual daily activities and physiotherapy treatments. Following this the participants were tested again, firstly whilst wearing the Lycra Suit (S3), then immediately after removing the suit (NS3). Testing involved the patients performing three repetitions of a 10m walking test at their usual walking speed. Joint angles in the sagittal plane were measured at the hip, knee and ankle, and in the transverse plane at the hip. The results were reported as single case studies.

Results: Joint angles at the hip, knee and ankle all showed varying responses across all conditions, both within and across subjects. All eleven children showed changes in joint angle towards normal age-matched values. In conclusion it is clear that the responses to the lycra garments are as varied and individual as the presentations of Cerebral Palsy itself. With this in mind therapists should ensure continuing observations are carried out during periods of wear, ensuring physical ability both with and without the suit are not being reduced as a consequence.

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Glossary of Terms

Ataxia- Occurs in approximately10% of Cerebral Palsy cases and is a result of involvement of the cerebellum or its pathways. Weakness, incoordination and intention tremor result in unsteadiness, a wide-based gait and difficulty with rapid or fine movements (Merck, 1999).

Athetosis- occurs in approximately. 20% of Cerebral Palsy cases and results from involvement of the basal ganglia. The extremities are affected by slow, writhing involuntary movements, abrupt, distal movements may also occur. The movements increase with emotional tension and disappear during sleep (Merck, 1999).

Cerebral Palsy- A term used broadly to describe a number of motor disorders characterized by impaired voluntary movement resulting from prenatal developmental abnormalities, or perinatal or postnatal CNS damage occurring before age 5 yr (Merck, 1999).

Diplegia- Mostly affected in the legs, with less involvement in the upper body and arms (Rowland & Pedley, 2000).

Hemiplegia- Caused when the brain lesion affects one cerebral hemisphere and affects the arm and leg on one side (Rowland & Pedley, 2000).

Hypertonus- High muscle tone (Rowland & Pedley, 2000).

Hypotonus- Low muscle tone (Rowland & Pedley, 2000)

Quadriplegia/Tetraplegia- All four limbs are affected, often by double hemiplegia with the arms and legs being affected differently and to varying degrees (Rowland & Pedley, 2000)

PEDI- a validated assessment tool used by physiotherapists to assess the functional ability of children to carry out day to day tasks.

Spasticity- occurs in approximately. 70% of Cerebral Palsy cases and is caused by upper motor neuron involvement. Motor function may be affected mildly or severely and may produce hemiplegia, paraplegia, quadriplegia or diplegia. Affected limbs are underdeveloped and show increased deep tendon reflexes, muscular hypertonicity, weakness and a tendency toward contractures (Merck, 1999).

1. BACKGROUND

1.1 DESCRIPTION OF CEREBRAL PALSY AND ITS CAUSES

The term ‘Cerebral Palsy’ refers to a heterogeneous group of brain disorders that are acquired prior to or during birth, and in some cases up to 60 months post-birth (Miller & Bachrach, 2006). The brain disorder has to meet three criteria before it is confirmed as a type of Cerebral Palsy, these criteria are that the symptoms are long-lived, generally lasting throughout the life of the child. The brain lesion which is accountable for the disorder is also static, even though the clinical manifestations may change and develop as the child grows and matures. Finally the motor function impairments caused by Cerebral Palsy include muscular weakness, stiffness, poor coordination and/or involuntary movements (Goodman in Howlin & Udwin, 2002). Cerebral Palsy is the most common cause of motor deficiency in children with up to 5 being affected in every 2000 live births in the United States (Miller and Bachrach, 2006) and 2 in every 1000 live births within the UK (Surman et al, 2006). Cerebral Palsy was originally thought to be caused by asphyxia during child birth, but this has since been linked to only 10% of cases (Levitt, 2004). The majority of cases are thought to be caused by problems during foetal development. Prenatal causes include brain haemorrhage, infections passed on from the mother, such as cytomegalo-virus (CMV) or rubella, or even the effects caused by something ingested by the mother, for example toxoplasmosis caused by eating undercooked meat. Perinatal causes include asphyxia during the birth, due to the umbilical cord being around the neck. Postnatal causes of Cerebral palsy occur during the first five years of life and include head injury, infections such as meningitis or asphyxia caused by choking or near drowning (Stanton, 2002). The cause of the Cerebral Palsy often has little bearing on the diagnosis so it is more important for the therapist to familiarise themselves with the case history and relate the treatment to the development of the child, rather than taking the cause into account (Levitt, 2004). Children may also suffer with other disorders also related to brain injury such as epilepsy, mental retardation and learning difficulties (Miller and Bachrach, 2006).

1.2 TYPES AND LEVELS OF CEREBRAL PALSY

There are further sub classifications of Cerebral Palsy, which describe the type of motor problems encountered by the child, and what areas of the body are affected, which can be seen in table 1.2.1. The distribution of motor problems varies between children. Hemiplegia affects one arm and one leg, both on the ipsilateral side of the body. Diplegia predominantly affects both legs, the arms may also be involved, but to a much lesser extent. Finally, Quadriplegia affects all limbs equally.

Table 1.2.1 Classifications of Cerebral Palsy. From Miller and Bachrach (2006).

type of movement	
Spastic	Too much muscle tone
Athetoid	No muscle control
Hypotonic	Decreased muscle tone (not enough tone)
Ataxic	Balance and coordination problems
mixed	Mixture of two or more of the above
By involved body parts	
Hemiplegia	One arm and one leg on the same side of the body
Diplegia	Predominantly both legs (arms also involved)
Quadriplegia	All four extremities

Spasticity is the most prevalent type, where muscle groups become stiff and weak, limiting movement. Hypotonia refers to low muscle tone, which results in weakness. Ataxia is a gross lack of coordination of muscular movements. Athetosis describes those with slow involuntary movement, particularly in the feet, face and hands with fingers flexing and extending separately in an irregular fashion.

1.3 GAIT DEVIATIONS CAUSED BY CEREBRAL PALSY

Spastic Diplegia, which is the most common form of Cerebral Palsy, usually results in reduced joint motion caused by spastic muscle groups. Children with the condition are regularly described as having a ‘crouch gait’, which is characterised by increased pelvic anterior tilt, flexed and internally rotated hips, flexed knees and plantar flexed ankles

(Rab, in Howlin and Udwin, 2002). Equinus is common in Hemiplegics and causes forefoot strike during the initial gait cycle and earlier plantar flexion in the early to mid-stance phase, causing collapse at the ankle joint. Increased flexion at the knee occurs during the stance phase, yet knee flexion during the swing phase occurs late, and is less profound than in non-pathological subjects. Causes of equinus include spasticity of the triceps surae and/or the planter flexors, or may be a compensatory response to spastic hamstring muscles.

Four important factors during the function of normal gait were outlined by Perry (1992). These were stability of the weight bearing foot throughout stance, clearance of the non-weight-bearing foot during swing, appropriate pre-positioning of the foot and adequate step length. The characteristics of Cerebral Palsy gait infringe on all four of these. The continuous flexion at both the knee and ankle cause instability during weight bearing and foot clearance during swing phase is greatly reduced by equinus. This often leads to tripping, especially on slopes, steps and uneven surfaces.

1.4 QUALITY OF LIFE MEASURES

Cerebral Palsy varies widely in severity from child to child. This, along with the different types of presentation has called for systems to be developed to assess each child's ability. The two main recognised systems used are the Gross Motor Function Classification System for Cerebral Palsy (GMFCS-CP) and the Gross Motor Function Measure (GMFM).

GMFCS-CP (see appendix 4)

This is a five level classification system designed to identify the child's abilities and limitations in motor function. The system is based upon self-initiated movement with emphasis placed upon sitting and walking (Palisano et al, 1997). Level I is the most physically able child through to level V being the least able. Each level is broad and is not designed to describe all of the child abilities, but is more aimed at a 'best fit', so if a child can carry out most activities for a level then that is the level at which they will be classified. The levels also have differing expectations dependant on four separate age ranges to account for changes due to maturation and the natural learning process during growth. These age groups are: before the 2nd Birthday, between the 2nd and 4th Birthday, between the 4th and 6th Birthday and between the 6th and 12th Birthday.

GMFM (see appendix 5)

The GMFM is a clinical tool developed by Russell and colleagues (2002). It is used to evaluate gross changes in the physical ability of children with Cerebral Palsy. The test was originally developed with 88 items measuring ability in lying and rolling, sitting, crawling and kneeling, standing, and walking, running and jumping, this has since been reduced to 66 items. The tool provides detailed scoring within each measure, from 0-3, with 0 being unable to initiate the skill, and 3 being able to complete it. The variety of tasks covered allows for realistic and individual goal-setting.

2. LITERATURE REVIEW

2.1 INTRODUCTION TO THE CLINICAL MANAGEMENT OF CEREBRAL PALSY.

2.1.1 BOTULINUM TOXIN INJECTIONS

Botulinum toxin injections (Botox) can be used directly on spastic muscles, acting as a relaxant. The injections are most commonly used to assist in the treatment of equinus by reducing spasticity in the calf muscles. The injections are often used in conjunction with ankle-foot orthoses (AFOs) to add further support around the ankle and prevent gait problems such as tripping caused by equinus. Botox is also used following surgery to assist with the healing process by relaxing spastic muscles, therefore decreasing the strain put through muscles and tendons which have been operated upon. Botox is not a permanent form of treatment and injections are repeated every three to four months where necessary to ensure the effect is maintained. Due to the nature and effect of Botox injections any child who had received them within the previous 12 months to testing were excluded from the study.

2.1.2 PHYSIOTHERAPY

Physiotherapy and orthotics are the most common non-invasive treatment options. Physiotherapy is often carried out using ongoing exercise therapy programs which focus on the stretching of spastic muscles and strengthening of supporting muscles to assist with movement during gait. The prolonged stretching results in a desensitization of the stretch receptors, reducing the spastic reflex (Akbayrak et al, 2005). Stretching techniques include Proprioceptive Neuromuscular Facilitation (PNF) and antispastic positioning, which involves keeping a muscle in a stretched position for as long as possible before it becomes uncomfortable (Akbayrak et al, 2005). Stretching can be applied directly by the physiotherapist or parent, or by orthoses or splints designed to hold limbs in stretched positions. Akbayrak et al (2005) carried out a study investigating the short-term effects of antispastic stretching in 20 children with spastic diplegic CP. The children were supported in a sitting position with their hips abducted to 45˚ with the hips externally rotated and ankles bent to 90˚, this position was held for 20 minutes. The stretching was found to produce a significant reduction in muscle tone and passive dorsiflexion of the foot. Physiotherapists are in regular contact with their patient and continuously assess the physical ability of the child adapting their treatment accordingly as the child grows and develops. Most children are referred by their physiotherapist, rather than their GP or specialist, to an orthotist for fitting of orthotics.

2.1.3 ORTHOSES

Orthotic options include ankle foot orthoses (AFOs), used to reduce equinus at the ankle; knee ankle foot orthoses (KAFOs) which work to stabilise the knee as well as the ankle joint (see figure 2.1.3a), and foot orthoses, which are used in mild cases to assist with excessive pronation (Nester, 2003). There are different types of AFOs- solid, hinged, posterior leaf-spring and dynamic (see figure 2.1.3b).

Fig. 2.1.3a Knee Ankle Foot Orthosis (KAFO)

Fig 2.1.3b Ankle Foot Orthoses (AFOs) l-r Hinged AFO, Assorted posterior leaf-spring AFOs, Dynamic AFO.

Solid AFOs give full support and allow no movement around the ankle. Whilst decreasing equinus and contractures in ankle plantar flexor muscles this type of AFO also prevents the natural dorsiflexion which occurs when the tibia moves over the foot during the stance phase of walking. This in turn causes the heel to rise early before the swing phase (Abel et al, 1998). Despite this, wearing solid AFOs has been found to significantly increase stride length in comparison to wearing no AFOs. Abnormal ankle plantar flexion during initial foot contact, midstance and toe off has also been shown to be reduced (Radtka et al, 2005). Sienko Thomas and colleagues (2002) carried out a study with thirty hemiplegic children aged 4-18, investigating the effects of posterior leaf spring, hinged and solid AFOs against barefoot conditions during stair ascent and descent. The study spanned a year in total, with the children completing a 3 month period without AFOs followed by a randomised sequence of AFO wear. Each AFO was worn daily for 3 months and the tests were carried out at the end of each period to allow the children to become used to them. During stair ascent and descent 67% and 53% of the children were able to keep up with the normal children respectively whilst wearing the hinged AFO, however no significant difference was found between these measures taken using the PEDI. There was also no difference found in walking velocity. Joint kinematics measured with a 3D motion analysis system Vicon 370 revealed that during stair ascent the hinged AFO significantly increased dorsiflexion over the solid AFO and barefoot conditions. Plantarflexion was limited by all AFOs during both swing and stance phases when compared to barefoot. No significant differences were found at the knee, and flexion at the hip was only found to increase whilst wearing the posterior leaf-spring AFO in comparison to the solid AFO. During stair descent plantar-flexion was significantly decreased across all AFOs when compared to barefoot, which is to be expected. Dorsiflexion was also found to decrease in a similar fashion during the swing phase, as the AFOs work directly to prevent equinus. In conjunction with this knee flexion was found to decrease significantly as the leg is not lifted as high to prevent tripping. Overall the study found that wearing an AFO improved foot contact position during stair ascent. As no significant difference was found between the joint kinematics for the AFOs and barefoot it seems that the children may adapt their gait pattern to account for the limitation in ankle movement.

2.1.4 DYNAMIC ORTHOSES

Aside from solid AFOs there are several types of orthosis which allow varying degrees of movement depending on the support required. Dynamic AFOs are solid around the foot and stop superior to the malleoli and aim to maximise midline stability around the ankle whilst still allowing freedom of movement across all three planes.

Hinged AFOs are similar to the solid version, but have a hinge which allows dorsiflexion about the ankle joint whilst still preventing plantar flexion. Posterior leaf-spring AFOs are made from flexible plastic and are not as strong as the solid AFOs (Fig. 2.1.3b). These are used to assist dorsiflexion during the swing phase in less affected individuals (Richards, 2008). Hinged AFOs have been shown to be the most effective during gait (Tyson & Thornton, 2001) and sit-to-stand mobility tasks (Park et al, 2004). Although AFOs are frequently prescribed it has been shown that orthotic management can vary widely depending on the treatment available within their NHS district (Morris et al, 2002).

A small number of studies have been carried out comparing the hinged AFOs with other types of AFO, or wearing no orthosis at all. Park and colleagues (2004) investigated the effect of wearing a hinged AFO on sit-to-stand transfer, compared to no AFO in a group of 19 children. The participants served as their own control, the two conditions- orthosis and no orthosis- were randomly assigned and tested on the same day. The hinged AFO significantly increased the speed of rising, along with the power and moment around the knee and hip joint during the task. However all findings relate to the immediate effect of the AFOs and do not give an indication on how prolonged wear may differ from this.

Romkes and Brunner (2002) compared the functional changes caused by dynamic orthoses and hinged orthoses in 12 hemiplegic children. They found that a third of the children improved with the dynamic orthoses, but no further improvement came about whilst wearing the hinged orthoses. Overall the hinged orthosis was found to change a toe walking gait to a heel-toe gait pattern in all hemiplegic patients. Significant differences were found between ankle dorsiflexion angles at heel strike in barefoot (-18.5±10.3), dynamic orthoses (-8.0±7.3) and hinged AFO (3.7±4.0). The hinged AFO was thought to be more successful due to the prevention of foot-drop during the swing phase allowing heel strike to occur. Romkes and colleagues found similar ankle joint kinematics in a later study carried out in 2005 which compared hinged AFOs to wearing no AFO. However a limitation of the study was that the children were tested barefoot without the AFO, but wore their shoes whilst tested with the AFO. This raises the question as to whether some of the changes in motion could be brought about by the added support of the shoes. Also the 3D reflective markers were placed on the shoes in the 'positions best projecting the anatomical markers' (Romkes et al, 2006), which may not be as easily identifiable as barefoot markers and would therefore differ in location to the bare foot.

Tyson and Thornton (2001) also compared the effects of a hinged AFO against wearing no AFO, but chose to measure stride and step length, cadence and walking velocity. The study recruited 25 subjects with a mean age of 49.9 years and had all developed hemiplegia following stroke. Alongside the gait analysis they questioned the AFO wearers about their opinions with regards to the AFOs including functional measures such as toe lift and leg swing, weight bearing, confidence in walking, speed and distance. The AFOs were significantly found to increase stride and step length on both affected and unaffected sides. Cadence and walking velocity also increased significantly. When questioned about the importance of function and quality of movement 96% also felt function (speed of walking) was more important than quality of movement (walking without a limp). The more positive attitudes towards the AFOs, especially with regards to aesthetics and comfort may be attributed to the age group that were tested. Adults are less likely to be put off by how the orthosis appears if it genuinely helps them whilst walking when compared to children and adolescents who are under pressure to dress and appear similar to classmates and others of a similar age. Also, the subjects recruited had developed hemiplegia following stroke, and it can be assumed were healthy prior to this occurring. This group will possibly have different aims whilst wearing the AFOs to those with cerebral palsy who have had difficulties since birth.

Overall all studies have found that AFOs assist most cerebral palsy patients by preventing equinus. Walking is shown to improve, along with activities of daily living such as stair ascent and descent and sit to stand. Most problems with AFOs are caused by the lack of tibial movement over the foot during the stance phase, which in turn causes premature heel lift prior to toe off. Some wearers find them to be uncomfortable due to the solid materials they are manufactured from, and as reported by Tyson and Thornton (2001) they were also found to be heavy and unattractive to wear. These are important points to consider despite the clear benefits of wearing AFOs as some patients, especially in younger age groups, may be reluctant to wear AFOs due to embarrassment, peer pressure and other social reasons.

2.2 EVIDENCE FOR THE EFFECT OF DYNAMIC ORTHOSES

Alongside AFOs lycra suits and garments can also be considered a dynamic form of orthosis, allowing movement around the joints that are being supported. Lycra suits are made from a strong polycotton lycra material, and can be made to fit the whole, or individual parts of the body. (see fig.2.2a). Lycra garments are also available to support individual limbs. Lycra suits are also now becoming known as Sensory Dynamic Orthosis (SDO), they are tailored individually for the patient and consist of several sections of material sewn together. These sections are stretched in the direction necessary to create tension and support where needed before being sewn into place. The thickness and type of material may also vary between panels, for example thicker material can be used to produce more support where needed, and water absorbent material may be used under the arms. Although regularly prescribed by NHS physiotherapists the suits have to be bought privately and can cost between £200 and

£600. Therefore the treatment can become expensive to the parents, especially when children may require a replacement every 2-3 months due to growth. Lycra suits are also reported to produce adverse effects in wearers, such as decreased respiratory function (Blair et al, 1995), over-heating and difficulties toileting, which have discouraged parents from continuing with their wear (Nicholson et al, 2001; Rennie et al, 2000).

Plastic boning may also be added to the lycra suit to provide extra support, particularly around the trunk area. The suits and garments are dynamic in nature, rather than rigid or made of rigid materials, meaning that they move with the wearer, allowing freedom of movement and flexibility whilst still providing support. It is possible for the wearer to experience a wider range of movement by prepositioning limbs.

Fig 2.2a Examples of lycra suits and garments.

Lycra suits and garments are used in the treatment of neurological conditions resulting in abnormal tone, including cerebral palsy, acquired brain and spinal injury, cerebellar ataxia, spina bifida, stroke, multiple sclerosis and focal dystonia (Jobskin Ltd, 2010). Although no direct research has been carried out as to how the suits and garments work it is believed that changes are brought about via a mixture of sensory and proprioceptive feedback (Karem et al, 2001), and musculo-skeletal support and alignment. The continual stretch applied to spastic muscles by the garments has been suggested to inhibit tone, soft tissue contracture and involuntary movements (Rennie et al, 2000). This approach reflects the physiotherapy treatment approach of applying passive stretching to spastic muscles (Akbayrak et al, 2005) as mentioned earlier in the chapter.

A systematic review was undertaken by searching CINAHL, EMBASE and Medline. The search terms used were ‘cerebral palsy’ AND ‘lycra suits’, ‘lycra garments’ and ‘lycra orthoses’ (as keywords and MESH terms). A total of 19 results were found, though 6 of these were repeated across the three databases, leaving a total of 13 original journal articles; only 8 of which were relevant to the research question. Two of these were discarded as they only investigated the effects on upper limb movement, one was discarded as it was a discussion paper investigating all orthotic options, and a final paper was discarded as it involved parental reports rather than quantitative measures.

2.2.1 EFFECT OF LYCRA GARMENTS ON UPPER LIMB MOVEMENT

A systematic review of management options in upper limb function in children with cerebral palsy was carried out in 2001 (Boyd et al, 2001). This highlighted a paucity of evidence for the effect of lycra suits. The review uncovered only one article by Blair and colleagues in 1995. A total of 32 participants were recruited to the study, 24 of which were assigned to wearing a lycra suit. The remaining 8 children were paired up with a child assigned a suit following neurodevelopmental assessment and acted as matched controls. The study followed a crossover ABAB design where each period, either with or without the suit, lasted for three weeks. Each period was preceded by one week of habituation to allow the participants to become used to the suit. Video analysis was taken at the end of each period, and shown to therapists blinded to condition in a randomised order who then rated the movement and functional ability shown. Overall the suits were found to have a positive effect on postural stability, and dynamic functional effect was positive in all movements except rolling, for example from a prone to supine position. Upper limb movement was rated as significantly improved with the addition of the lycra suit and involuntary movement was found to be reduced in most. This reduction in involuntary movement was also found to carry over after the removal of the suits, especially in the older children with spastic muscles. Overall the findings of the study were positive.

More recently systematic studies have been carried out by Blackmore and colleagues (2006) and Coghill and colleagues (2010). The review by Blackmore and colleagues concentrated exclusively on the effects of lycra garments on upper limb function. Their extensive search yielded a total of 966 hits, but only 5 of these papers met the criteria set, though this is still an increase on the earlier review by Boyd and colleagues (2001). Overall there was found to be no significant difference between groups of CP children who had and hadn't worn lycra garments in areas including muscle strength, spasticity, ROM, postural control, proximal stability and sensory and proprioceptive feedback. They did find that problems regarding discomfort and inconvenience reduced compliance by up to 50% in the studies. The review by Coghill and colleagues (2010) discovered 8 suitable studies, mostly involving single case studies with small participant numbers. The findings of these studies did suggest that lycra garments can improve proximal stability, but again the evidence is limited. Both reviews conclude that existing studies were weakened by small, non-homogenous groups of participants.

Gracies et al (1997) investigated the effects of three different lycra splints on ten healthy subjects. The different splints were designed to supinate the forearm, pronate the forearm or produce no supination or pronation (neutral). Each garment was manufactured to fit the individual subject reaching from the under arm to the wrist. The subject was blind to which garment they were wearing at any one time. As the fitting of lycra suits and garments has been shown to be key in their effectiveness the garments were fitted by one of the experimenters. For the first two series of experiments the 'fitter' was blind, and for the second two unblinded. The results showed that the garments did provide rotation at the forearm, but this was only significant when they were fitted accurately. This effect decreased over a 6hr time span, which they reported as possibly due to movement of the garment during wear, though habituation may also be a contributing factor. A further study by Gracies et al (2000) investigated the effects of dynamic supinator-extensor garments of the same design on upper limb function in hemiplegic patients. In addition the patients wore a custom fitted glove splint which incorporated two semi-flexible plastic splints to oppose wrist flexion. Sixteen patients were tested in a cross-over design study for 3 hours at a time. On one day they wore the garment, on the other they wore no garment with the order being randomly assigned. The garments were fitted by one of the investigators to ensure correct placement. Resting posture was found to be improved at the elbow and the wrist, where flexion decreased significantly. Spasticity levels in the elbow supinators and wrist extensors were found to be close to nil at the onset and completion of the 3 hour testing period with the garment, however no difference was found in the elbow flexors, extensors and pronators. The garments were also found to impair the ability to flex the fingers, reducing grip.

The only study investigating the effects of lycra garments on upper limb function directly on children with Cerebral Palsy was carried out by Nicholson et al (2001). Twelve children with athetosis, ataxia and spasticity were scored using the PEDI scale. The children were scored prior to, and after wearing the garment for a minimum of 6 hours a day for 6 weeks. Eight of the children were also selected for motion analysis, which was carried out immediately before the garments were fitted, and again after 8 weeks whilst still wearing the garment. The selection criteria for motion analysis were not outlined. The passive position of the child's arm at 90° shoulder flexion and full wrist and elbow extension was measured prior to the test (Nicholson et al, 2001). The selected children then carried out a reach-and-grasp task with their most affected arm. The results from the motion analysis were reported individually for each child. Overall all five children showed greater stability around the trunk, but at a cost of decreased shoulder stability. Despite this the improvement in proximal stability allowed for more controlled movements in the upper limbs. Child 3, who had ataxia, was shown to have the greatest improvement in functional skills overall. Significant improvements were found in postural movement, self-feeding, handling objects and walking with a frame. The two children with spasticity were also reported to show slight reductions in hypertonia caused by the garments. The children with ataxia and athetosis showed increased smoothness of movement, which in turn increases fine motor control.

2.2.2 EFFECT OF LYCRA GARMENTS ON LOWER LIMB MOVEMENT

The only study investigating the effect of lycra suits on lower limb function was carried out by Rennie et al (2000). The study utilised 3D motion analysis and the PEDI. Eight children were tested prior to the introduction of the lycra suits. They then wore the suits for a 2 week familiarisation period, followed by 6 weeks of daily wear. The children were then tested again following the eight week period. The walking distance completed by each child during the 3D analysis is not outlined, though the inclusion criteria state that each child could walk unsupported for at least 5m. Gait analysis results were reported using the root mean square error (RMSE) which reports the level of variability across the number of trials, giving an indication of stability. The degree of stability was measured proximally around the pelvis in sagittal, coronal and transverse planes, and distally around the hip, knee and ankle joints in the sagittal plane. The raw RMSE scores are reported for each child individually in table form, but the results overall are described for the group collectively. Proximal stability was found to increase in 5 of the 8 children, though the level varied greatly between those. Distal stability was only found to increase in 3 of the children. The PEDI scores reported no significant changes in the group overall, though 3 of the children did improve slightly. Rennie et al (2000) reported that the small sample size and the heterogeneous nature of the group tested possibly reduced the chance of finding significant changes. The period during which the children wore the suits was relatively short which may have reduced the possibility of more significant differences being found also. As many studies have shown an individual response to the lycra suits and garments (Nicholson et al, 2001) a larger sample size with subjects of a very specific group may be more likely to produce significant results, though in turn each ‘sub-group’ of cerebral palsy would need to be investigated individually.

2.3 DEVELOPMENT OF MEASUREMENT TECHNIQUES

2.3.1 VIDEO ANALYSIS

Analysis of gait and movement patterns in cerebral palsy and similar patient groups has often utilised video analysis. Video cameras are used to capture 2D footage of the children carrying out movement tasks by placing a single camera orthogonal to the movement of interest (Richards, 2008). As the video only captures footage along one plane of motion this is all that can be analysed, meaning that rotational movements around joints cannot be accounted for using this method. This is a problem especially when analysing movements and gait in children with cerebral palsy as many characteristics of their gait are caused by such movements. Inward rotation at the hip and equinus are both characteristics of cerebral palsy ‘crouch’ gait and work across more than one plane of movement.

The video files captured can then be watched and analysed by experienced physicians using any of several measurement techniques including the PEDI and the GMFM. The video files can be shown to the assessors in a randomised order to blind them to the condition they are currently rating. However due to the nature of 2D video analysis it can be very difficult to ensure full blindness. The identity of the children in the videos would be hard to hide in many cases, as would the visibility of the lycra suit, as the high neckline may be visible underneath the child’s clothing. This brings into question whether the trials can really be blinded fully at all. The nature of 2D video analysis therefore is open to inter and intra-rater bias (Rennie et al, 2000).

A number of studies have used video and photographic analysis to capture differences found between conditions investigating fine motor controlled movements. These studies used 2D video (Gracies et al, 1997) and 2D photography (Gracies et al, 2000) to measure and record the differences in resting posture and passive rotation around the forearm. The movements were carried out against a grid which had angular landmarks allowing accurate measurement of positional changes. These studies quantified the differences brought about by lycra garments successfully along a single plane of movement, however these movements are very simple in nature and do not reflect the complex multi-plane movements carried out during day to day activities.

2.3.2 3D MOTION ANALYSIS

3D motion analysis utilises a multi-camera system to track markers which have been placed on particular anatomical landmarks of the body. Multiple cameras are necessary as some markers will not be visible to all cameras at all times, they may be occluded by limb movement such as the arms swinging past the hips during gait, or changes in direction during the completion of movement tasks. More complex movements, and more complex marker sets therefore require higher numbers of cameras to ensure accurate data, as a result 10 camera systems are becoming common in research laboratories (Richards, 2008).

The markers used with the 3D camera systems are made of a retro-reflective material. This reflects the infra-red light which is emitted by the cameras, allowing the cameras to track the movement of the markers throughout a calibrated area. Singular markers are used to identify the joints of the body, and are placed in line with the joint axis following anatomical palpation by the tester. To allow motion tracking of the body, clusters of markers are then placed on the body segments, such as the shank or thigh. A significant amount of research has been carried out to discover the most accurate form of marker cluster arrangement, and it is now widely accepted that a rigid cluster with four markers is the most favourable solution (Cappozzo & Capello, 1997). The four marker clusters allow full 3D motion tracking of the segment even if one of the markers becomes occluded during the movement tasks being carried out. Visibility of two markers will allow the orientation of the body segment to be tracked, but the presence of a third marker in relation to these ensures that rotations will also be tracked which is ultimately the benefit 3D analysis has over 2D.

3D motion analysis is becoming increasingly popular in the diagnosis and treatment of children with cerebral palsy and similar movement disorders and this is evident in the research that has been carried out in the area. The studies found investigating the use of

AFOs in CP children all used 6 camera Vicon (Romkes & Brunner, 2002; Park et al, 2004; Romkes et al, 2006) or NEC corp (Japan) systems (Radtka et al, 2005). This reflects on the practice of using 3D motion analysis to assist with the prescription of AFOs with these groups. The studies carried out investigating the effects of lycra garments were more likely to have used 2D photographic or video analysis, with only two studies opting to use a 6 camera Elite system in their research (Rennie at al, 2000, Nicholson et al, 2001). Both of these studies however used the 3D data to investigate stability around joints, rather than the variation in degrees of motion. Nicholson and colleagues (2001) used a very simple marker set consisting of 11 markers placed over the trunk, shoulder, elbow, wrist, thumb and finger. Although Rennie and colleagues (2000) chose a more comprehensive and standardised marker set developed by Davis, they used the data across all three planes to measure stability at the pelvis, choosing to analyse the sagittal plane only around the hip, knee and ankle.

2.4 SUMMARY OF WHAT IS KNOWN AND GAPS IN THE EVIDENCE BASE

The review of the research carried out has highlighted the paucity of scientific knowledge surrounding lycra suits and garments and how, or if, they work for patients in a positive manner. This is particularly surprising as lycra garments are becoming an increasingly popular therapy option, despite most of the observations relating to their success being purely anecdotal. With the cost of lycra suits and garments being between £200 and £600 patients and their families are spending a lot of money with no real evidence base for their effect. Overall the garments and suits were found to illicit improvements in more children than negative effects or no effect at all (Blair et al, 1995; Nicholson et al, 2001; Rennie et al, 2000). Increased postural stability appears to be the most common improvement found, which in turn allowed for more controlled upper body movements (Blair et al, 1995; Gracies et al, 2000; Nicholson et al, 2001; Rennie et al, 2000). The results of the studies did highlight differences in response to the garments and suits varied greatly between children. Nicholson and colleagues (2001) found that children with ataxia and athetosis had increased smoothness of movement and improved fine motor control and those with spasticity showed a slight decrease in hypertonia. However the study was too small to show whether this pattern was standard for the different types of cerebral palsy, or whether it was just coincidence between the 12 children tested. Rennie and colleagues (2000) also reported that the improvements found in proximal stability brought about by the lycra suits varied greatly between the individual children.

There is sufficient evidence throughout the studies to suggest that the fitter of the garment has an effect on how well the garments work. The effects of the lycra suits and garments are significantly improved when fitted by a trained individual (Gracies et al, 1997). The effect of the garments were also found to dissipate over a 6hr period of wear, most likely due to the garment shifting over time due to body movement. This highlights the importance of the garment placement, and it seems necessary to ensure that carers and parents be trained in the fitting of the suit to ensure correct positioning and therefore optimal effect at all times. Finally evidence was found that the effects given by the garments may ‘carry over’ providing a lasting effect after removal (Blair et al, 1995).

Overall the research findings to date are very limited, though there is evidence that lycra suits increase postural stability in some children, assisting upper limb function, little else has been investigated. Only one study has investigated the effect of lycra garments on gait, and despite the availability and frequent use of 3D motion analysis, the data gathered in the studies are still limited to the sagittal plane only. The 3D motion data has been used to define the level of stability around joints, but has not been used to report changes in angular motion, or rotation around joints, which are often the more obvious cause of crouch gait in those with cerebral palsy (Whittle, 2007). More research is therefore needed to define how the lycra garments and suits improve movements, and also to what extent.

3. METHODOLOGY

3.1 RESEARCH QUESTION- AIM AND OBJECTIVES

The aim of this project was to evaluate the effectiveness of Lycra Suits in children with Cerebral Palsy during walking. This project allowed insight as to whether Lycra Suits bring about changes in joint control towards a more normal gait, therefore revealing the fitness for purpose of Lycra Suits in lower limb and pelvic function.

Objectives

To determine whether full body Lycra Suits bring about changes towards a normal gait pattern.

- To determine any possible changes at the hip, knee and ankle in the sagittal plane throughout the gait cycle
- To determine possible changes in inward rotation at the hip throughout the gait cycle
- To determine whether the effects of the suit change after a three month period of wear.

3.2 PROPOSED MULTIPLE SINGLE-CASE EXPERIMENTAL DESIGN

The investigation consisted of a laboratory based exploratory study consisting of multiple single case experiments following a within subject cross over design at two separate time-points.

3.2.1 RATIONALE- STRENGTHS OF THIS DESIGN TO ADDRESS THE RESEARCH AIMS

The series of single case experiments was chosen as there is such a wide variation between the participants CP presentations. The CP presentations even vary within CP type and level so grouping the participants would be very difficult, especially with the small numbers of subjects that were likely to be recruited for this MPhil project.

The single cases also meant that if any testing sessions are missed by the participants then their data can still be reported, this is especially important as compliance in such groups can be low due to age, possible discomfort and study length.
The testing was carried out in the movement laboratory at UCLan. Although the cameras are portable a large space is required for their set-up, and lighting conditions need to be regulated to ensure optimal data capture. The laboratory is the therefore the most suitable location and also ensured that the testing conditions were reproducible.
The initial walking assessment carried out prior to the Lycra Suit fitting acted as the baseline measurement from which change was established. During assessment the children wore their usual orthotic boots and their ankle-foot orthotics during all trials to ensure any changes found were brought about by the wearing of the Lycra Suit. They also used any walking aid, such as a frame or sticks which they used on a day-to-day basis (see table 4.1).

4. METHODS

4.1 SUBJECTS

Eleven children (nine male and two female) with Cerebral Palsy or similar neurological disorders (see table 4.1) were recruited to participate in the study. The children ranged in age from 2yrs to 9yrs old. Inclusion criteria consisted of GMFCS measures of I-III and who are able to stand and walk independently with or without support. In addition, children who had undergone surgery or Botox treatment within 12months prior to testing were excluded from taking part. The children were all prescribed the bespoke Lycra Suits as part of their treatment, in addition to their on-going physiotherapy program.

Ethical approval was sought from the University of Central Lancashire ethics committee, and NRes the NHS research ethics service. Written informed consent was obtained from the older children, and from the parents of the younger children and those with learning difficulties (see appendices1-3).

The patients were recruited through the Paediatric Physiotherapy Service based at Reedley Hall, Burnley. The children were not paid to take part in the study, however they were provided with the Lycra Suits, which range in price from £200 to £600, for free and were able to keep their suit after the end of the study. The research was funded by DMO orthotics who manufacture the lycra suits, however all research was funded without any involvement from the company other than fitting the children with the suits. Parents were very keen for their children to take part in the study and as a result recruitment was non-problematic. No subjects dropped out from the testing, however it was decided that participant number 3 should not return for the second testing session as he had found the initial testing particularly stressful. Data for participants 7 and 8 were of poor quality so were not reported, however their data from the initial testing session as included. It is unclear if the promise of the free Lycra Suits was the major incentive for some parents choosing to allow their children to be included in the study. Written informed consent was obtained from the child’s parents or guardians prior to participation in the study.

Table 4.1. Patient Demographic Information

Patient No.	Sex	Age (yrs)	Diagnosis	GMFCS level	GMFM score	Assistive walking device
1	M	2	Ataxic CP	II	85%	Hand Held
2	M	5	Hemiplegia-left side	I	85%	N/A
3	M	10	Dystonia-lower limbs	III	54%	Walking Sticks
4	M	5	Diplegic CP	III	80%	Walking Sticks
5	F	11	Mild Diplegia	II	85%	N/A
6	M	3	Developmental Delay	II	87%	Walking Frame
7	M	8	Spastic Diplegia	II	87%	N/A
8	M	4	Spastic Diplegia	II	74%	Walking Frame
9	M	3	Spastic Diplegia	II	70%	Hand Held
10	M	9	Hemiplegia-left side	I	94%	N/A
11	M	2	Hemiplegia- left side	I	71%	Hand Held

4.2 PROCEDURES

The testing procedures followed a within subject cross over design at two separate time points as shown in Table 4.2. The results will be reported as a series of single case studies.

Table 4.2. Study Design

Initial Testing		Three Months	
No Suit	With Suit	With Suit	No Suit

Patients were individually measured for the Lycra Suits by a trained physiotherapist who works for DM Orthotics Ltd, the manufacturers of the suits. This took place during one of the patients' regular physiotherapy appointments at Reedley Hall 2-3 weeks prior to the first testing session.

<u>Week 1</u>- The patients were initially tested without the Lycra Suit (NIni). They were tested again once they had put the Lycra Suit on for the first time (SIni).
The participants were then asked to wear the suit as in normal clinical practice for the next twelve weeks, whilst continuing their usual daily activities and physiotherapy treatments.

<u>Week 12</u> - The participants were assessed firstly whilst wearing the Lycra Suit (S3), and then immediately after removing the suit (NS3).

Testing involved the patients performing three repetitions of a 10m walking test, three gait cycles were extracted from each trial, resulting in 9 gait cycles for analysis in each condition. The patients walked at their usual comfortable walking speed throughout the testing.

The initial testing of the patients before the introduction of the suit was used as the baseline control. The measurements taken immediately after the patients had first put the suits on explored whether there were any immediate effects on gait patterns caused by wearing the suit. During the second visit to the Movement Analysis Laboratory the patients were tested initially with the suit, to determine whether there had been any improvement caused by wearing the suit for a prolonged period. The testing of the patients without the suits aimed to discover whether there were potentially any lasting effects from the suits after their removal.

4.3 DATA COLLECTION

Movement analysis data was be carried out using a 10 camera ProReflex motion analysis system (Qualysis Medical AB, Sweden) at 200Hz. The cameras work by emitting infra-red light, and then recording the reflection from the retro-reflective markers which are placed on the patients. The cameras were arranged to encircle the entire 10m walkway, as shown in Figure 4.3a.

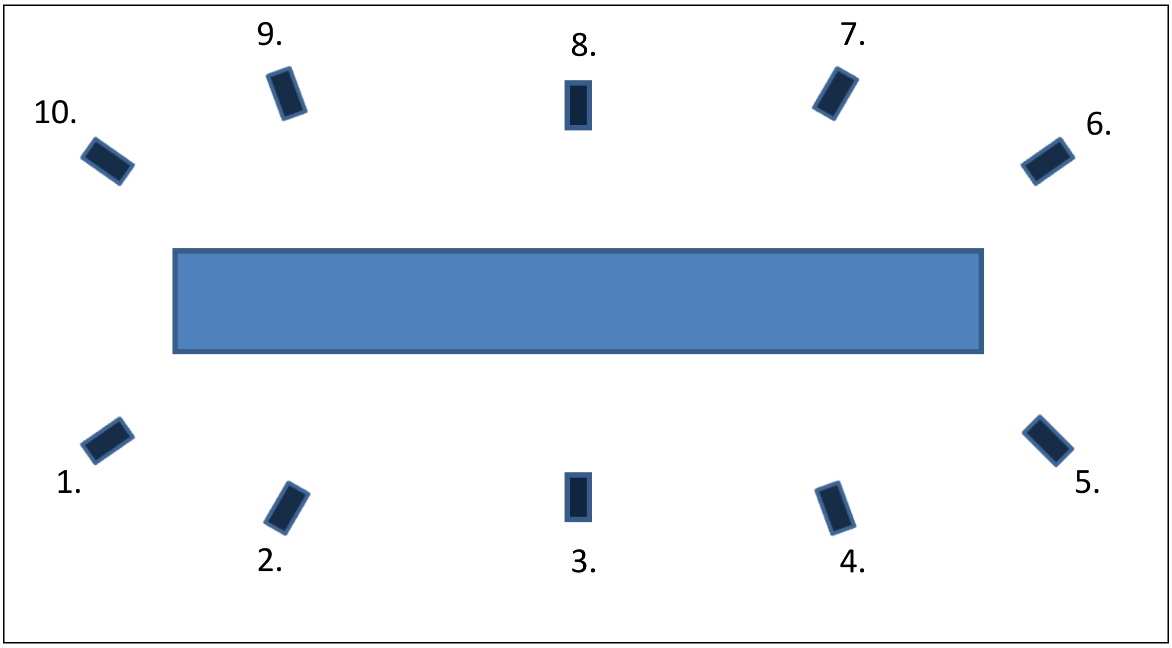

Figure 4.3a Camera Arrangement

One camera was placed either side of the walkway to capture the marker movement from the sides (cameras 3 and 8). These were placed around head height of the patient being tested. The cameras towards the ends of the walkway were placed at increasing heights from the centre cameras, this allowed them to capture over a longer distance, ensuring a full gait cycle was obtained, and from different angles to reduce the chances of marker occlusion. Dynamic calibration was carried out using the small calibration wand; the distance between the markers is known to be 300m. Any calibrations above 1mm error were discarded to ensure accuracy.

The marker placement used was based upon the Calibrated Anatomical Systems Technique (CAST) (Cappozzo et al, 1995). Static ‘anatomical calibration’ markers were placed bilaterally on the shoulder (acromion process), ASIS, PSIS, hip (greater trochanter), knee (lateral epicondyle,) ankle (lateral malleolus), heel (calcaneous) and foot (1^{st}, 2^{nd} and 5^{th} metatarsal head) (See figure 4.3b).

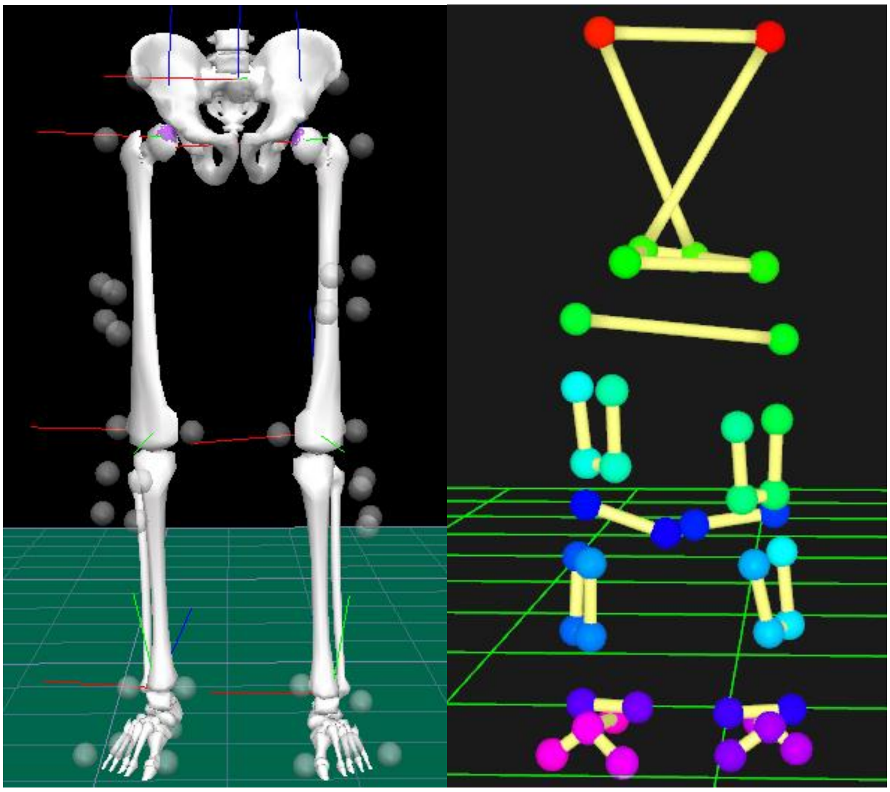

Figure 4.3b Static views of the marker placement in Vis3D (left) and QTM (right)

These serve to identify the proximal and distal ends of each body segment (Capozzo, 1997). Rigid cluster plates with four reflective markers attached were positioned on each of the thighs and shanks and were fixed in place using elasticated bandage. The bandage was used across all conditions in the same position, ensuring that any change detected was brought about by the introduction of the suit alone. This allowed a three dimensional analysis of full body movement during the gait analysis. The standard clusters used within the Biomechanics Laboratory were too large to fit on the thighs and shanks of the smaller patients.

Figure 4.3c Bespoke marker clusters made for the testing.

As a result it was necessary to make smaller clusters. Rectangular pieces of fibreglass casting bandage (Delta-Lite Plus, Smith and Nephew, NZ) were formed around the forearm to recreate the shape of the thigh and tibia on the smaller patients. Four markers were then placed on the corners of the fibreglass plates to create rigid marker clusters (figure 4.3c).

4.4 DATA ANALYSIS

3D data were tracked using the Qualysis Track Manager (Qualysis AB, Gothenburg, Sweden) as .qtm files. Each marker was manually labelled, then checked frame by frame throughout each file to ensure there was no drop-out or crossing over of the markers as they were placed so close together. This was especially needed on the data captured for the smaller children. This method was repeated for each individual static and movement file. The cardan sequence X-Y-Z was applied to all joints (Sinclair et al 2010, Sinclair et al, 2011).

Once the data had been fully tracked it was then exported as .c3d files to be opened in the Visual3D (C-Motion, Inc. USA) software. The data were filtered with a 4th order zero-lag Butterworth filter (Winter, 1990) with a cut-off frequency of 6Hz, which is regularly used for gait data as the signals produced are relatively low, usually around

1Hz (Vaughan, 1982). This allows excess signal noise to be removed whilst causing minimal interference to the movement signal.

Heel strike and toe off were manually identified from the movement files by scrolling through each file frame by frame and identifying the points of foot contact (heel-strike) and the foot leaving the floor (toe-off). This was necessary as the Visual 3D software was unable to define the gait events automatically due to the abnormal gait patterns captured. Force data and kinematics were also unable to assist in identification of events due to the abnormality of gait patterns recorded.

Ankle rockers were defined as-
1st rocker- in normative participants this would be the plantarflexion of the foot following heelstrike to bring the foot flat to the floor. In those with CP this may present as dorsiflexion due to toe-strike rather than heel-strike caused by equinus or there may be no movement due to a flat-footed floor contact. As a result the first rocker was defined as the movement occurring around the ankle joint between floor contact and the foot becoming flat on the floor.
2nd rocker- Defined as the movement of the tibia over the foot during weight bearing.
3rd rocker- in normative participants this would be plantarflexion of the ankle prior to toe-off, however as many of the children presented with reduced plantarflexion due to their AFOs and did not present with a clear toe off. This was defined as the change in ankle angle prior to the foot leaving the floor.

Data was then exported to Excel, where the mean values for joint angles in X-(sagittal plane, flexion and extension); Y (coronal plane- abduction and adduction) and Z (transverse plane, internal and external rotation) across the three trials were used to identify changes at the hip, knee and ankle joints across all testing variables.

4.5 PRESENTATION OF RESULTS

The study design of single case studies means it is vital that the results for each participant are presented individually. Each participant will have an individual and comprehensive results section concentrating on the findings for them in particular. To present the findings as group data would make for a more condense results section, but would negate the principles addressed by carrying out a single case study design, such as lack of homogeneity across subjects, and small sample size. The individual results sections will be followed by a short summary highlighting any trends that may have occurred across the group overall.

Data for each individual was reported by statement of change in degrees, as used in previous studies reporting joint angle during gait (Flanagan et al, 2009; Provost et al, 2007). The minimal clinically important difference (MCID) for changes in joint angle in CP gait is unknown, however the possibility of angle changes being caused by marker movement were reduced by ensuring the same person placed the markers for each testing, and the data was filtered, a method also carried out by Flanagan and colleagues (2009). As there is no normative data available for the CP population the ranges of motion around the joints presented in the following graphs of age-matched normal children were taken as reference points. A change in joint angle towards what is normally found in age-matched data was interpreted as a positive change; conversely a change in joint angle away from this was interpreted as a negative change.

The report for each individual participant will be concluded with a summary of findings table and short discussion addressing the possible implications of any changes in joint angle for the participant. Summary of findings tables have been found to assist the reader in finding key information and understanding results more correctly (Rosenbaum et al, 2009), and are recommended to be included in systematic reviews submitted to the Cochrane Review (Higgins & Green, 2009). Ankle plantarflexion and dorsiflexion was reported in relation to the ankle angle at heelstrike to show changes in functional movement. Maximal flexion and extension at the knee during the gait cycle was reported in relation to the knee angle at heel strike to show changes in functional movement. By assuming the angle of the ankle and knee at heelstrike to be 0° the trials could be standardised and movement patterns compared more easily. Maximal hip flexion and extension was reported alongside angle at heelstrike rather than in relation to it. This was due to the angles at maximal flexion and heelstrike being close due to crouch gait found in most CP patients that flexion appeared minimal or non-existent.

Hip range of motion (ROM) was reported as the difference between the angles at maximal internal and maximal external rotation reached throughout the entire gait cycle.

The results recorded in the participants aged 2, 3, 4 and 5 years of age were compared to the following graphs from Sutherland et al (1988) which depict the normative ranges found in children at those ages. Sutherland and colleagues carried out extensive investigations into the changed of gait during early childhood, this allowed the differences in gait brought about by the development of mature walking to be taken into account. Again the developmental process within CP children may be delayed; however there is no normative data for CP children to use as a comparison.

Age 2 Years

The following graphs from Sutherland et al (1988) show normative values for children of 2yrs old, and are used as a reference for the data collected on 2yr old participants.

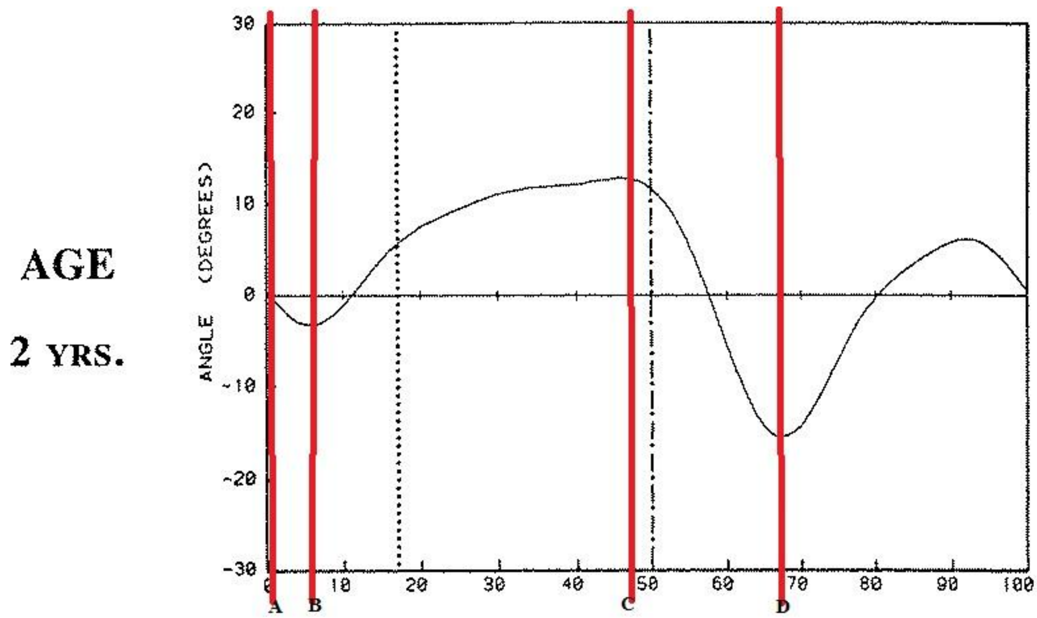

Figure 4.5a. Plantarflexion and dorsiflexion of the ankle joint in a 2 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Minimal angle at plantarflexion, C- Maximum angle at dorsiflexion, D- Minimal angle at plantarflexion

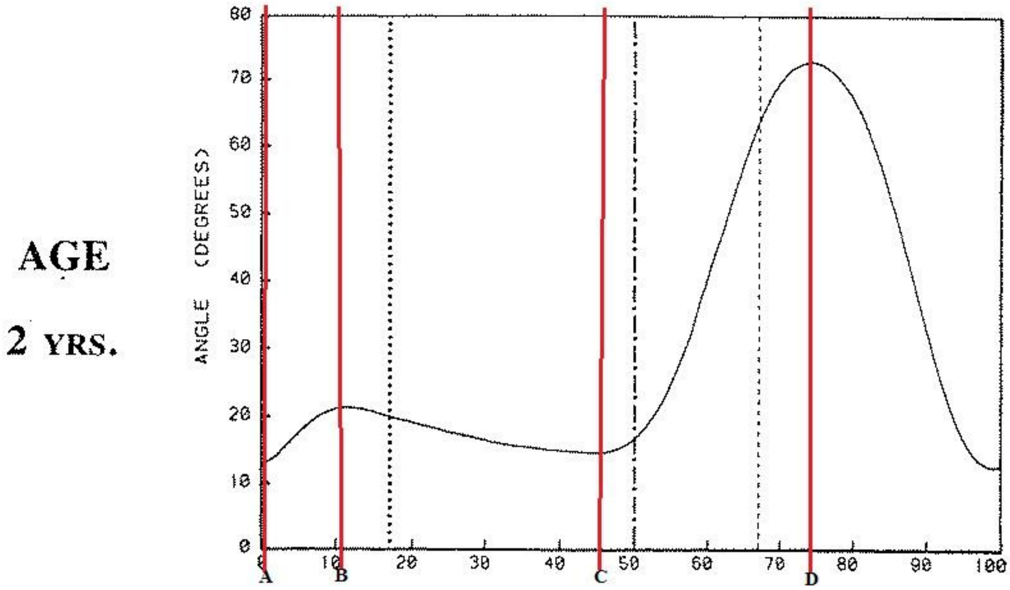

Figure 4.5b Knee joint flexion pattern in sagittal plane in a 2 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Maximal flexion during weight-bearing, C- Minimal angle at extension during stance phase, D- Maximal flexion during swing phase.

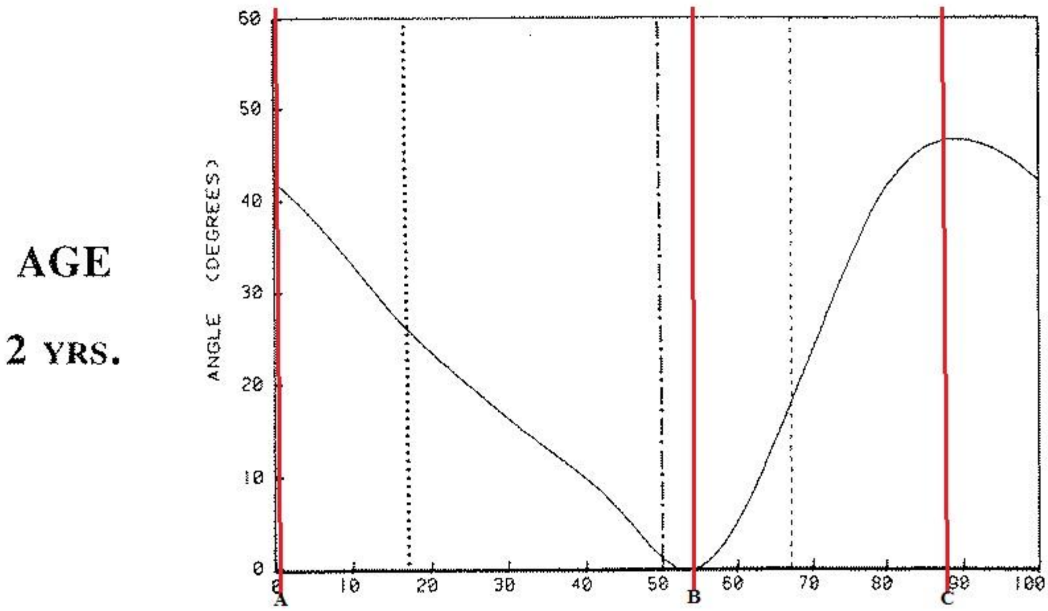

Figure 4.5c Motion of the hip joint in the sagittal plane in a 2 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Maximal extension, C- Maximal flexion

ROM at the hip was taken from maximal internal rotation of 5° to a maximal external rotation of -13°, a total of 18° in normative 2yr old children (Sutherland et al, 1988).

Age 3 Years

The following graphs from Sutherland et al (1988) show normative values for children of 3yrs old, and are used as a reference for the data collected on 3yr old participants.

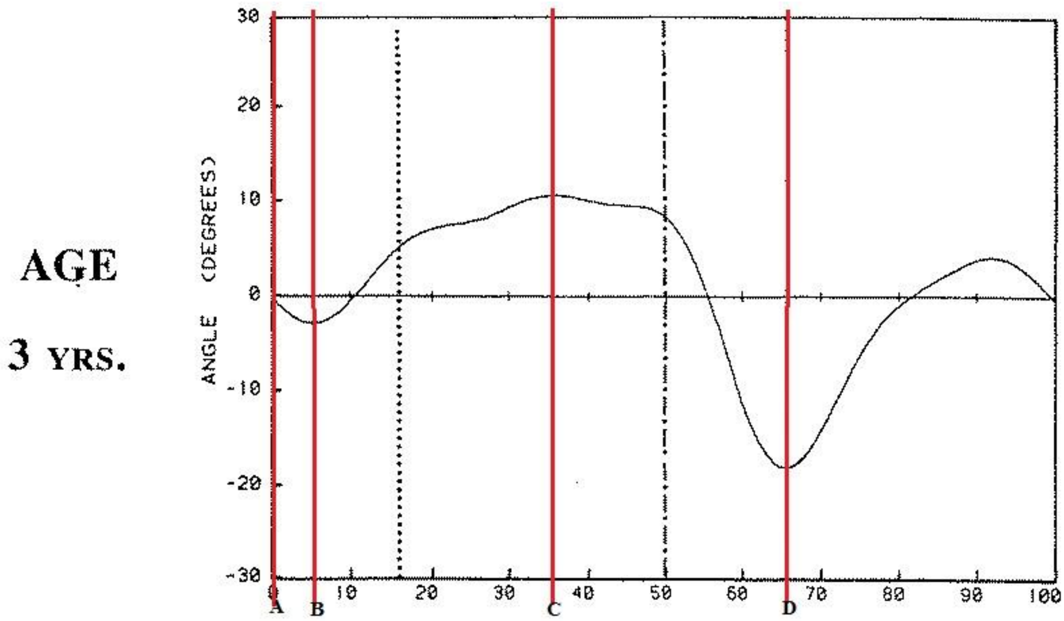

Figure 4.5d Plantarflexion and dorsiflexion of the ankle joint in a 3 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Minimal angle at plantarflexion, C- Maximum angle at dorsiflexion, D- Minimal angle at plantarflexion

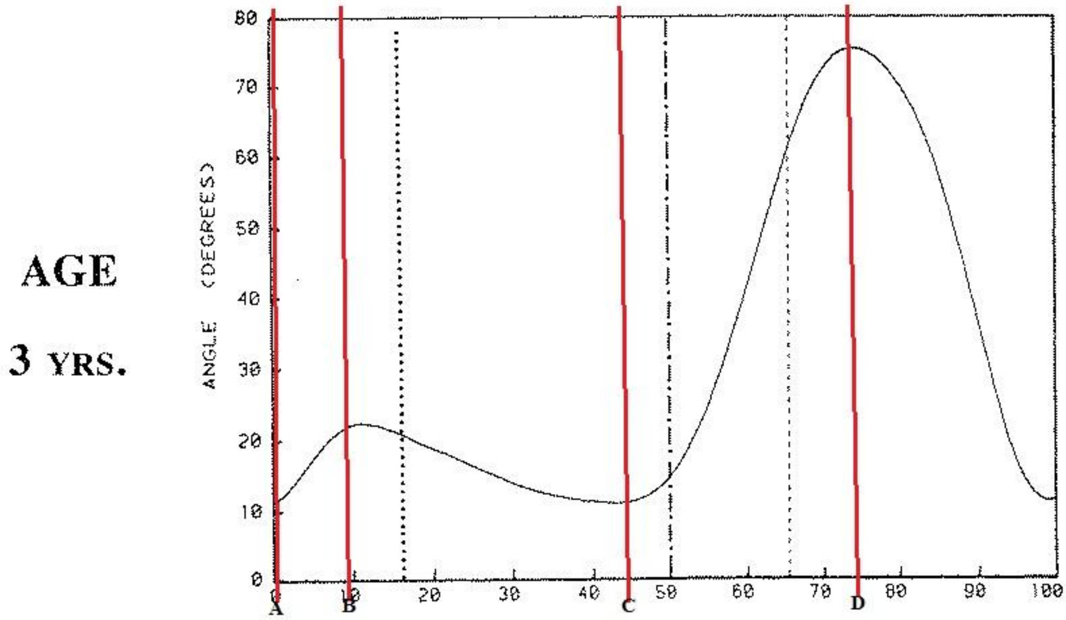

Figure 4.5e Knee joint flexion pattern in sagittal plane in a 3 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Maximal flexion during weight-bearing, C- Minimal angle at extension during stance phase, D- Maximal flexion during swing phase.

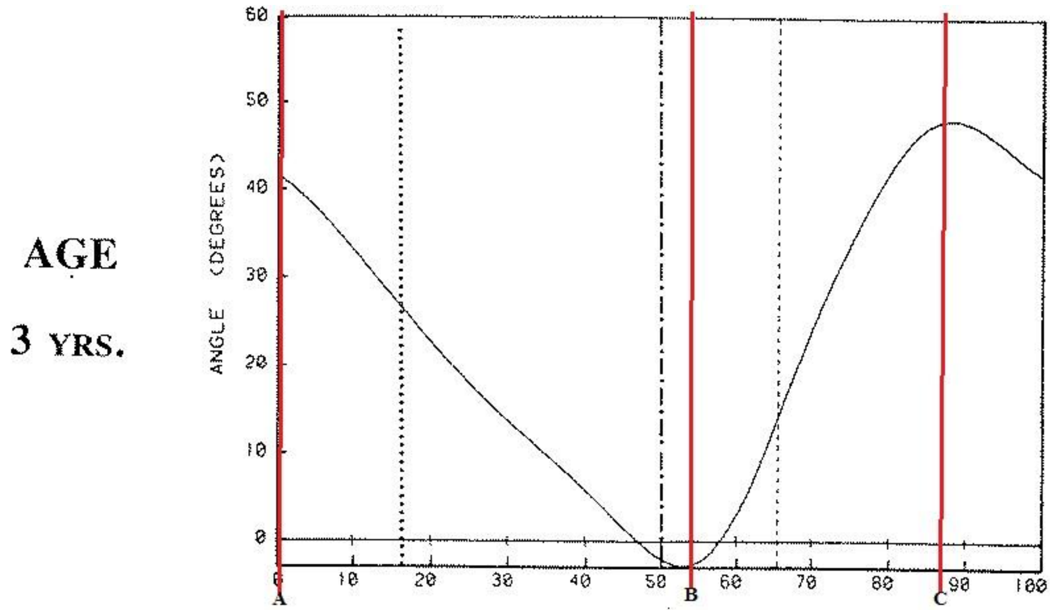

Figure 4.5f Motion of the hip joint in the sagittal plane in a 3 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Maximal extension, C- Maximal flexion

ROM at the hip was taken from maximal internal rotation of 8° to a maximal external rotation of -10°, a total of 18° in normative 3yr old children (Sutherland et al, 1988).

Age 4 Years

The following graphs from Sutherland et al (1988) show normative values for children of 4yrs old, and are used as a reference for the data collected on 4yr old participants.

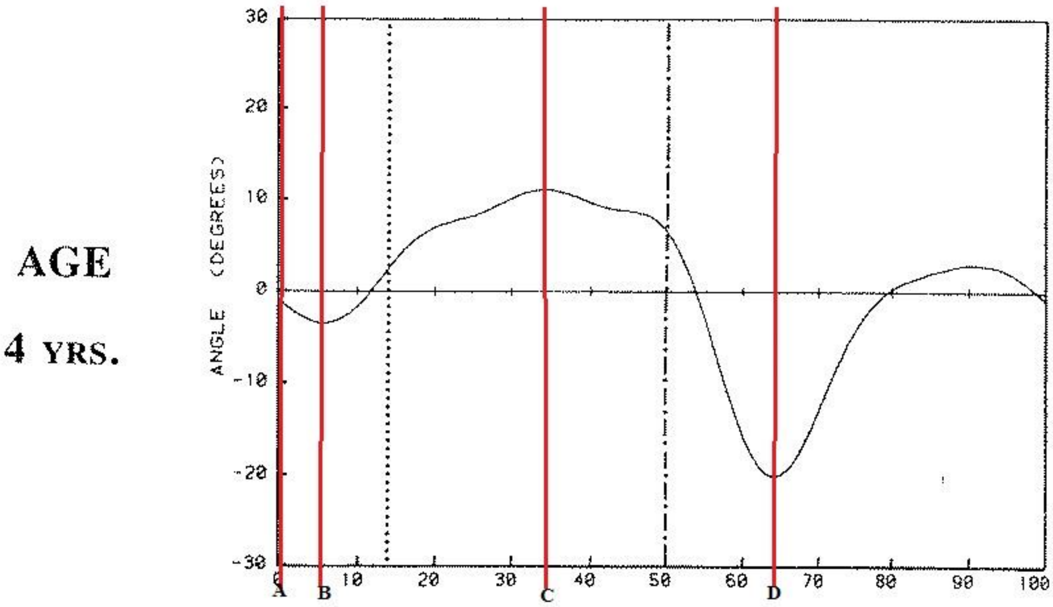

Figure 4.5g Plantarflexion and dorsiflexion of the ankle joint in a 4 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Minimal angle at plantarflexion, C- Maximum angle at dorsiflexion, D- Minimal angle at plantarflexion

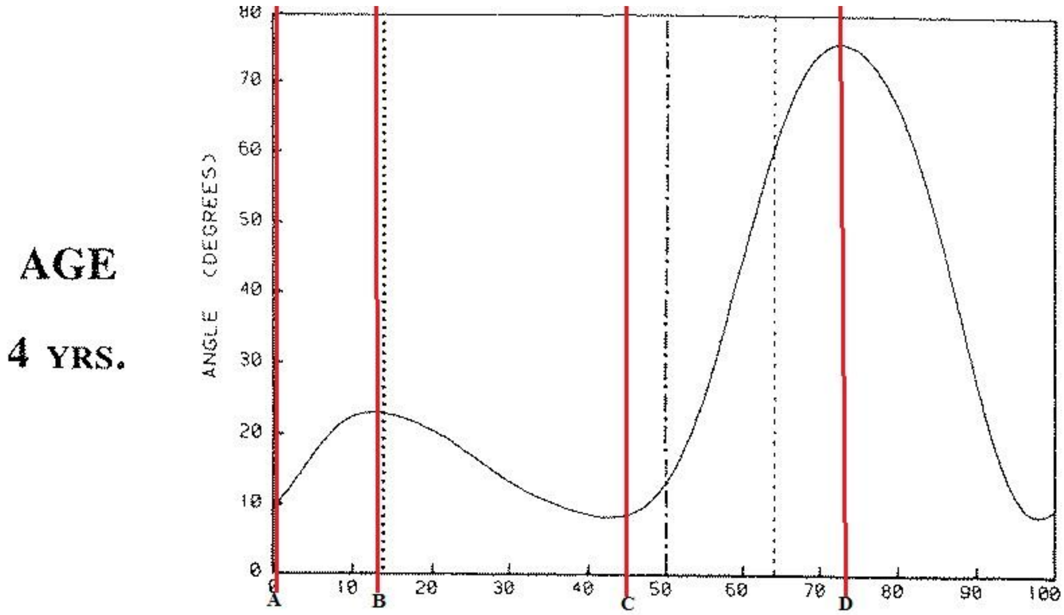

Figure 4.5h Knee joint flexion pattern in sagittal plane in a 4 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Maximal flexion during weight-bearing, C- Minimal angle at extension during stance phase, D- Maximal flexion during swing phase.

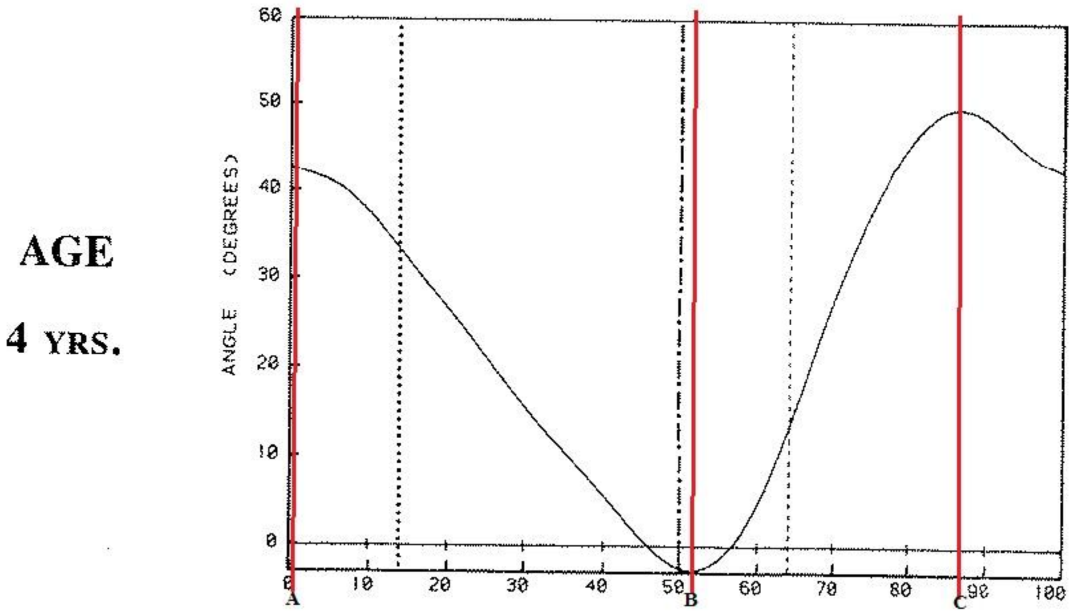

Figure 4.5i Motion of the hip joint in the sagittal plane in a 4 year old child (from Sutherland et al, 1988)

Heel strike, B- Maximal extension, C- Maximal flexion

ROM at the hip was taken from maximal internal rotation of 7° to a maximal external rotation of -10°, a total of 17° in normative 4yr old children (Sutherland et al, 1988).

Age 5 Years

The following graphs from Sutherland et al (1988) show normative values for children of 5yrs old, and are used as a reference for the data collected on 5yr old participants.

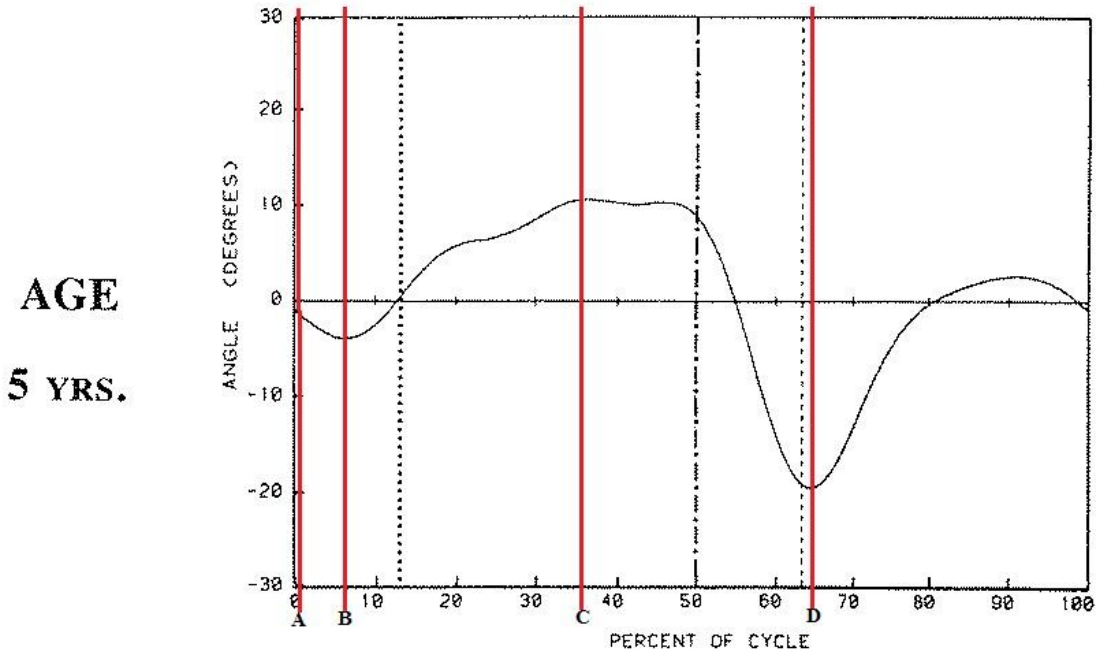

Figure 4.5j Plantarflexion and dorsiflexion of the ankle joint in a 5 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Minimal angle at plantarflexion, C- Maximum angle at dorsiflexion, D- Minimal angle at plantarflexion

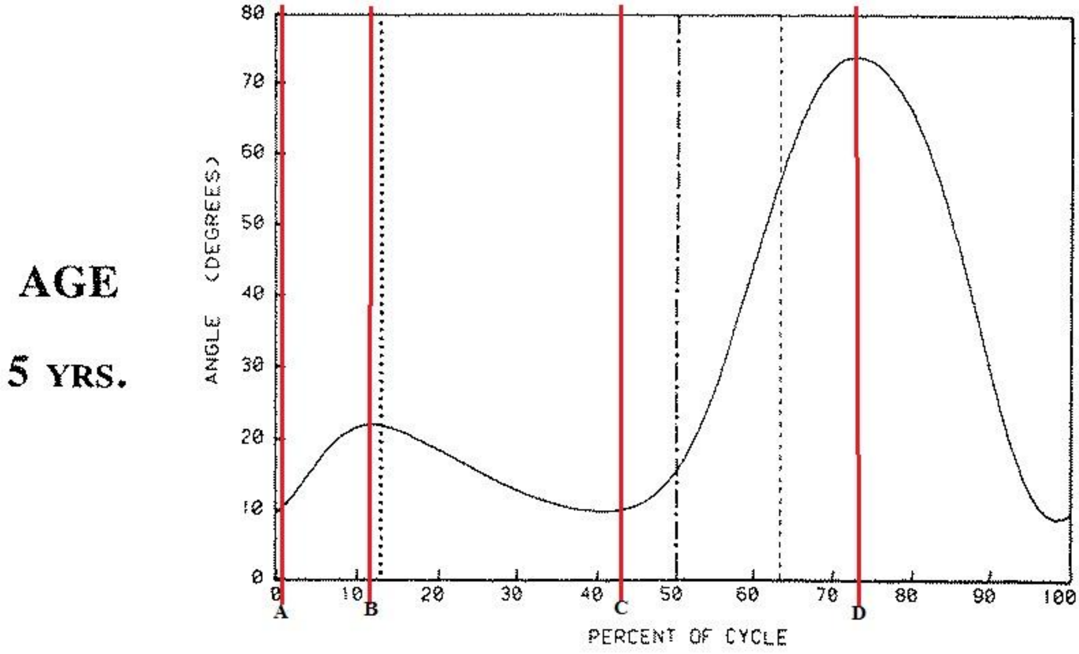

Figure 4.5k Knee joint flexion pattern in sagittal plane in a 5 year old child (from Sutherland et al, 1988)

A- Heel strike, B- Maximal flexion during weight-bearing, C- Minimal angle at extension during stance phase, D- Maximal flexion during swing phase.

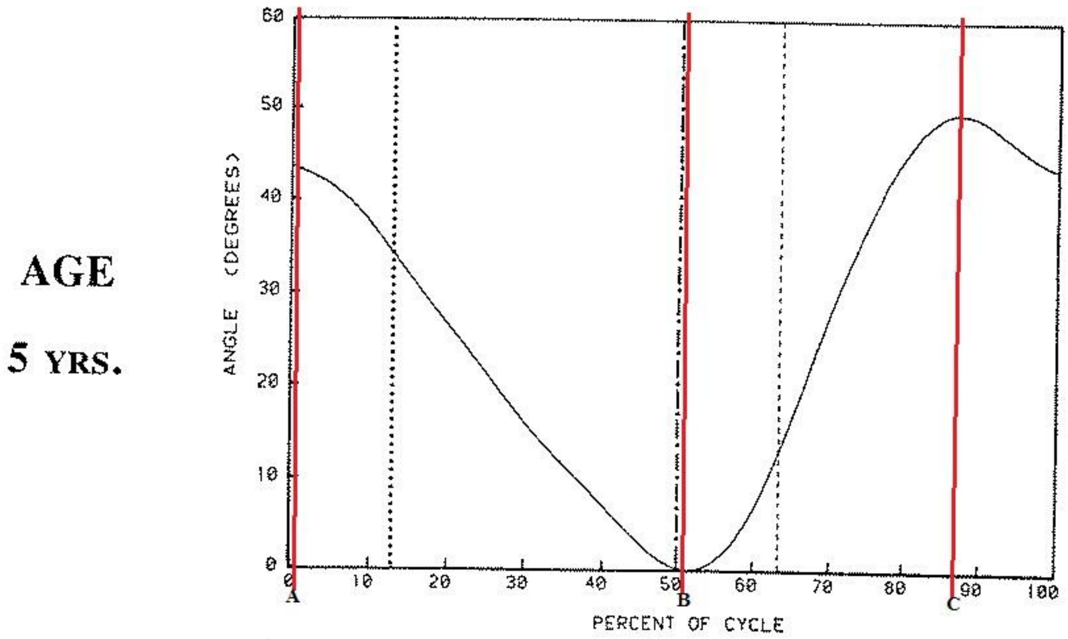

Figure 4.5l Motion of the hip joint in the sagittal plane in a 5 year old child (from Sutherland et al, 1988)

A-Heel strike, B- Maximal extension, C- Maximal flexion

ROM at the hip was taken from maximal internal rotation of 6° to a maximal external rotation of -8°, a total of 14° in normative 5yr old children (Sutherland et al, 1988).

Age 8 years and above.

Joint angle at specific points in the gait cycle were identified as shown in the graphs below. The following graphs, from Richards (2008), were used as a reference point for normative ranges to compare the data from children aged 8yrs and above.

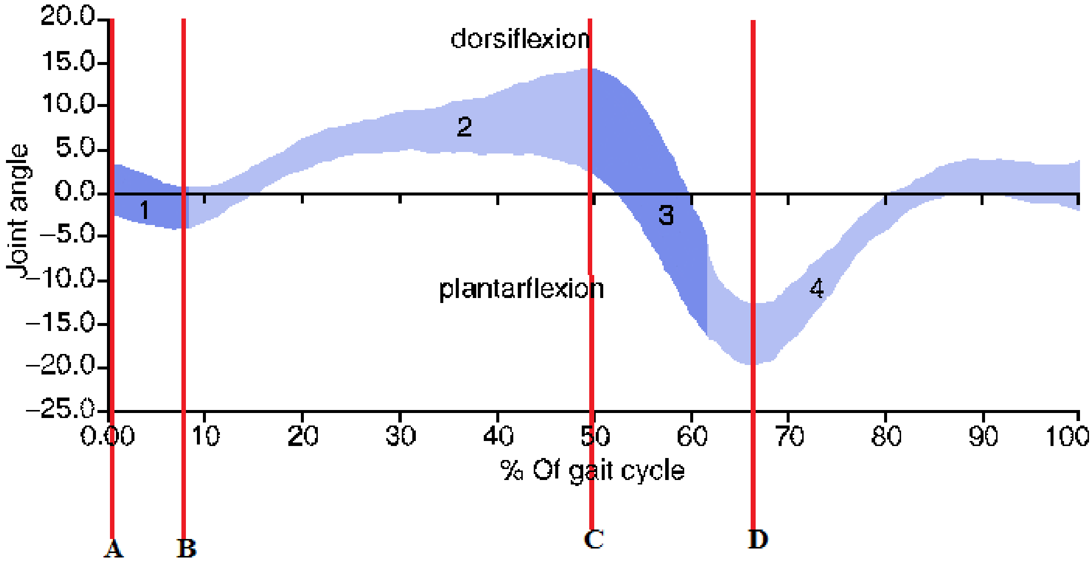

Figure 4.5m Plantarflexion and dorsiflexion of the ankle joint (from Richards, 2008)

A- Heel strike, **B**- Minimal angle at plantarflexion, **C**- Maximum angle at dorsiflexion, **D**- Minimal angle at plantarflexion

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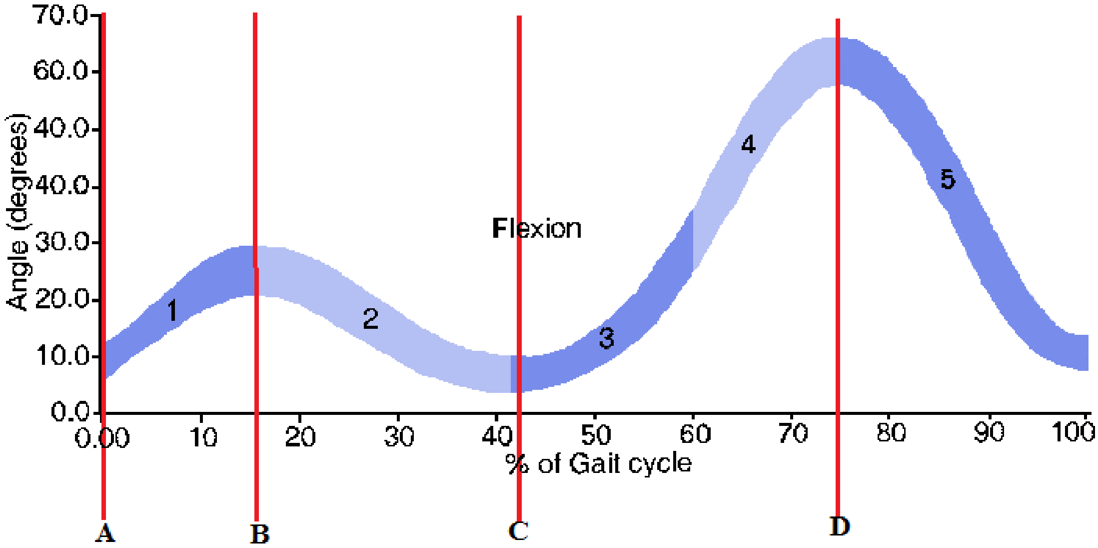


Figure 4.5n Knee joint flexion pattern in sagittal plane (from Richards, 2008) A-Heel strike, B- Maximal flexion during weight-bearing, C- Minimal angle at extension during stance phase, D- Maximal flexion during swing phase.

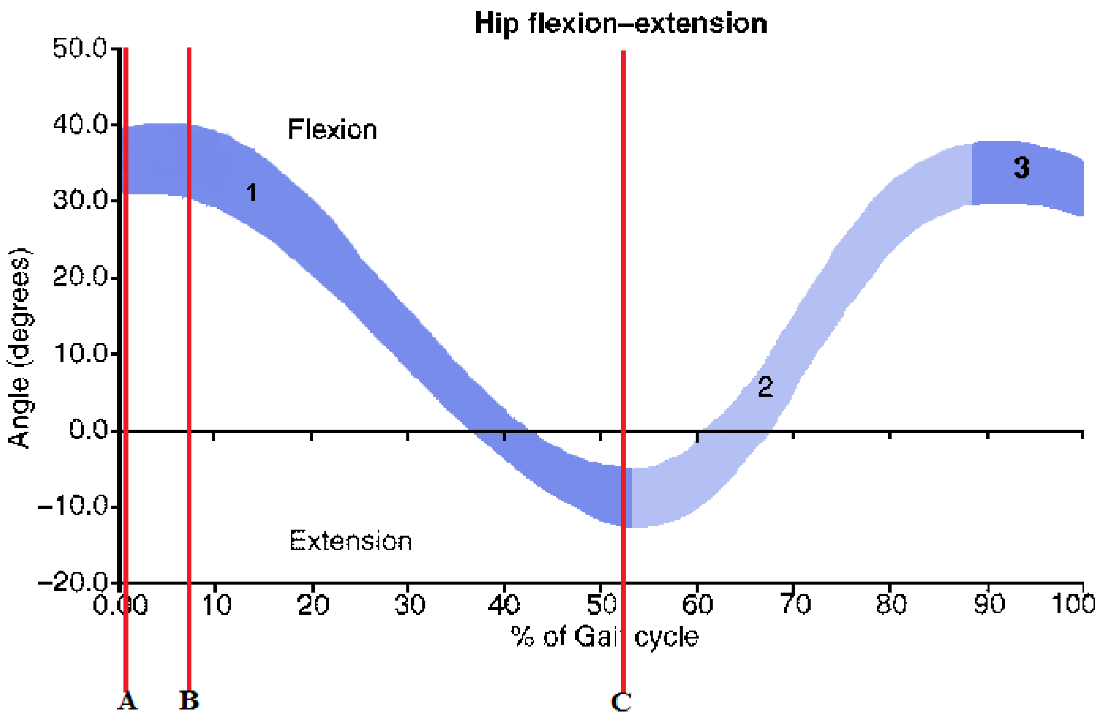


Figure 4.5o Motion of the hip joint in the sagittal plane (from Richards, 2008) A- Heel strike, B- Maximal flexion, C- Maximal extension

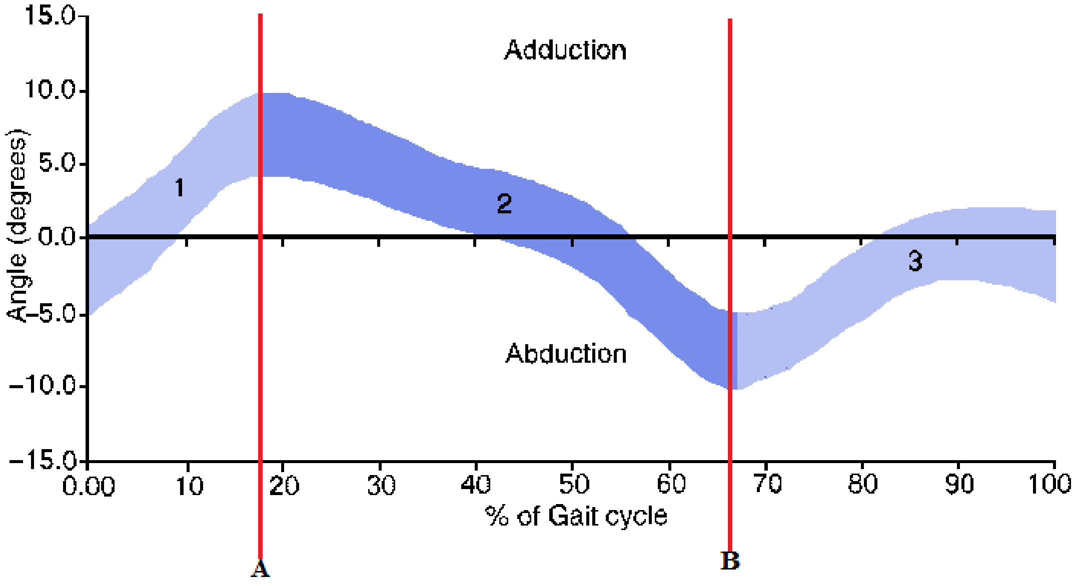


Figure 4.5p Motion of the hip joint in the coronal plane (from Richards 2008)

A- Maximal adduction, B- Maximal abduction

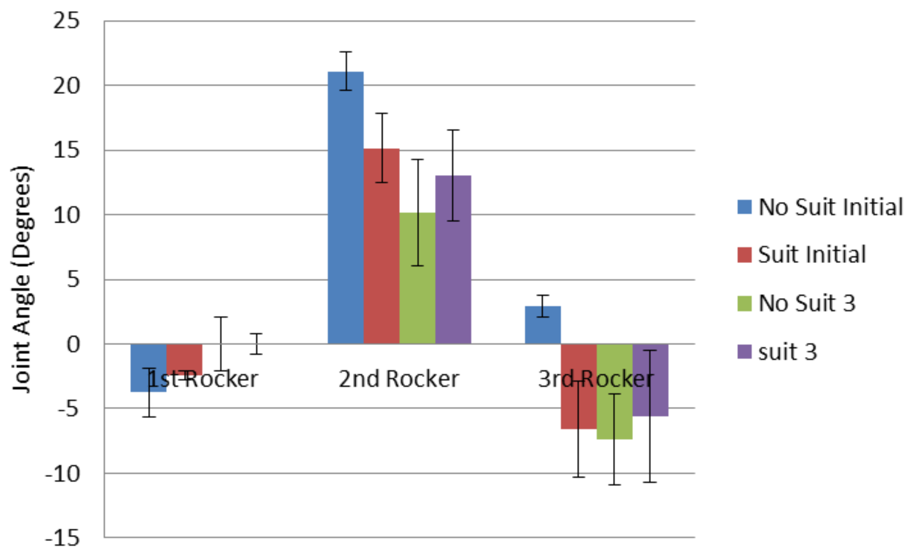
ROM at the hip was taken from maximal internal rotation of 5° to a maximal external rotation of -10°, a total of 15° in normative 8yr old children and above (Richards, 2008).

5. RESULTS

5.1 INDIVIDUAL PARTICIPANT REPORTS

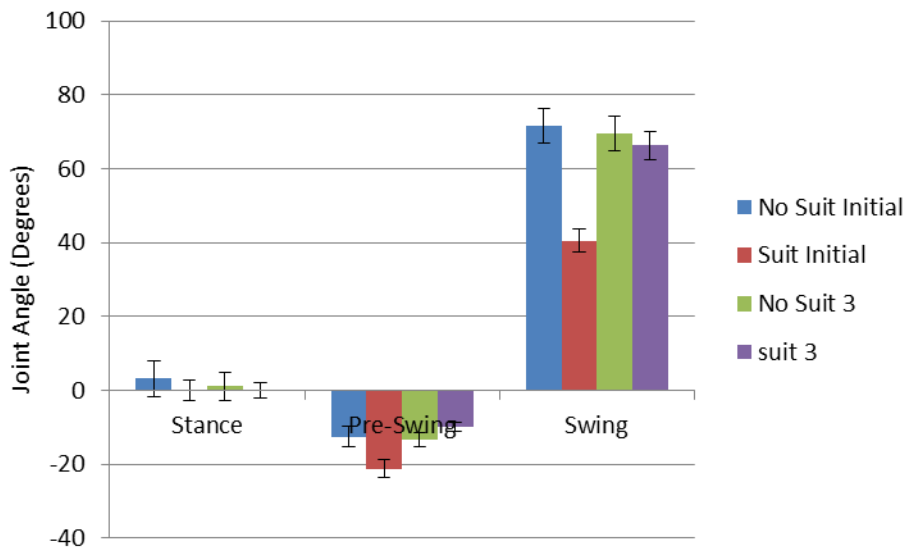
5.1.1 PARTICIPANT 1- A 2YR OLD WITH ATAXIC CP

Right Leg- Affected



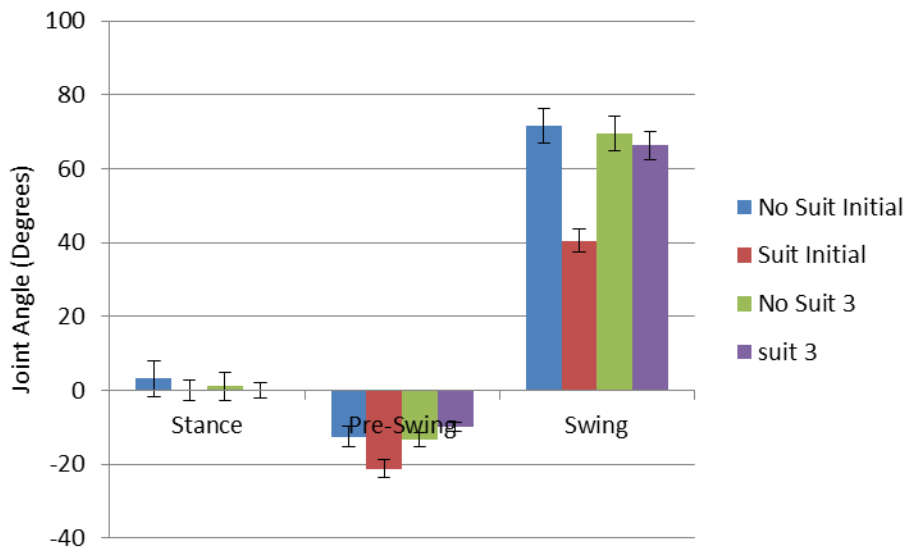
Graph 5.1 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Ankle angle at heel strike and 1st rocker are the same after three months, during both NS3 and S3 (see graph 5.1). This suggests a flat-footed floor contact. During the second rocker the 21.06° movement is much higher than the 11° found in the normal population (see figure 4.5a). After 3 months the angular motion has decreased to 10.14° during NS3, showing greater control. As the ankle moves into plantar flexion during the 3rd rocker the ankle would be expected to reach around -15°, although the angles found here are less the greatest increase is found again during NS3 (see graph 5.1).



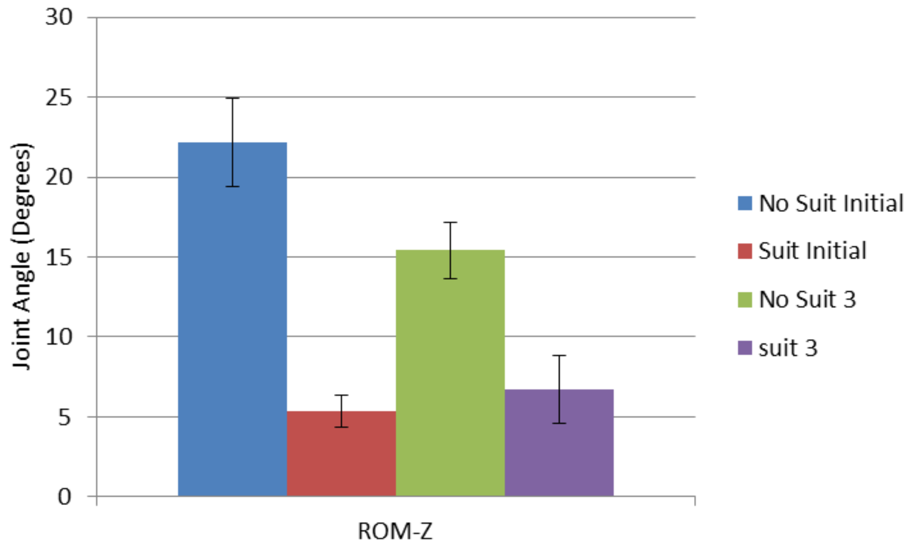
Graph 5.2 Maximum and minimum affected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance phase, compared to that at heel strike is minimal, across all conditions compared to the 21° found in age-matched normal subjects (see figure 4.5b). The extension during the pre-swing phase is higher than seen in the normal population, especially at SIni, though this is due to re-extension following crouch gait at heel-strike. Knee flexion during the swing phase is only 5°-10° higher than that at heel strike, during NIni they were 11.72° more than the normative range of 60° at 71.72° (see graph 5.2).



Graph 5.3 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

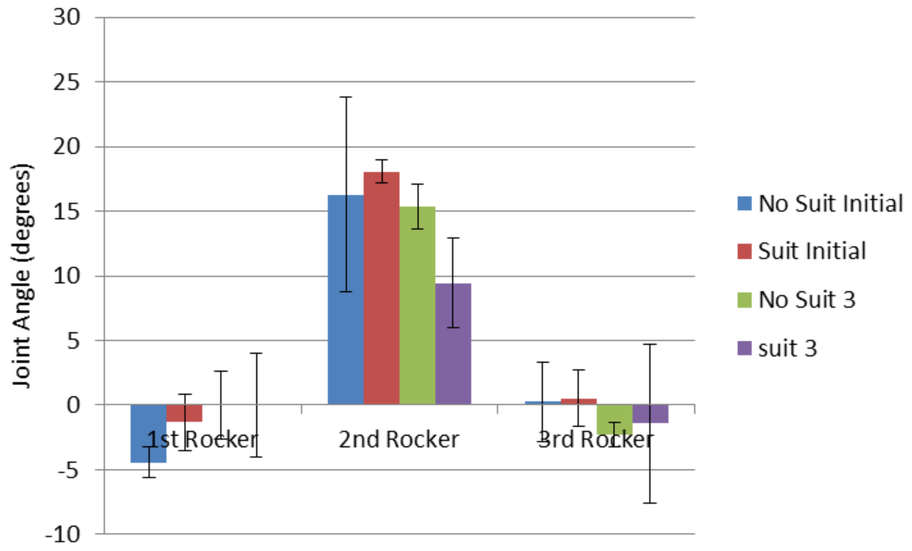
Maximal hip flexion usually occurs at heel-strike; however, as seen in graph 5.3, the hip continues to flex for a further 17°-19° during maximal flexion in NIni, which is usual of crouch gait. Hip extension would be expected to reach -12° in normal age matched subjects (see figure 4.5d), but all conditions show much less. This is especially apparent during 3NS where the hip is remaining flexed at 5.86°. Maximal flexion was shown to be reduced during SIni reaching 29.66°, which is a 20° reduction from NIni. A similar pattern is evident after 3 months wear (see graph 5.3).



Graph 5.4 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

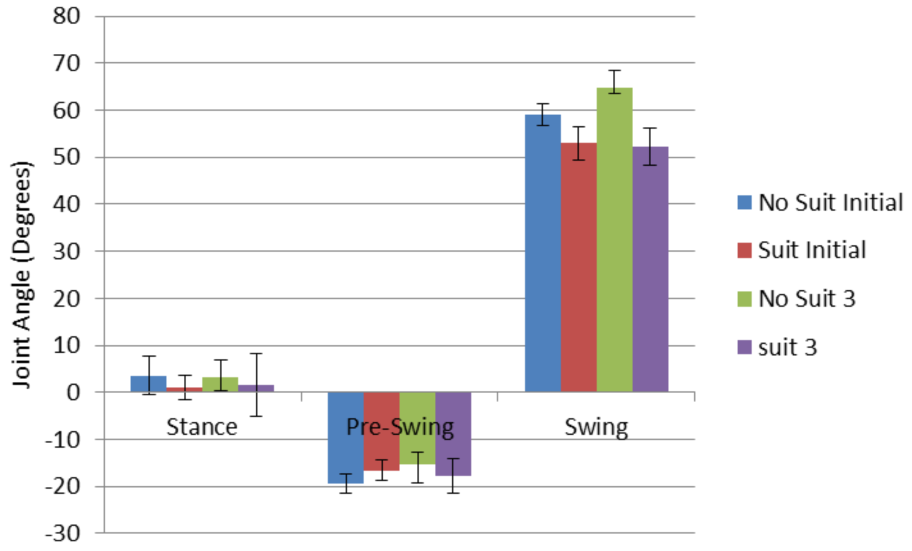
The range of motion usually found throughout internal and external rotation of the hip is 18° in 2yr olds. 22.14° was found during NIni, which is usual of a crouch gait. ROM was reduced to 5.34° during SIni and again to 6.73° during S3 (see graph 5.4). After three months the internal and external rotation was 15.4° without the suit which is within the normal age matched range.

Left Leg- Affected



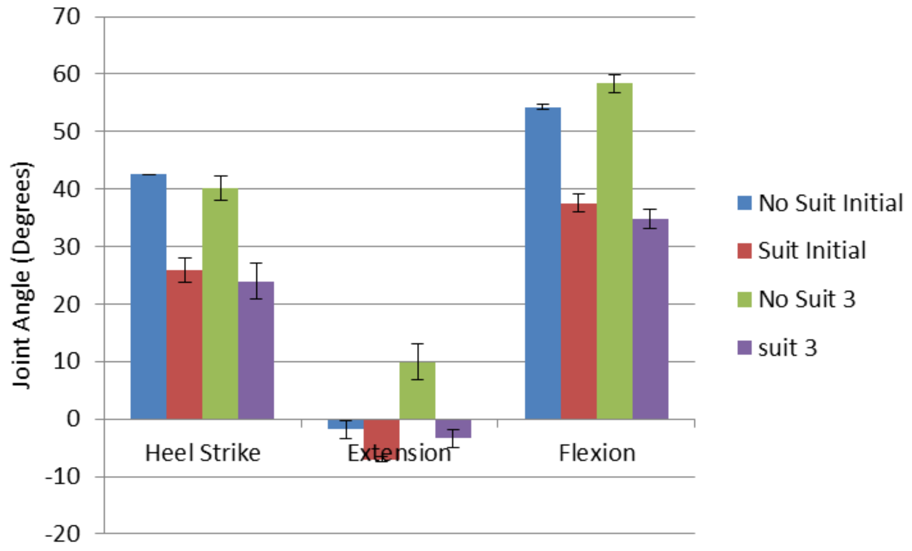
Graph 5.5 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Graph 5.5 shows ankle angle during 1st rocker is the same as heel strike in both conditions after 3 months, indicating flat-footed floor contact. Dorsiflexion during the 2nd rocker is increased to 18.07°, which is higher than the 11° found in normal age matched populations (see figure 4.5a). During S3 the dorsiflexion is reduced greatly to 9.41°, which is within the normative range. Plantarflexion during the 3rd rocker is non-existent for both initial conditions, however this increases greatly after 3 months with NS3 measuring –2.3° (see graph 5.5), which is still low compared to a normal aged matched value of -15°.



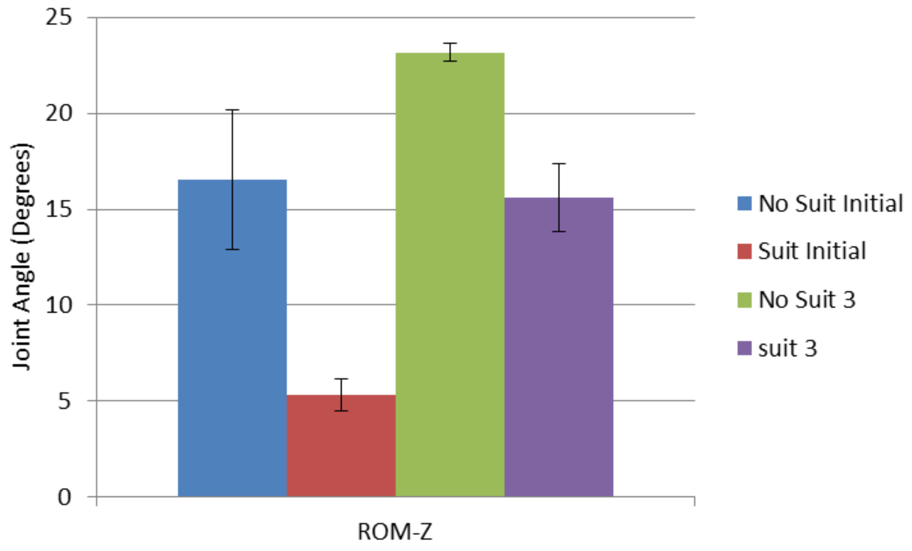
Graph 5.6 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Flexion during the stance phase was reduced slightly during both SIni and S3. During the pre-swing phase the knee extends further than seen in the normal population, though this is seen to reduce to -15.4° during NS3. During the swing phase both suit conditions reduce knee flexion to around the normal 60° range (see graph 5.6).



Graph 5.7 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike during both NIni and NS3 is close to the normal range angle of 41°. Flexion is reduced by approximately 15° in both SIni and S3. Extension is greatly reduced during 3NS, with the hip staying flexed at 9.88°, though the suit condition does bring about -3.37° extension. Maximal flexion is controlled, keeping the angles within the normal range. Without the suit flexion is increased above normal by 10°-15° at NIni and NS3 (see graph 5.7).



Graph 5.8 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM is close to the normal 18° initially without the suit, the suit reduces this by around 12° when first worn. After 3 months hip ROM increases without the suit by over 10° above baseline measures (see graph 5.8), but is returned to a normal range once the suit is replaced.

Table 5.1 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

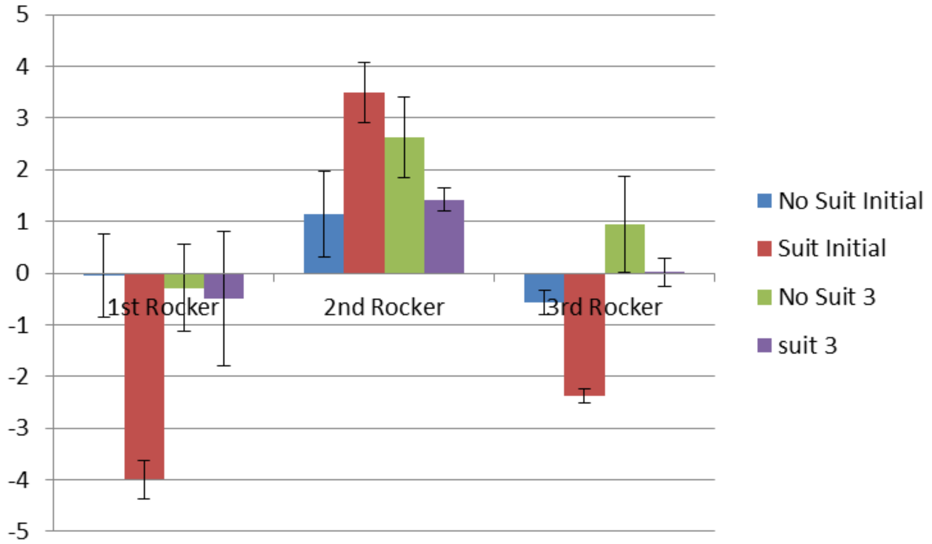
		Right Initial No	Right Initial Suit	Right 3mth No	Right 3mth Suit	Left Initial No	Left Initial Suit	Left 3mth No	Left 3mth Suit
Ankle	1st Rocker	-3.76	-2.44	0	0	-4.43	-1.33	0	0
	2nd Rocker	21.06	15.12	10.14	13.06	16.26	18.07	15.33	9.41
	3rd Rocker	2.92	-6.56	-7.41	-5.56	0.25	0.53	-2.3	-1.44
Knee	Stance	3.23	0	1.06	0	3.61	1.05	3.17	1.63
	Pre-Swing	-12.62	-21.15	-13.3	-10	-19.41	-16.62	-15.4	-17.71
	Swing	71.72	40.57	69.67	66.33	58.99	52.93	64.65	52.17
Hip	Flexion	50.97	29.66	46.26	30.89	54.27	37.56	58.33	34.79
	Extension	-4.95	-8.94	5.86	-9.81	-1.85	-7.01	9.88	-3.37
	ROM	22.14	5.34	15.4	6.73	16.56	5.32	23.17	15.6

Participant 1-Summary of findings

Participant 1 has ataxia and is affected on both sides of the body. The ankle joint is affected most markedly on both legs. Both ankles showing no plantarflexion or dorsiflexion during the 1st rocker in relation to angle at heel strike after wearing the suit for 3 months. This suggests that there is now a flat-footed contact with the floor in both with and without suit conditions. Dorsiflexion of the right ankle is reduced to a normal level at NS3, but is increased when the suit is replaced (see graph 5.1). This may be due to a possible carryover effect from the suit. The left ankle responds differently, with movement being restricted both with and without the suit after 3 months of wear (see graph 5.5). Knee flexion during stance phase is barely evident on both legs across all conditions, which may be a response to prevent collapse at the knee during weight bearing; however the left knee (see graph 5.6) has a more positive response moving towards a more normal range of flexion than the right knee (see graph 5.2). The same response is found at the hip. It is possible that the more negative changes at the ankle bring about positive increases in flexion at the knee and hip on the left leg to compensate, or vice versa. Overall the most positive changes were found at NS3, so it is apparent that there is some positive carry-over effect from the suit.

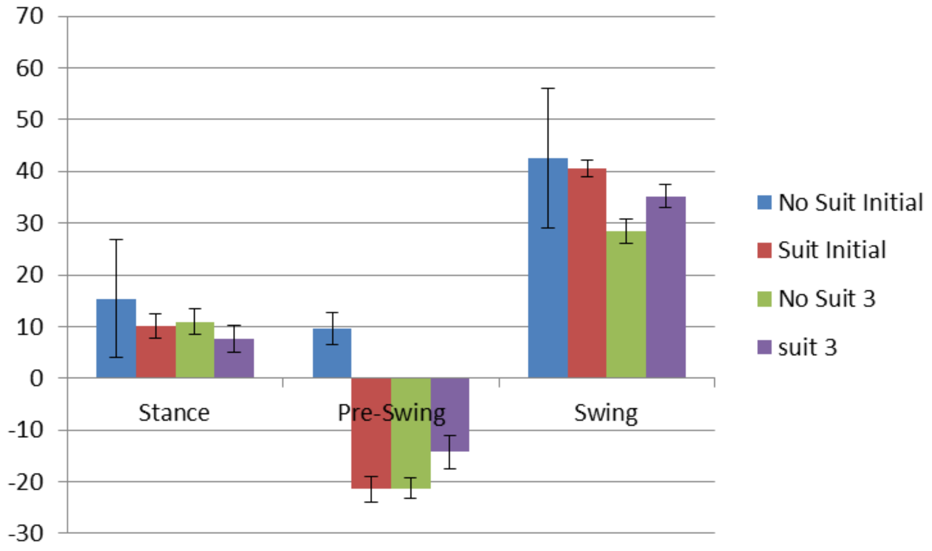
5.1.2 PARTICIPANT 2- A 5YR OLD WITH HEMIPLEGIA- LEFT SIDE AFFECTED

Left Leg- Affected.



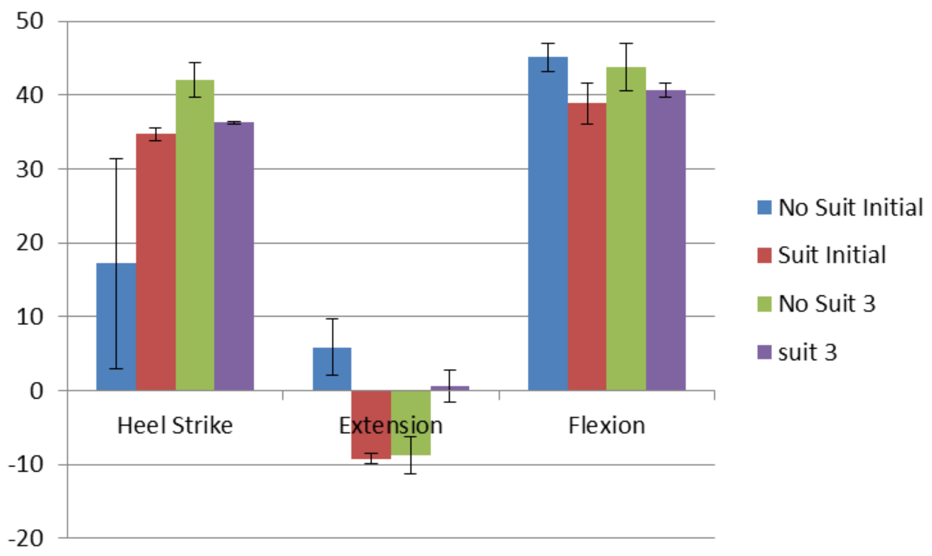
Graph 5.9 Maximum and minimum ankle joint angles on the affected (left) side at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

During SIni plantarflexion increases to the normal level of -4°, though this amount of change is not evident after 3 months of wear. Dorsiflexion during the second rocker is much lower than the 12° above heel strike found in normal age-matched children. This occurs across all conditions, though a 2.5° increase is evident at SIni when compared to NIni. After 3 months the dorsiflexion at S3 is reduced to near baseline level. Plantar flexion during the 3rd rocker is also much lower than the normal age-matched value of -17° (see graph 5.9).



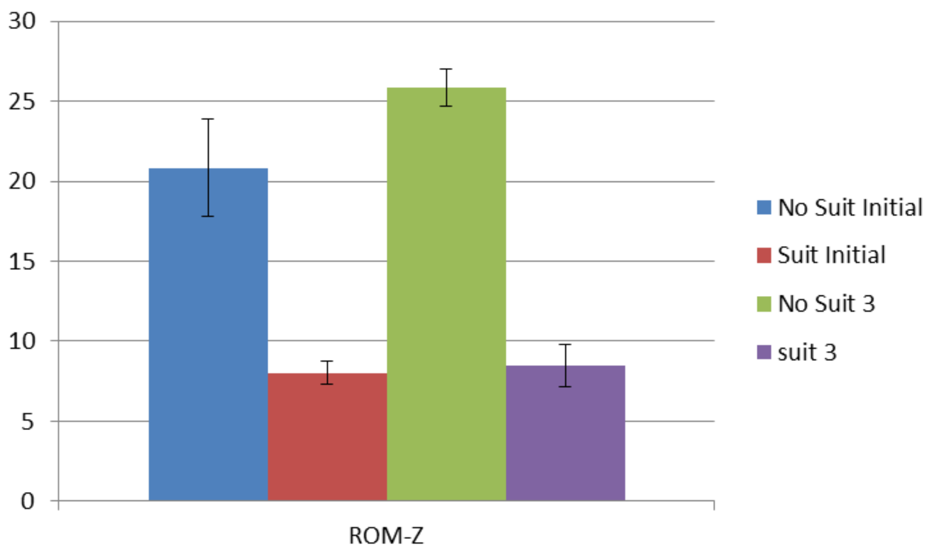
Graph 5.10 Maximum and minimum joint angles of the affected (left) knee during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

During stance phase flexion of the knee is above the normal 12° found in 5yr olds (see figure 4.5k) at NIni. Knee flexion is below normal age-matched angles during all other conditions. The knee extends by around 10° during the NIni, so is still in flexion as often found in crouch gait. The knee extends to -21.41°, which is at least 20° more than normal during SIni; this is still evident at NS3. The knee extension is reduced whilst wearing the suit at 3 months to -14.26° (see graph 5.10), but is still above the normative range.



Graph 5.11 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

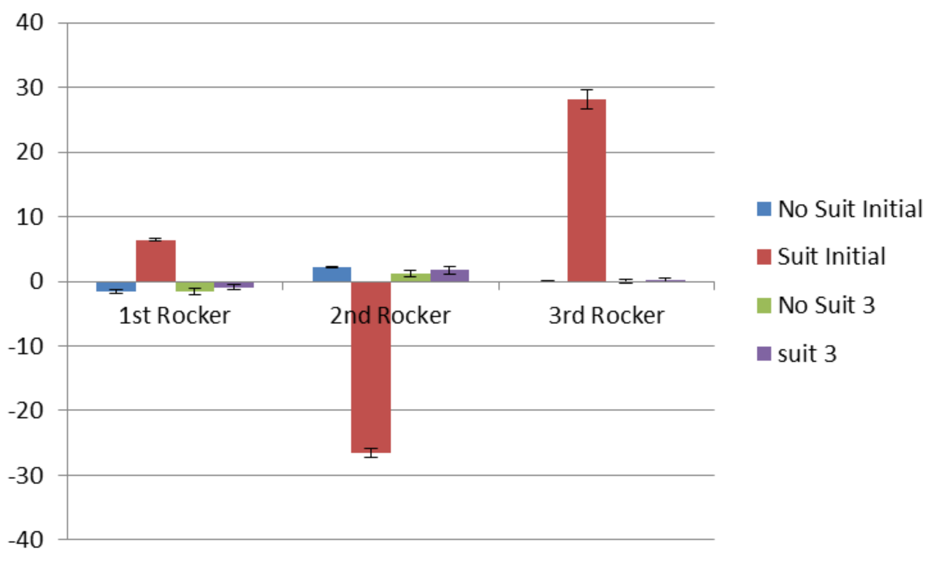
Initially hip flexion at heel strike is around 17° lower than normal age-matched values (see figure 4.5l); the introduction of the suit brings this within normal range and is still evident after 3 months. The hip does not extend during mid-gait cycle initially or after 3 months with the suit. Extension is closest to the normal 0° at NS3. Maximal flexion is below the normal 50° found in 5yr olds in all conditions. Flexion increases slightly above normal during NS3 (see graph 5.11).



Graph 5.12 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

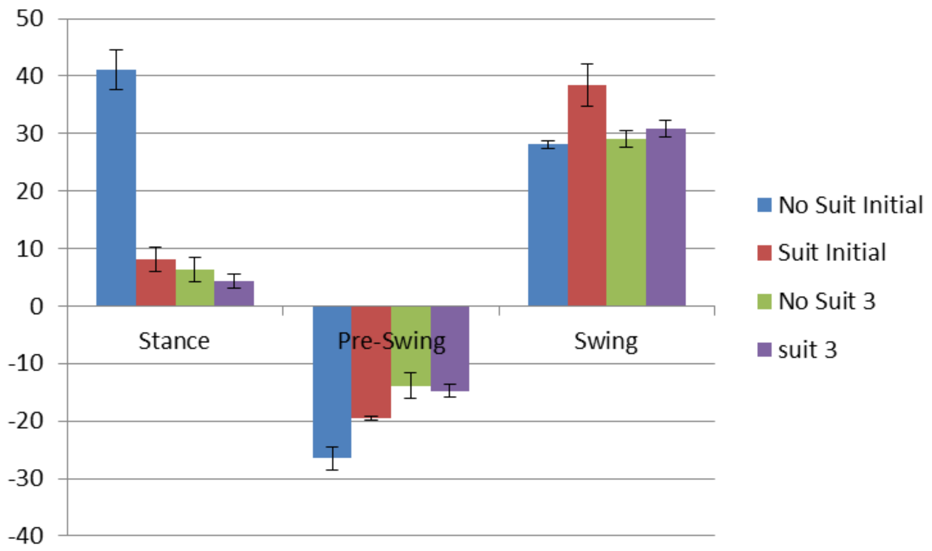
ROM is found to be above the normal 14° in both conditions without the suit, and below it in both conditions with the suit (see graph 5.12).

Right Side- Unaffected



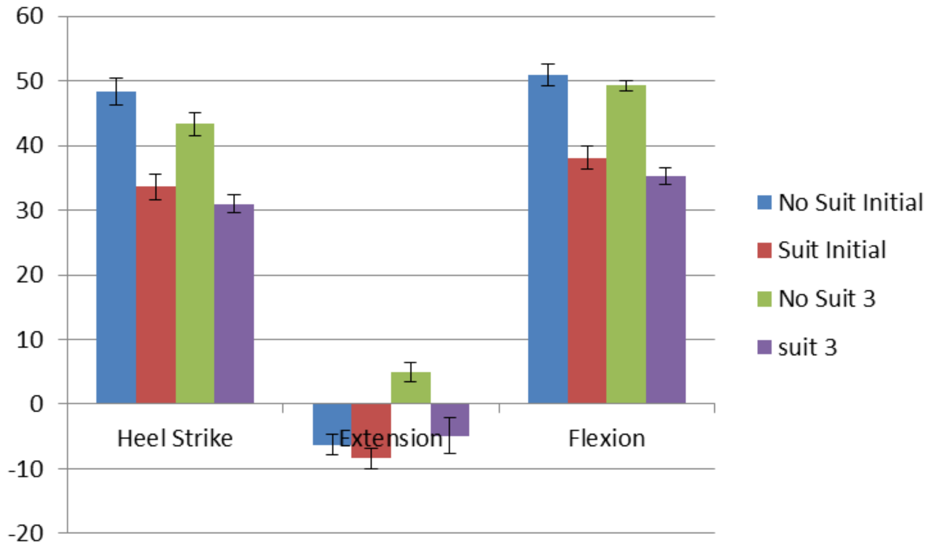
Graph 5.13 Maximum and minimum ankle joint angles on the unaffected (right) side at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

The ankle moves into dorsiflexion during the first rocker during SIni, suggesting further collapse around the ankle. Plantarflexion does occur during all other conditions and is around the normal 2° found in 5yr olds. The 2nd rocker shows -26.51°of plantarflexion during SIni (see graph 5.13). The ankle would be expected to reach 12° of dorsiflexion during this phase. During the 3rd rocker there is little difference in angle in relation to heel strike, though 28.14° dorsiflexion is reached during SIni, which is higher than -17° plantarflexion found in normal age matched children (see figure 4.5j).



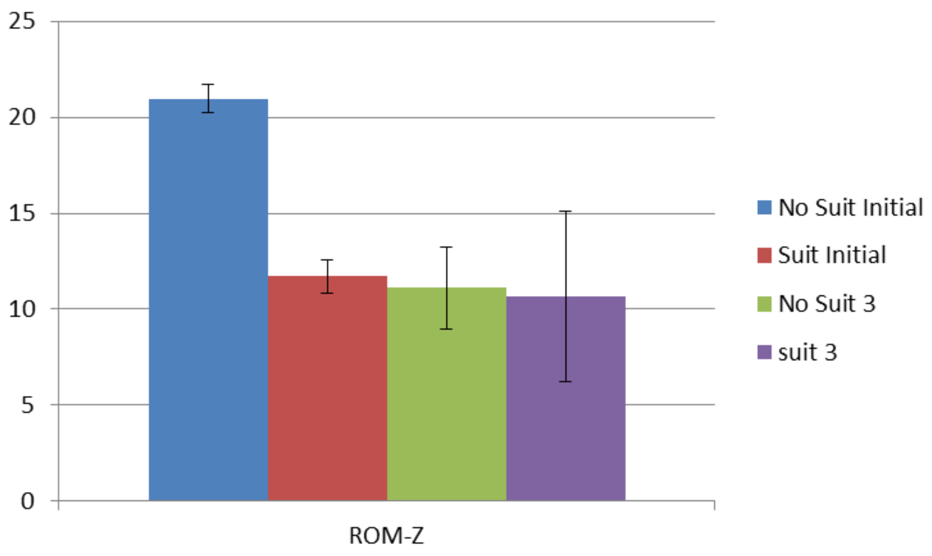
Graph 5.14 Maximum and minimum joint angles of the unaffected (right) knee during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance is a lot higher than the 12° found in normal age-matched children (see figure 4.5k) during NIni, and is lower than normal across all other conditions. Extension of the knee during pre-swing is initially higher than the normal -1°, but is reduced by 5° during SIni. The reduction is further evident after 3 months in both with and without suit conditions (see graph 5.14), but is still around 13°-15° above normal.



Graph 5.15 Angles at heel strike, maximum flexion and extension at the unaffected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike is higher than 44° found in normal age-matched children (see figure 4.5l) at NIni. Wearing the suit reduces the flexion at heel strike by 10°-14° at both time-points. The hip does not extend during NS3, though extension does occur in all other conditions none are close to the normal 0° found in 5yr olds. Maximal flexion is close to the normal 50° initially and is just below at NS3. Wearing the suit reduces flexion by 10°- 15° below normal at both time-points (see figure 5.15).



Graph 5.16 Range of motion of the unaffected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip ROM is around 7° more than the usual 14° during the initial testing. ROM values are reduced to around 10.69°-11.71° across all conditions (see graph 5.16), which is slightly lower than that found in normal populations

Table 5.2 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

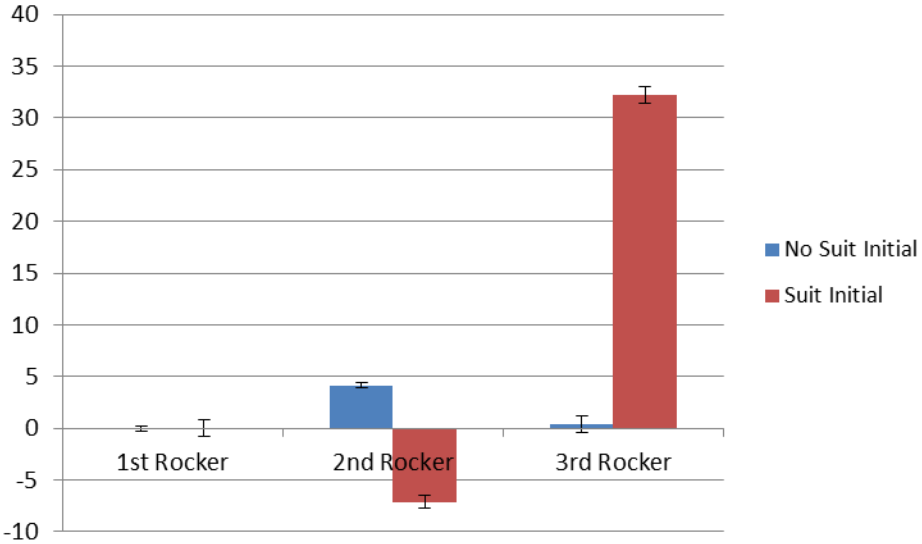
		Right Unaffected				Left Affected			
		Initial No	Initial Suit	3mth No	3mth Suit	Initial No	Initial Suit	3mth No	3mth Suit
Ankle	1st Rocker	-1.58	6.43	-1.61	-0.94	-0.05	-4	-0.29	-0.49
	2nd Rocker	2.19	-26.51	1.21	1.7	1.14	3.49	2.62	1.42
	3rd Rocker	-0.04	28.14	-0.06	0.24	-0.57	-2.38	0.94	0.02
Knee	Stance	41.08	8.06	6.3	4.38	15.41	10.14	10.91	7.64
	Pre-Swing	-26.51	-19.55	-13.88	-14.74	9.69	-21.41	-21.26	-14.26
	Swing	28.14	38.35	28.99	30.77	42.55	40.61	28.47	35.17
Hip	Flexion	50.92	38.1	49.24	35.23	45.11	38.84	43.8	40.63
	Extension	-6.27	-8.4	4.89	-4.88	5.89	-9.2	-8.76	0.64
	ROM	20.94	11.71	11.1	10.69	20.83	8.03	25.85	8.48

Participant 2-Summary of findings

The 2nd participant is Hemiplegic and affected on the left side of the body. Movement around the left ankle is greatly restricted across all conditions, despite the initial introduction of the suit bringing about a large increase in movement throughout the gait cycle (see graph 5.9). A similar increase was found in the unaffected right ankle, with movement across all other conditions being greatly restricted (see graph 5.13). It is possible that the ankle restriction is a result of the AFOs prescribed to prevent equinus as these were worn throughout all testing, however they should not produce such restrictions in movement. Initially the left (affected) knee was found to stay in flexion during pre-swing, which is common during crouch gait. The knee extends up to -21° during pre-swing, which is much higher than the 0° found in normal 5yr old gait patterns (see graph 5.10). Hip flexion at heel strike is initially low, but this is brought much closer to normal across all further conditions. Extension is closest to normal during S3. Rotation at the hip is reduced to below normal in both with suit conditions, returning to above normal without the suit, showing no evidence of a carry-over effect. The unaffected knee initially shows a higher than normal flexion during the stance phase (see graph 5.14), suggesting collapse during weight bearing which would not be expected. Flexion is then reduced to below normal across all other conditions, with flexion and extension around both the knee and hip moving away from normal gait patterns throughout the entire gait cycle. The ROM of the unaffected leg is also alot higher during NIni (see graph 5.16), further suggesting weakness and possible crouch gait patterns. The ROM in the affected hip is above normal without the suit, which is expected due to internal rotation during crouch gait. ROM is reduced to below normal whilst wearing the suit. The pattern is repeated at both time-points showing no change over time (see graph 5.12).

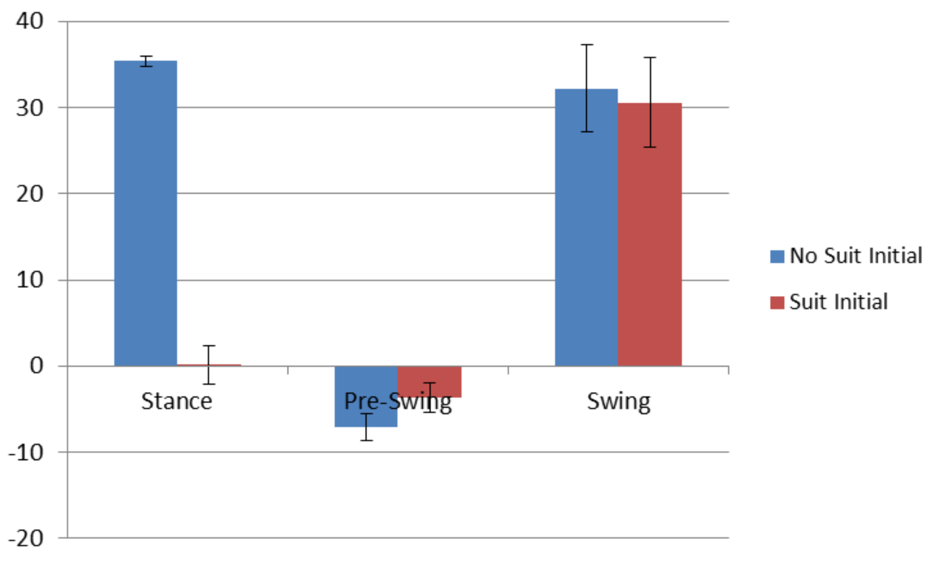
5.1.3 PARTICIPANT 3- A 10YR OLD WITH DYSTONIC DIPLEGIA-BOTH SIDES AFFECTED

Right Leg- Affected



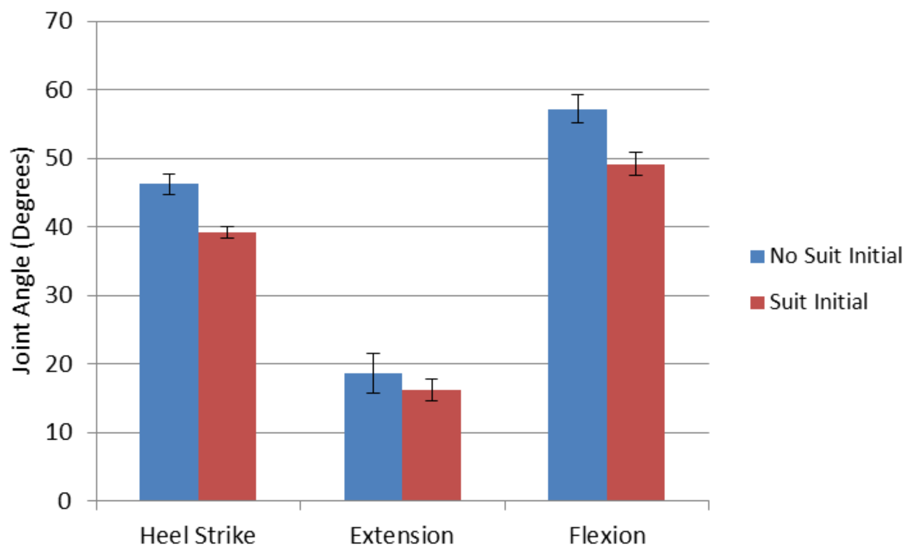
Graph 5.17 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion does not occur during the 1st rocker indicating a flatfoot contact with the floor. Dorsiflexion without the suit is 6° less than the normal 10°, plantarflexion occurs with the suit, which suggests the heel lifts during the 2nd rocker stance phase. The ankle dorsiflexes very slightly during the 3rd rocker without the suit, this is increased by wearing the suit by around 32°, where plantarflexion of -15° to -20° would be expected (see graph 5.17).



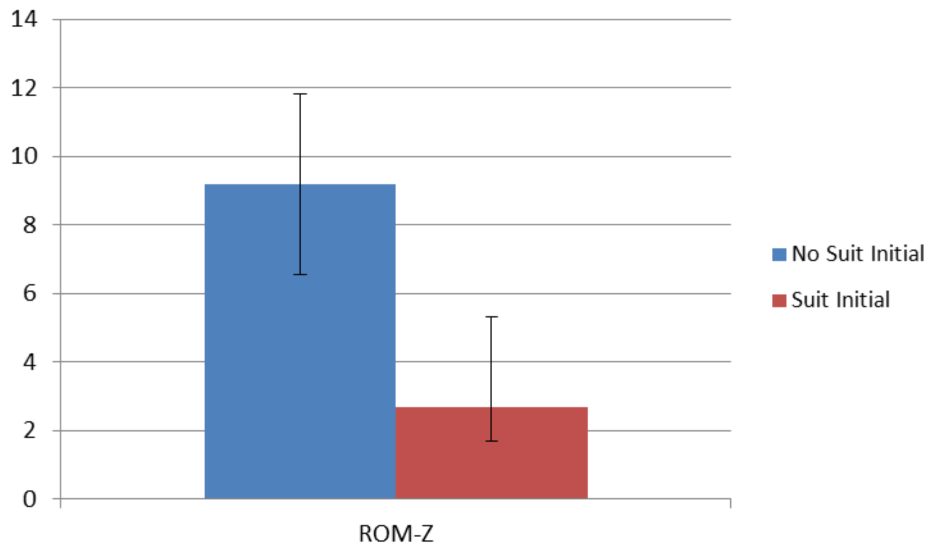
Graph 5.18 Maximum and minimum joint angles of the affected (right) knee during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance is 15° higher than the normal 20° during NIni, no flexion occurs between heel strike and stance phase during SIni. Knee extension during pre swing is within the normal age-matched vales of -5° to -10°, this is reduced to 3° with the introduction of the suit. Knee flexion during both conditions is half of the normal 65°-70° (see graph 5.18).



Graph 5.19 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

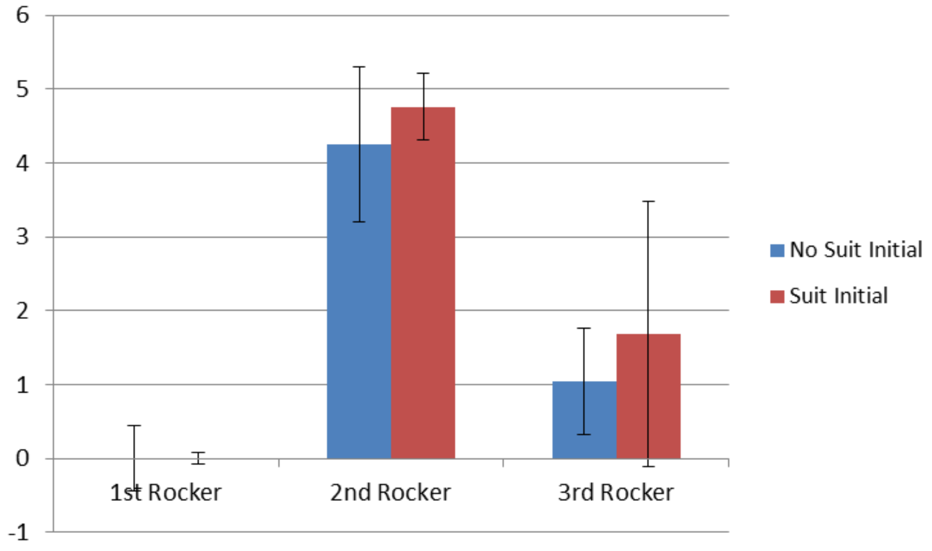
Hip flexion at heel strike is higher than the normal 30°-40° found in normal age-matched populations, though the ankle angle is within the normal range during SIni. The hip does not go into extension, remaining flexed between 16.24°-18.63°. Maximal flexion reaches 57.2° without the suit, which is higher than the 30°-40° found in normal age-matched populations (see figure 4.5o); the suit reduces this to 49.15° (see graph 5.19).



Graph 5.20 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

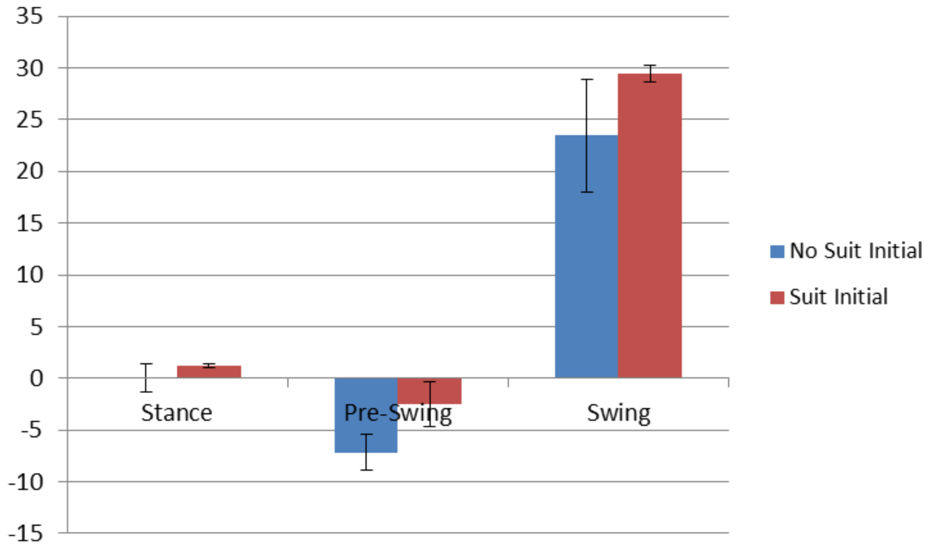
Hip ROM without the suit is lower than the normal 15°; this is restricted further with the suit to 2.7° (see graph 5.20).

Left Leg- Affected



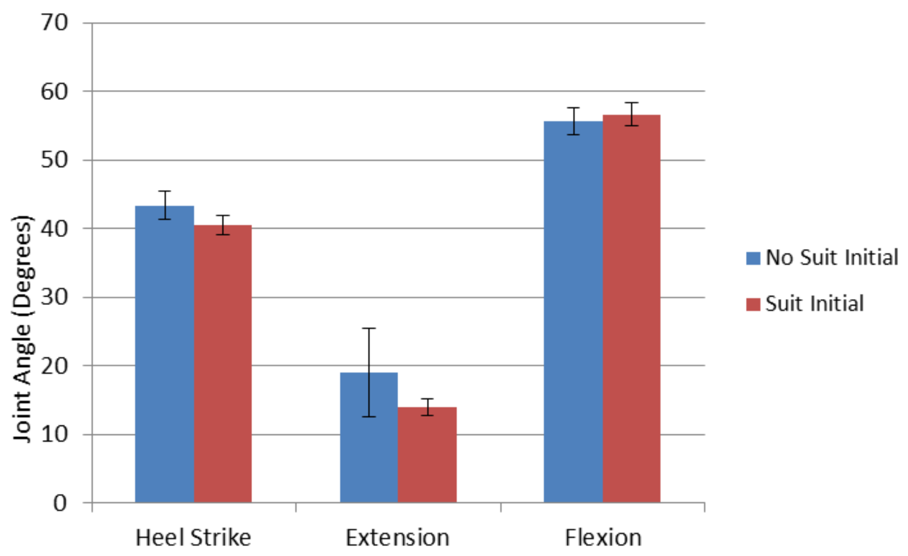
Graph 5.21 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

The ankle does not plantarflex in either condition during the first rocker, indicating a flat-footed floor contact. Dorsiflexion without the suit during the second rocker is less than half the normal 10°, this increased by 1° with the suit. The ankle remains dorsiflexed during the third rocker (see graph 5.21).



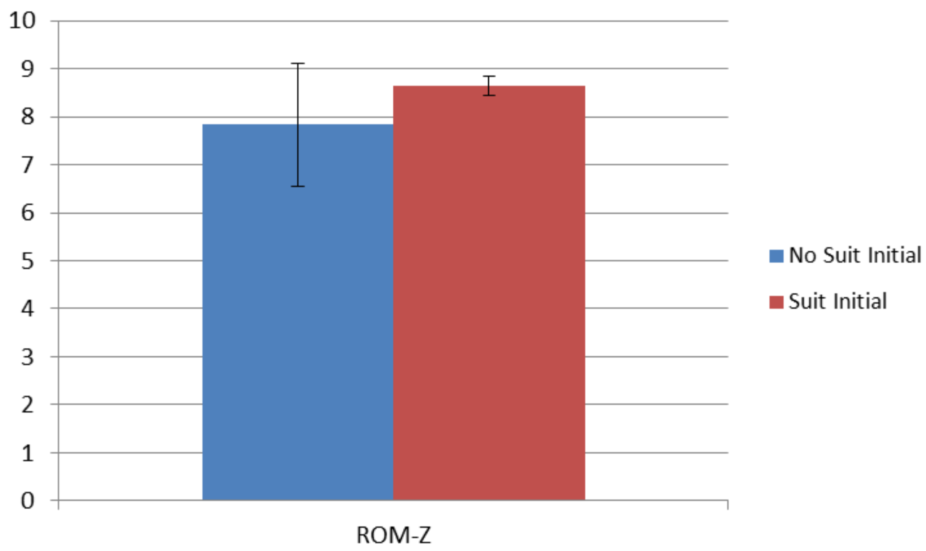
Graph 5.22 Maximum and minimum joint angles of the affected (left) knee during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Flexion during the swing phase does not occur without the suit, and only reaches 1.2° when the suit is worn. Extension of -7.17° during the stance phase is normal during NIni, but this is reduced below the normal range during SIni. Flexion during the swing phase is less than half the normal 60°-70° in both conditions (see graph 5.22).



Graph 5.23 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike is around 6°-10° more than the normal age-matched range of 30°-40° during NIni, the introduction of the suit has reduced this to within the normal range. The hip remains flexed at around 16.24°-18.63° and does not move into extension. Hip flexion reaches a maximum of 49.15°-57.2° (see graph 5.23) which is higher than the normal 30°-40° range.



Graph 5.24 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip ROM is initially at 7.83° which is much lower than the normal 15°, the introduction of the suit increases ROM by 1° (see graph 5.24).

Table 5.3 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait. Amber indicates no change occurred.

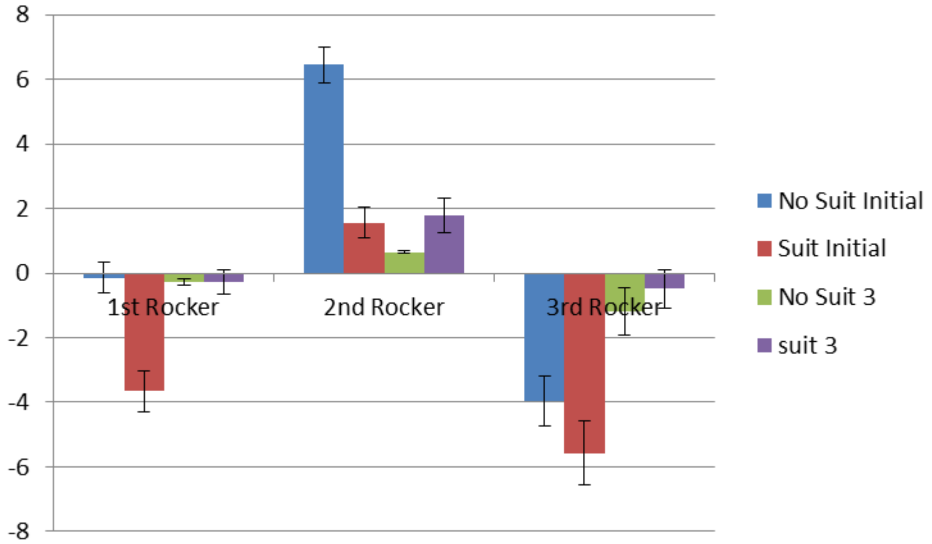
		Right Affected		Left Affected	
		Initial No	Initial Suit	Initial No	Initial Suit
Ankle	1st Rocker	-0.01	0	0	0
	2nd Rocker	4.12	-7.12	4.25	4.76
	3rd Rocker	0.42	32.19	1.04	1.69
Knee	Stance	35.37	0.11	0	1.2
	Pre-Swing	-7.12	-3.64	-7.17	-2.5
	Swing	32.19	30.57	23.44	29.46
Hip	Flexion	57.2	49.15	55.65	56.59
	Extension	18.63	16.24	19	14
	ROM	9.18	2.7	7.83	8.65

Participant 3- Summary of Findings

Participant 3 is a 10yr old with dystonic diplegia, motion data was only captured for the first testing period. Flat-footed contact is evident on both sides in both conditions. The introduction of the suit causes the right ankle to enter plantarflexion during the 2nd rocker (see graph 5.17), but increases dorsiflexion slightly on the left ankle (see graph 5.21). Both ankles remain dorsiflexed across both conditions during the 3rd rocker, increasing with the introduction of the suit. Knee flexion in the right leg during stance is higher than normal initially, indicating collapse. This is reduced greatly with the suit (see graph 5.18). The left knee shows no flexion at all, and is only slightly evident when the suit is worn (see graph 5.22). Both legs remain flexed at the hip throughout the gait cycle in both conditions; this could be due to crouch gait or an anteriorly rotated pelvis, or both. Flexion at heelstrike and maximal hip flexion are also both higher than normal, although hip rotation varies on both sides (see graphs 5.19 and 5.24). The ROM in both hips is below normal initially, but reduces on the right hip and increases on the left hip when the suit is worn (see graphs 5.20 and 5.24). The variation in effect on both sides in a diplegic patient is particularly interesting as it suggests that the changes brought about by the suit may vary within patients as well as between them.

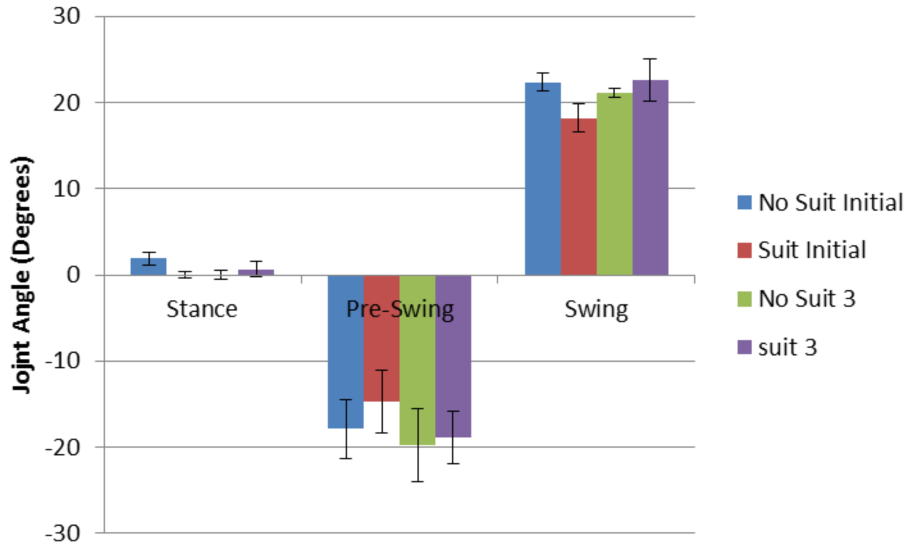
5.1.4 PARTICIPANT 4- A 5 YR OLD WITH DIPLEGIA- BOTH SIDES AFFECTED

Right Leg- Affected



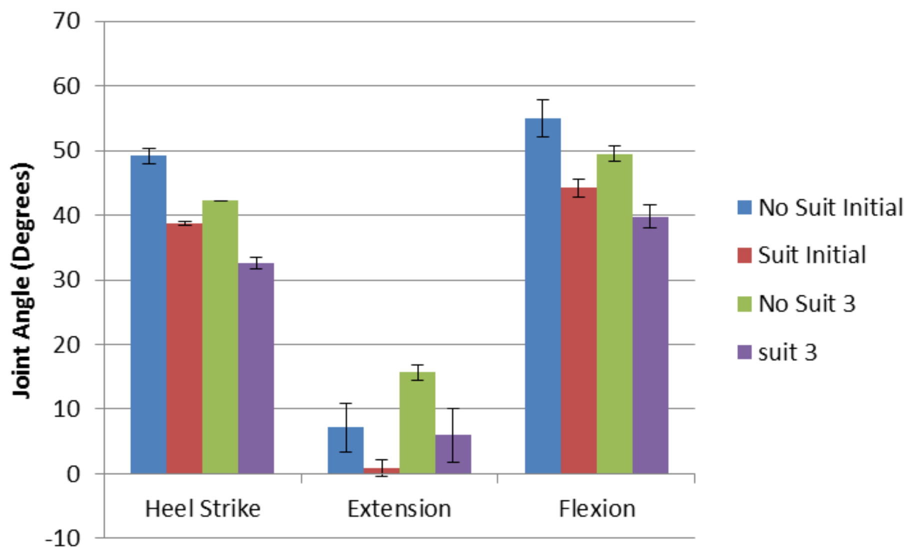
Graph 5.25 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion in all conditions is minimal except during SIni where it reaches -3.66° which is within the normal age-matched range (see figure 4.5j). Dorsiflexion during the second rocker is much lower than normal across all conditions, even though during NIni it reaches 6.44° (see graph 5.25); it is still below the normal value of around 12°.



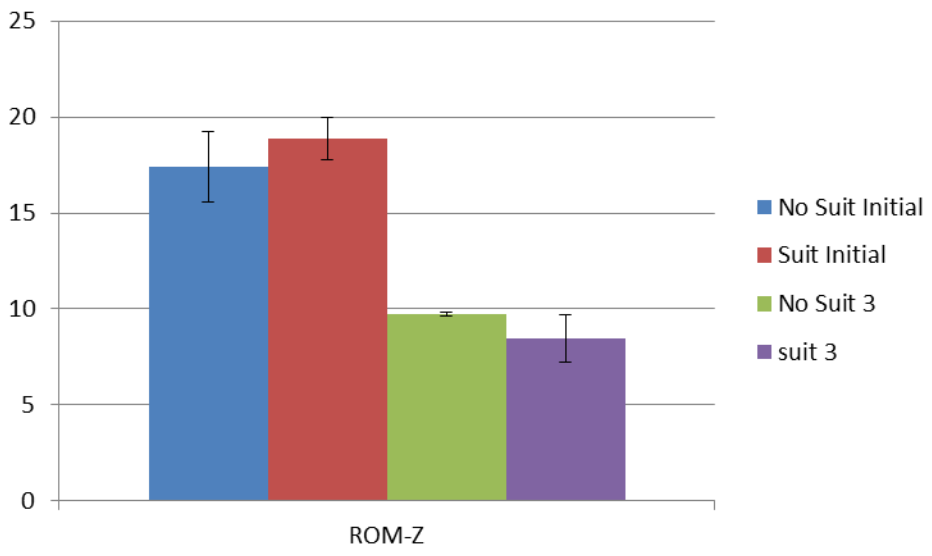
Graph 5.26 Maximum and minimum joint angles of the affected (right) knee during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Maximal knee flexion during the stance phase is much lower than the normal 12° found in normal 5 yr old gait (see figure 4.5k). Flexion does not occur at all in relation to angle at heel strike during SIni and NS3. Extension during the pre-swing phase was 16°-20° higher than the normal range of 1°. Flexion during the swing phase was much lower than the normal 63°, reaching a maximum of 22.64° across all conditions (see graph 5.26).



Graph 5.27 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

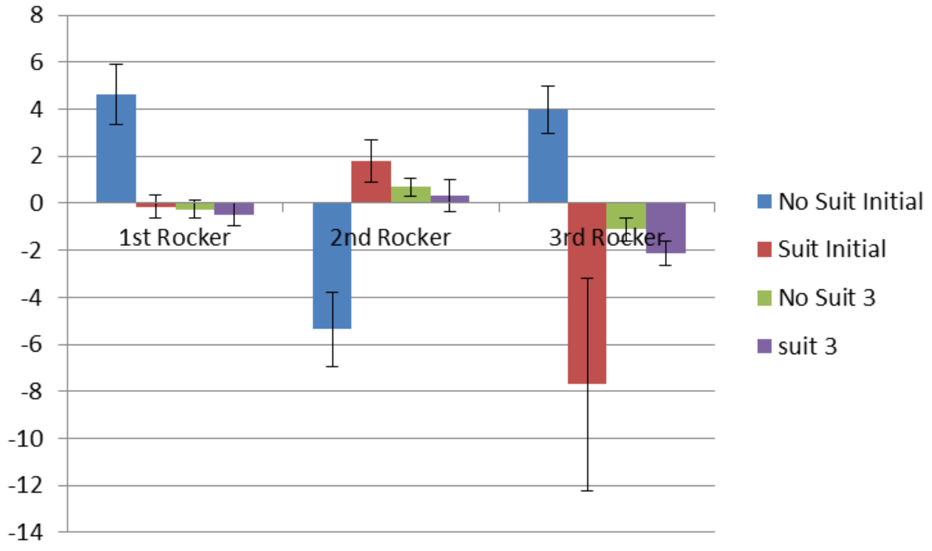
Hip flexion at heel strike was above the normal range of 44° during NIni, but is in the normative range during NS3. The hip does not move into extension, staying flexed at 7.12° during NIni, but reduces to 0.7° at SIni, which is much closer to 0° which is found in normal age-matched subjects (see figure 4.5l). Extension is further reduced after 3 months of wear, where the hip flexes to a greater degree of 15.66° without suit and 5.95° with the suit. Maximal flexion is initially above the normal angle of 50° and the introduction of the suit reduces this to 44.21°. After 3 months the flexion is 49.51° which is within the normal age-matched range, but this is again reduced during S3 (see graph 5.27).



Graph 5.28 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

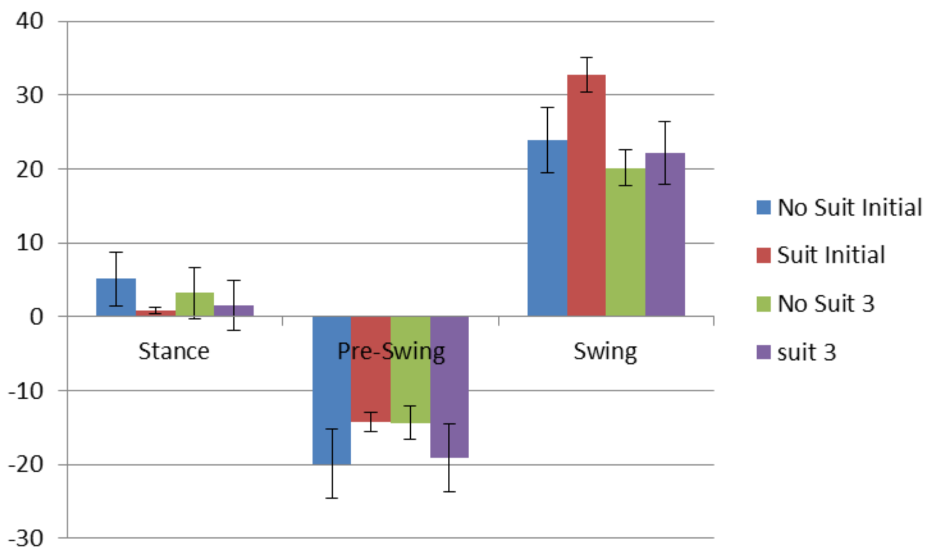
ROM is higher than the normal 14° in both initial conditions, with the suit increasing the ROM further from 17.38° to 18.86°. After 3 months hip ROM is reduced to 8.48° during S3 and 9.71° during NS3 (see graph 5.28), both of which are below the normal age-matched range.

Left Leg- Affected



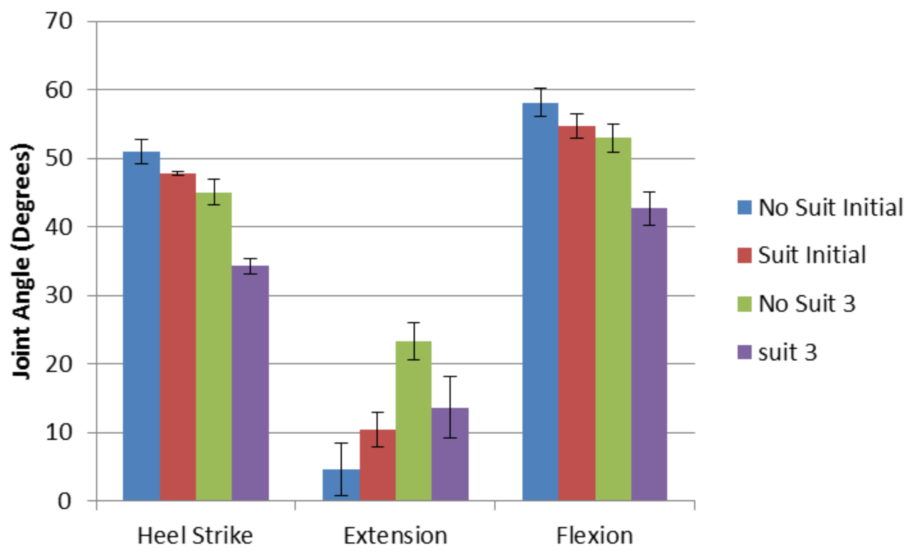
Graph 5.29 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

The ankle dorsiflexes to 4.63° after heel strike suggesting a toe strike during NIni. All other conditions show plantarflexion of less than 1°. During the 2nd rocker the ankle moves into -5.37° plantarflexion during NIni, which is below the 12° dorsiflexion found in normal age-matched subjects (see figure 4.5j). During the other conditions dorsiflexion occurs, however it is still much lower than in normal age-matched subjects. The 3rd rockers see the ankle dorsiflex during NIni, when plantarflexion of -17° would be expected, the introduction of the suit sees -7.69° of plantarflexion occur, though this is still below normal levels. After 3 months the level of plantarflexion decreases further during both S3 and NS3 (see graph 5.29).



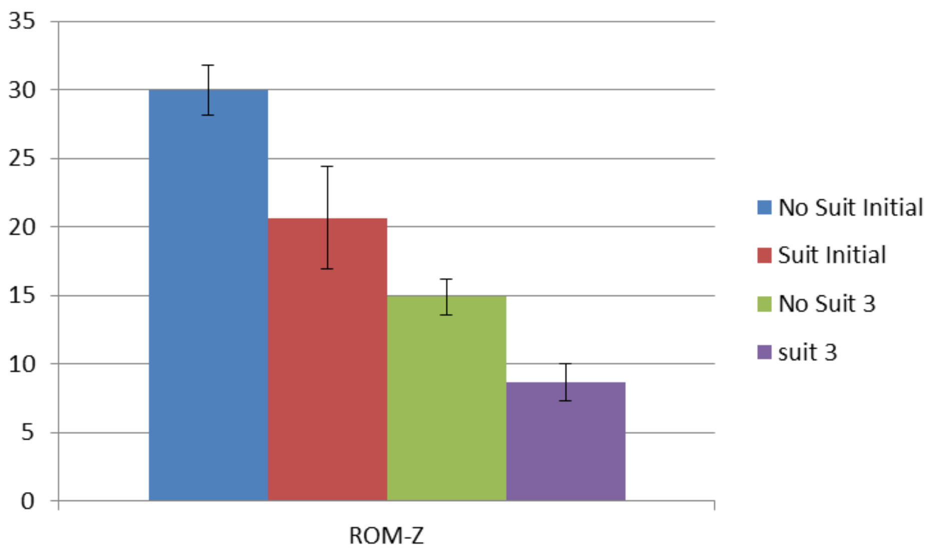
Graph 5.30 Maximum and minimum joint angles of the affected (left) knee during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance in relation to heel strike is between 0.83° and 5.12° across all conditions, which is much lower than 12° which is found in normal age-matched populations (see figure 4.5k). Extension during pre swing is reduced by 5.67° during SIni in comparison to NIni, with a similar value being found during NS3. Knee extension increases by 4.71° again to -19.08° during S3. Flexion during swing phase is less than half of the 63° angle found in normal age-matched populations being between 20.16°and 23.9° in all conditions except SIni. The flexion increased by 8.84° in comparison to NIni (see graph 5.30).



Graph 5.31 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike is around 51° in the initial no suit condition, and decreases by around 3° when the suit is worn initially. After 3 months the flexion has reduced further, being around 45° without the suit, which is close to the normal 43° found in 5 yr olds (see figure 4.5l). The suit flexion is reduced further with the suit to around 34° which is below the normal range. The hip does not move into extension during any of the conditions, remaining in 4.57°of flexion during NIni, after 3 months extension has increased to 23.28° during NS3 (see graph 5.31). Maximal flexion is below the 63° found in normal age-matched subjects across all conditions (see figure 4.5l).



Graph 5.32 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM is over double the normal age matched range without the suit at 30° during NIni, this is reduced by nearly 10° with the introduction of the suit. After 3 months the ROM is within the normal age-matched range during NS3 at 14.91°, though wearing the suit at this point reduces ROM further to 8.66° (see graph 5.32).

Table 5.4 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

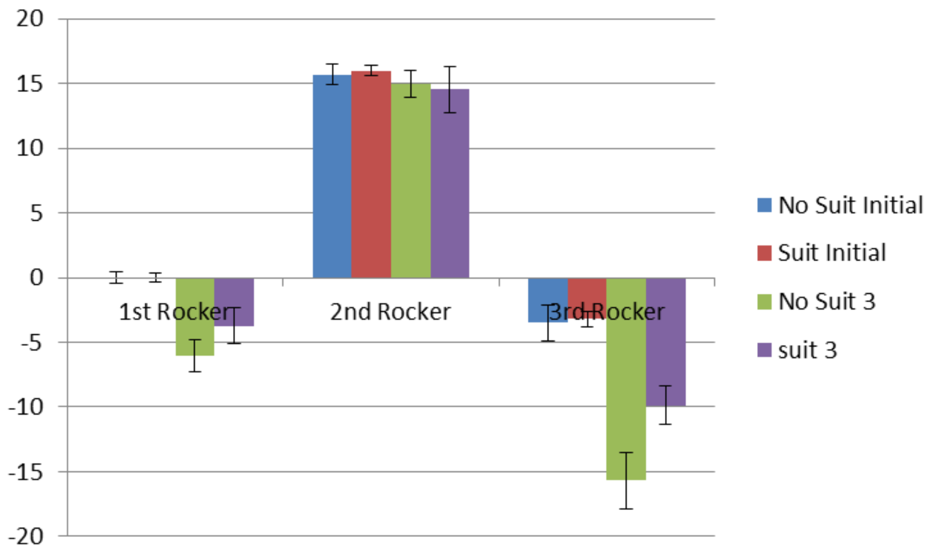
		Right Affected				Left Affected			
		Initial No	Initial Suit	3mth No	3mth Suit	Initial No	Initial Suit	3mth No	3mth Suit
Ankle	1st Rocker	-0.14	-3.66	-0.28	-0.27	4.63	-0.14	-0.25	-0.47
	2nd Rocker	6.44	1.56	0.64	1.78	-5.37	1.79	0.69	0.33
	3rd Rocker	-3.96	-5.58	-1.2	-0.49	3.98	-7.69	-1.12	-2.13
Knee	Stance	22.34	18.17	21.13	22.64	5.12	0.83	3.22	1.53
	Pre-Swing	-17.87	-14.74	-19.8	-18.86	-19.9	-14.23	-14.37	-19.08
	Swing	22.34	18.17	21.13	22.64	23.9	32.74	20.16	22.16
Hip	Flexion	54.98	44.21	49.51	39.79	58.15	54.76	52.95	42.66
	Extension	7.12	0.87	15.66	5.95	4.57	10.38	23.28	13.68
	ROM	17.38	18.86	9.71	8.48	30	20.64	14.91	8.66

Participant 4- Summary of Findings

Participant 4 is a 5yr old with diplegia, affected on both sides. The right ankle is restricted throughout the entire gait cycle across all conditions (see graph 5.25). The left ankle moves into dorsiflexion during the first rocker, suggesting a toe strike foot-contact. The pattern continues throughout the gait cycle with the ankle plantarflexing during the 2nd rocker and dorsiflexing during the 3rd rocker (see graph 5.29), which could indicate the foot being lifted during swing phase to prevent tripping. It is also possible that there were problems with the marker placement, though ankle markers were placed directly onto the orthotic shoes so this would be expected to cause problems during other trials also, which was not the case. The right ankle shows minimal movement during the 1st rocker except during SIni where plantarflexion is increased to normal levels found in 5yr olds. Movement through the ankle remains restricted across all conditions throughout the rest of the gait cycle (see graph 5.25). Knee flexion during stance phase is below normal in both legs across all conditions. Extension during pre-swing is above normal in both knees in relation to angle at heelstrike. This suggests that the knees are flexed at foot-contact, remaining at the same level of flexion until pre-swing when the legs straighten. Flexion during swing phase is much lower than normal in both legs also (see graphs 5.26 and 5.30). Hip flexion is above normal in both hips initially and probably compensates for the lack of knee flexion. After 3 months flexion reaches normal ranges during NS3. Extension does not occur in either hip at any point, and moves further into flexion during NS3. Maximal flexion is below normal across all conditions in both hips, reducing further in both conditions after 3 months (see graphs 5.27 and 5.31). Hip rotation is above normal on both sides initially, after 3 months the ROM in the left hip is reduced to normal (see graph 5.32) and the ROM of the right hip is normal during NS3, but reduced further during S3 (see graph 5.28).

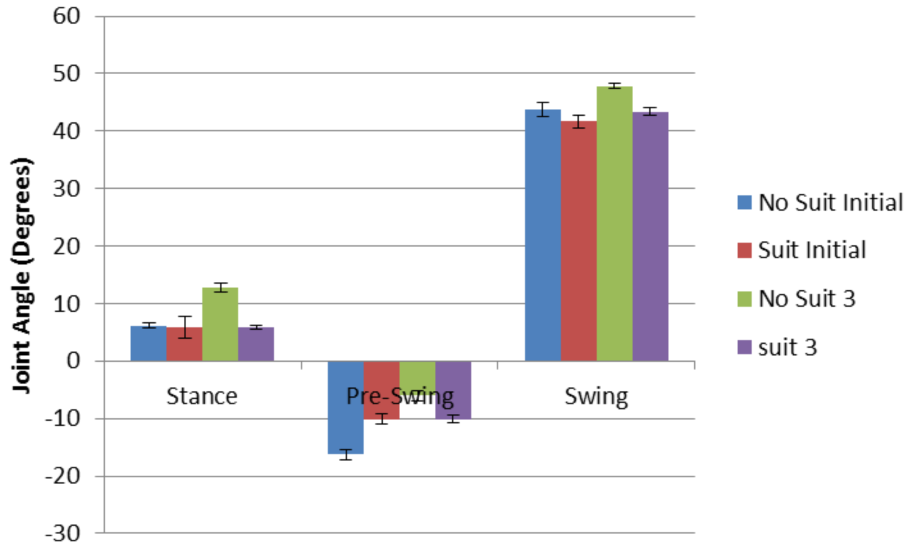
5.1.5 PARTICIPANT 5- AN 11 YR OLD WITH MILD DIPLEGIA

Right Leg- Affected



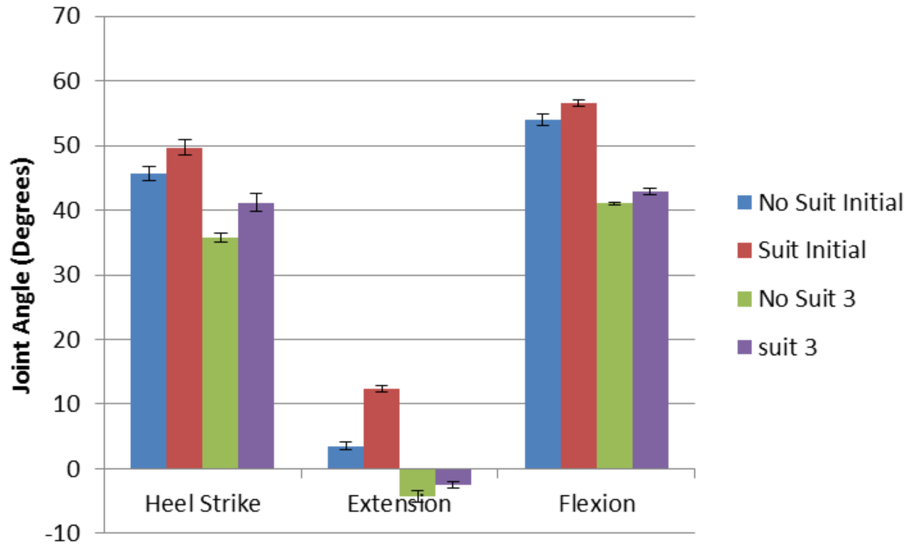
Graph 5.33 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

The ankle does not plantarflex during the 1st rocker in both initial conditions indicating a flat-footed floor contact. After 3months the ankle moves into -6.04° of plantar flexion during NS3, which is slightly above normal, and -3.73° during S3, which is within the normal age-matched range. Dorsiflexion during the 2nd rocker is 5° to 7° above normal across all conditions, reducing slightly after 3 months by around 1° during both NS3 and S3. In both initial conditions plantarflexion during the third rocker is much lower than the normal -15° to -20° at -3.49° during NIni and -3.21° during SIni. Plantarflexion increases greatly during NS3 to -15.68° which is within the normal age-matched range (see figure 4.5m); however this is reduced to -9.89° during S3 (see graph 5.33).



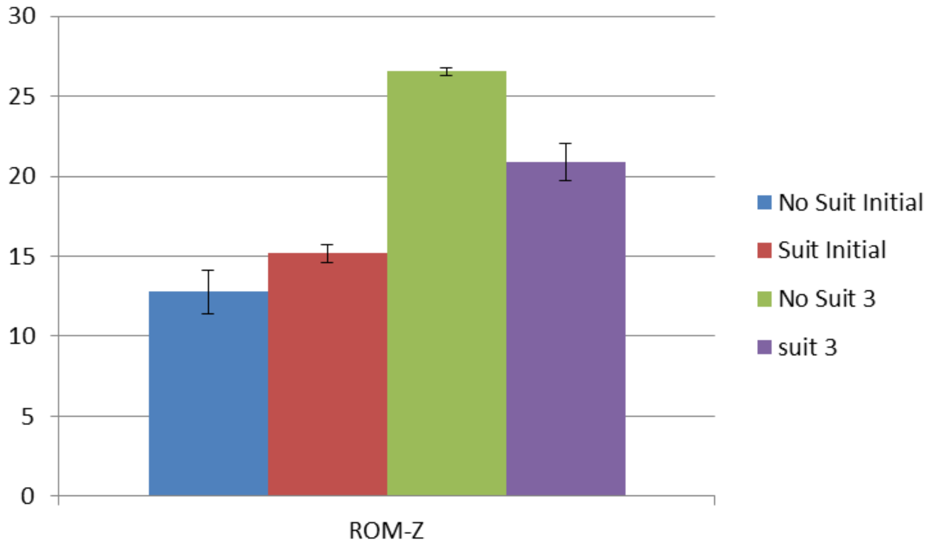
Graph 5.34 Maximum and minimum affected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion at stance phase is at least half the normal 20° (see figure 4.5n) in relation to heel strike across all conditions, only rising during S3. Extension during the pre-swing phase is higher than normal during NIni without the suit at -16.28°, but is reduced to the normal age-matched range across all other conditions. Whilst wearing the suit extension is around -10° at both time-points, this is reduced further to -6.03° during NS3. Knee flexion during swing phase is usually at 65° to70° higher than at heel strike, but here the flexion is lower, ranging from 41.7° to 47.83°. Flexion is reduced during the two suit conditions to 41.7° during SIni and 42.9° during S3 (see graph 5.34).



Graph 5.35 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

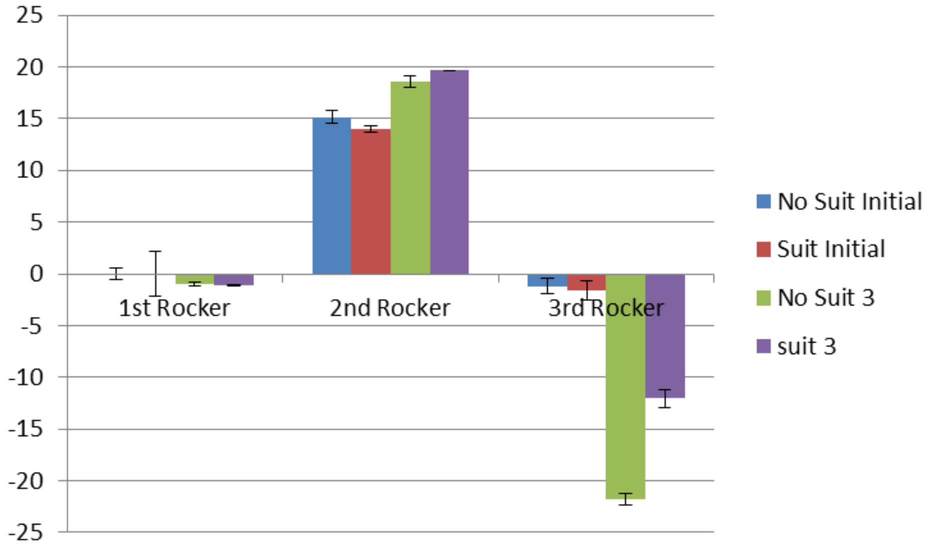
Hip flexion at heel strike is high in both initial conditions at 46° during NIni and increases further to 59° during SIni. After 3 months flexion is reduced during NS3 to35°, which is within the normal age-matched range of 30° to 40° (see figure 4.5o). Although hip flexion reduces during S3, it is not within the normal range at 41°. The hip does not extend in relation to angle at heel strike in either of the initial conditions, and is found to flex further during SIni to 12.34°. At 3 months the hip reaches -4.29° extension during NS3, which is closer to the -5° to -12° range found in normal age-matched subjects. Extension reaches -2.28° during S3. Maximal flexion in relation to heel strike is higher than normal in both initial conditions, increasing further during SIni to 56.63°. After 3 months flexion is reduced to 41.01° during NS3, which is within the normal age-matched range, but is increased again during S3 to 42.9° (see graph 5.35).



Graph 5.36 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

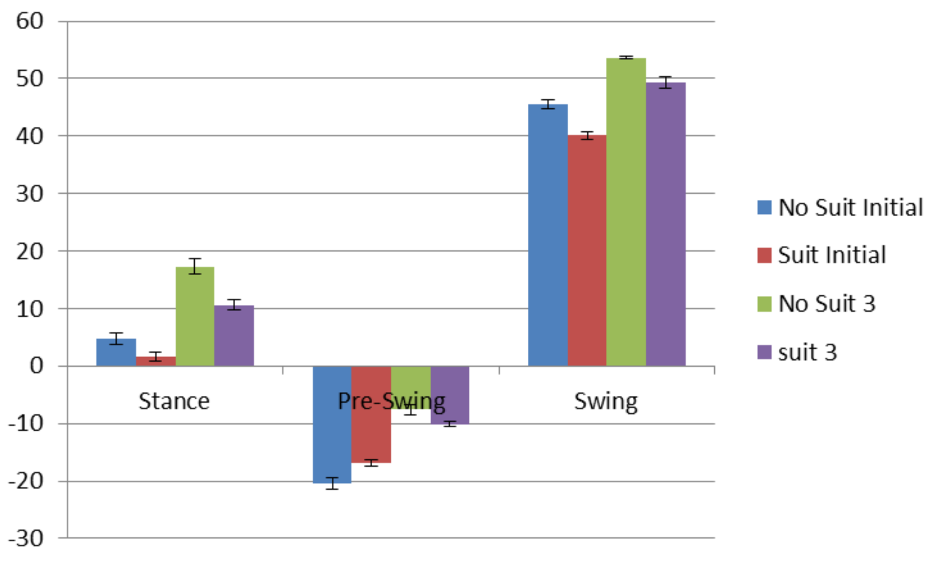
ROM is around normal at 14.94° during NIni, but is reduced slightly to 14.42° during SIni. During NS3 ROM increased to 23.57°, which is above normal age-matched values. Although this is reduced during S3 to 16.67° (see graph 5.36), this is still above what is found in normal age-matched populations.

Left Leg- Affected



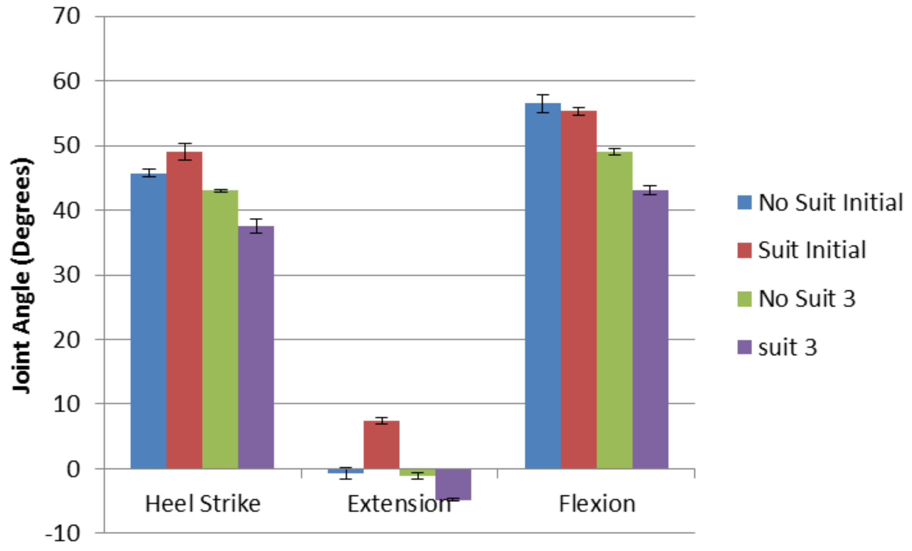
Graph 5.37 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Ankle plantarflexion does not occur in relation to angle at heel strike in either of the initial conditions, indicating flat-footed floor contact. After 3 months -1.02° is reached during NS3, and -1.11°during S3 but this is still less than the normal -3° to -5° (see figure 4.5m). Dorsiflexion during the 2nd rocker is above the normal 10° increase above heel strike across all conditions. The initial wearing of the suit reduces dorsiflexion from 15.55° during NIni to 13.99° during SIni. After 3 months dorsiflexion has increased to 18.59° during NS3 and 19.65° during S3. Plantarflexion during the 3rd rocker is below normal age-matched subjects in both initial conditions. After 3 months plantarflexion is greatly increased to -21.77° during NS3, which is higher than the -15° to -20° found in normal age-matched subjects. This is reduced to -12.06° during S3 (see graph 5.37).



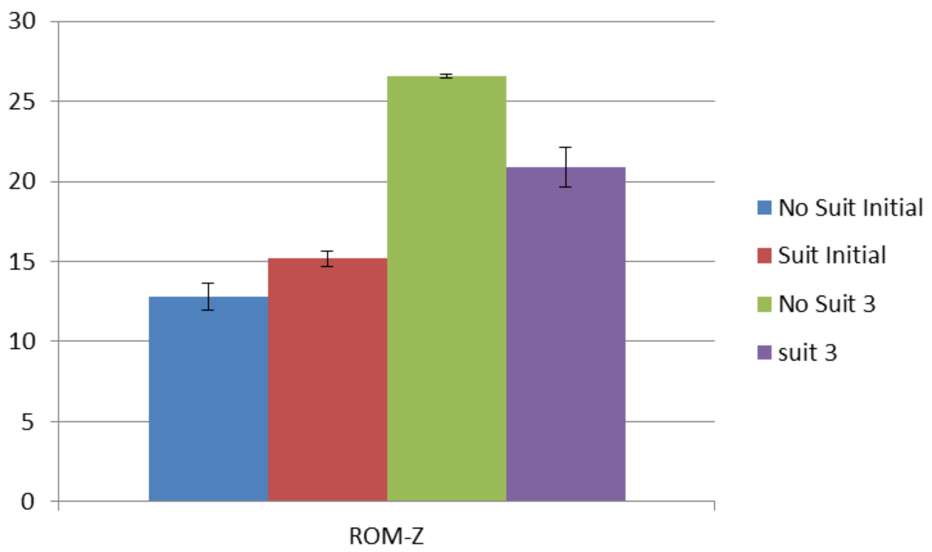
Graph 5.38 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Flexion at the left knee during stance is low in both initial conditions, being reduced further by the suit from 4.77° during NIni to 1.7° during SIni. After 3 months flexion has increased to 17.29° during NS3, which is closer to the 20° found in normal age-matched subjects (see figure 4.5n). This is again reduced during S3 to 10.12°. The knee extends to -20.42° during pre-swing in NIni. This is reduced to -16.89° during SIni. After 3 months knee extension is within the normal range of -5° to -10° in both conditions. Flexion during the swing phase is low compared to the normal range of 65° to 70° across all conditions, with the suit reducing flexion by around 5° in comparison to without suit conditions at each time point (see graph 5.38).



Graph 5.39 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike is high across all conditions, except during S3, where it falls within normal ranges at 37° (see figure 4.5o). Hip flexion is also reduced during NS3 to 42° in comparison to 46° during SIni, though this is still above the normal range of 30° to 40°. The hip extends by just -0.76° during NIni, and the introduction of the suit causes the hip to stay flexed to 7.36° during SIni. After 3 months extension is increased slightly during NS3 to -1.11°, and further during S3 to -4.79°, which is within the normal age-matched range of -5° to -10°. Maximal flexion reaches 55.27°- 56.48° in both initial conditions, which is higher than found in normal age-matched subjects. Flexion is reduced during NS3 to 49.02° and 43.09° during S3 (see graph 5.39), which are both still above normal age-matched values.



Graph 5.40 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM during NIni is slightly lower than normal age-matched values at 12.77°; the introduction of the suit during SIni brings this to normal age-matched values at 15.16°. ROM increases further after 3 months, reaching 26.55° during NS3 and 20.9° during S3 (see graph 5.40), both of which are above normal age-matched values.

Table 5.5 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait. Amber indicates that no change occurred.

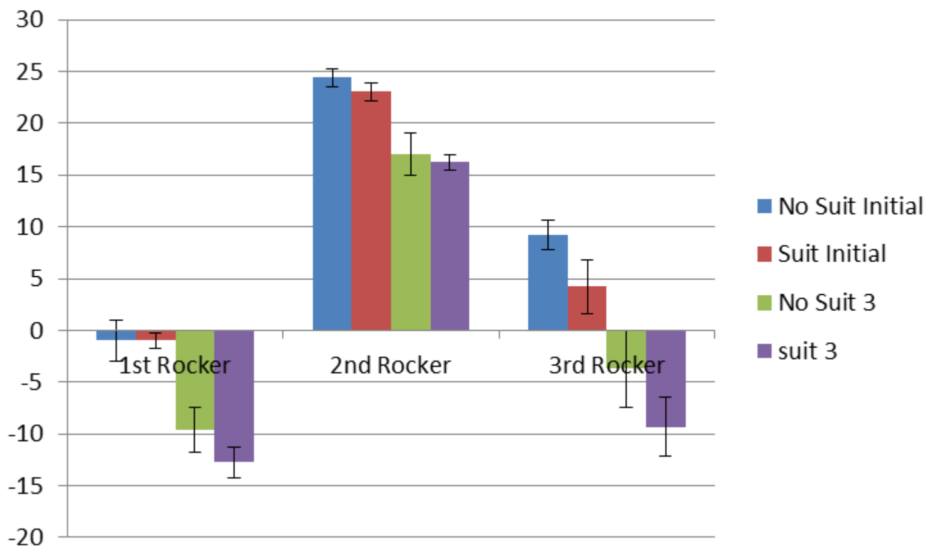
		Right Affected				Left Affected			
		Initial No	Initial Suit	3mth No	3mth Suit	Initial No	Initial Suit	3mth No	3mth Suit
Ankle	1st Rocker	0	0	-6.04	-3.73	0	0	-1.02	-1.11
	2nd Rocker	15.67	15.97	14.98	14.52	15.15	13.99	18.59	19.65
	3rd Rocker	-3.49	-3.21	-15.68	-9.89	-1.21	-1.61	-21.77	-12.06
Knee	Stance	6.14	5.84	12.68	5.91	4.77	1.7	17.29	10.63
	Pre-Swing	-16.28	-10.08	-6.03	-10.14	-20.42	-16.89	-7.62	-10.12
	Swing	43.77	41.7	47.83	43.34	45.6	40.1	53.66	49.34
Hip	Flexion	54.06	56.63	41.01	42.9	56.48	55.27	49.02	43.09
	Extension	3.52	12.34	-4.29	-2.48	-0.76	7.36	-1.11	-4.79
	ROM	14.94	14.42	23.57	16.67	12.77	15.16	26.55	20.9

Participant 5- Summary of Findings

Participant 5 is an 11yr old with mild diplegia, affected on the both sides. Both ankles show similar patterns of change throughout the study. Initially there is flatfooted contact on both sides, moving to a small amount of plantarflexion in both conditions after 3 months which falls within the normal age-matched range (see figure 4.5m) on the left ankle. Dorsiflexion is above normal on both ankles throughout all conditions. During the third rocker plantarflexion is below normal across both conditions. After 3 months this increases during NS3, the right ankle is at normal levels (see graph 5.33), whereas the left is above normal (see graph 5.37). Plantarflexion in both ankles is again reduced below normal during S3. This suggests that there may be some carryover effect from regular wear of the suit which increases movement around the ankle, but is then restricted by wearing the suit after this time. It’s possible that reducing the amount of time the suit is worn for may be beneficial. Again similar patterns of response are also found at the knee joint on both sides. Flexion during stance phase is low across all conditions except during NS3, where it increases, though not enough to be deemed within normal age-matched levels. Extension during the swing phase is above normal initially, and reduces during SIni to -10.08° on the right knee (see graph 3.34), which is within normal range, and -16.89° on the left knee which is still above normal (see graph 5.38). Flexion is reduced further during NS3, and is within normal range on both sides, wearing the suit increases flexion at this point to upper normal age-matched levels. During swing phase flexion is low across all conditions on both legs, though an increase is seen again during NS3. Hip flexion is high on both sides during initial conditions, with the introduction of the suit increasing this further on the right. After 3 months flexion without the suit is reduced on both sides reaching a normal angle of 41.01° on the right (see graph 5.35), though the left is still above this range at 49.02° (see graph 5.39). As knee flexion is low at heel strike it can be assumed that increased hip flexion is caused by anterior pelvic tilt rather than crouch gait, so the angular change may be evidence in change of pelvic angle. Rotation at the hip is close to normal on both sides in with and without suit conditions (see graphs 5.36 and 5.40). After 3 months wear the ROM increases to above normal levels, which is especially evident during NS3. It appears that although flexion at the ankle, knee and hip is brought towards normal age-matched values after 3 months whilst not wearing the suit, this is not the case in hip rotation.

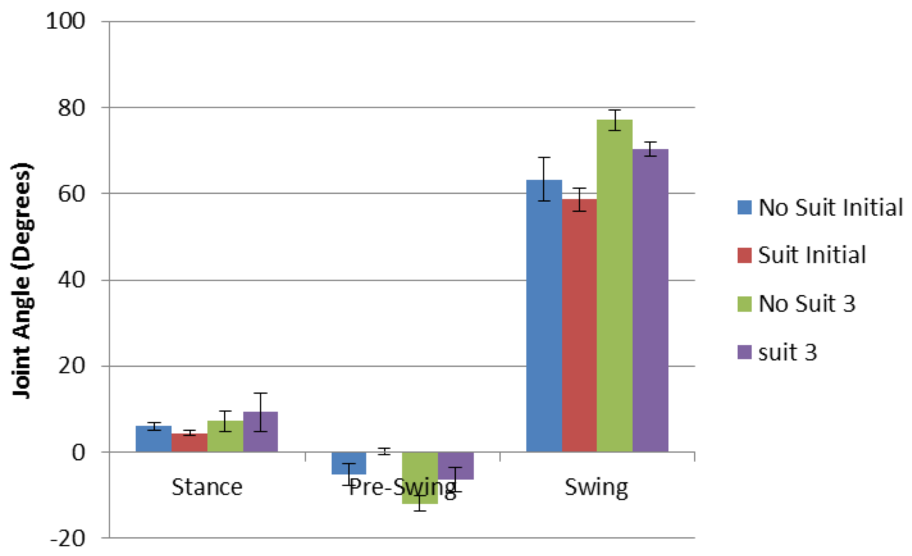
5.1.6 PARTICIPANT 6- A THREE YEAR OLD WITH DEVELOPMENT DELAY

Right Leg- Affected



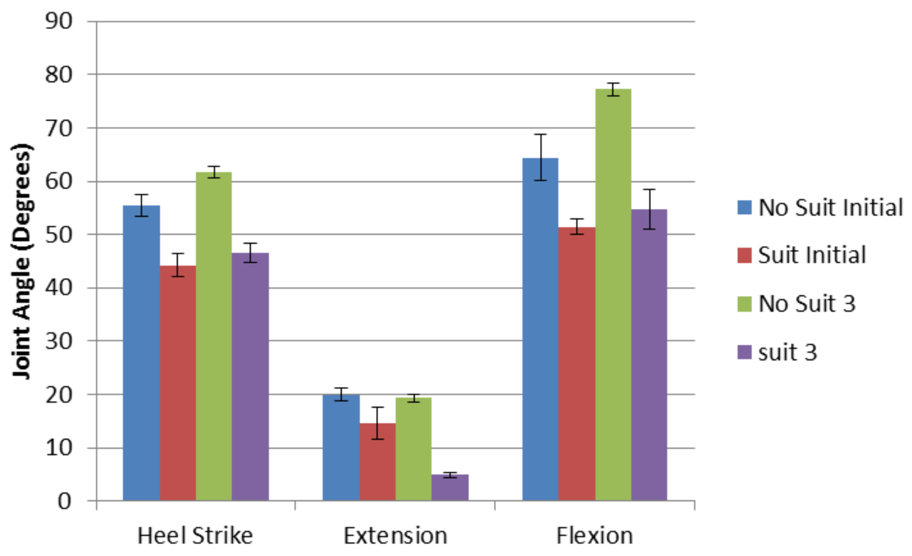
Graph 5.41 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion during 1st rocker is at -0.99° to -1° for both initial conditions which is below normal age-matched values. After 3 months plantarflexion is above the normal -2.5° to -5° at -9.56° during NS3 and -12.75° during S3. Dorsiflexion during 2nd rocker is higher than the normal 10° over all conditions, reaching 23.04° to 24.41° initially and 16.22° to 17° after 3 months. The ankle does not move into plantarflexion during the 3rd rocker in both initial conditions, though dorsiflexion reduces from 9.25° to 4.23° during SIni. At 3 months plantarflexion occurs, reaching -3.73° during NS3 and -9.34° during S3 (see graph 5.41), these angles are still below the normal age-matched range of -18° (see figure 4.5d).



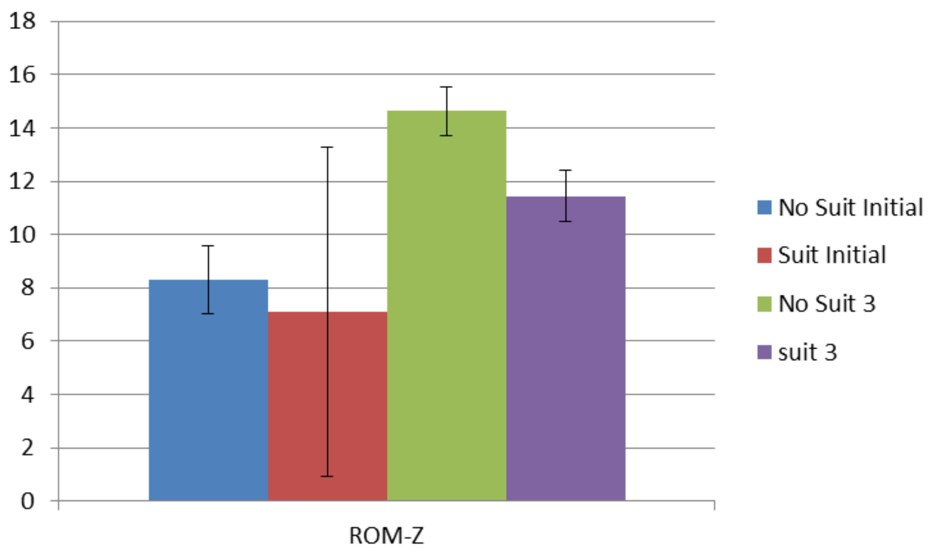
Graph 5.42 Maximum and minimum affected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion is expected to reach 10° above that found at heel strike and, though initially low, increases gradually across all conditions to 9.25° during S3. Extension at pre-swing during NIni is found to be above normal at -5.19°, and the introduction of the suit caused 0.16° of flexion to occur during SIni. At 3 months extension is increased to -11.89° during NS3, which is above the normal 0° (see figure 4.5e); however knee extension is increased to -6.31° which is within the normal age-matched range. Maximal knee flexion is at the normal age-matched range of 64.35° during NIni, though this is reduced during SIni (see graph 5.42). After 3 months, flexion increases above normal levels in both conditions.



Graph 5.43 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

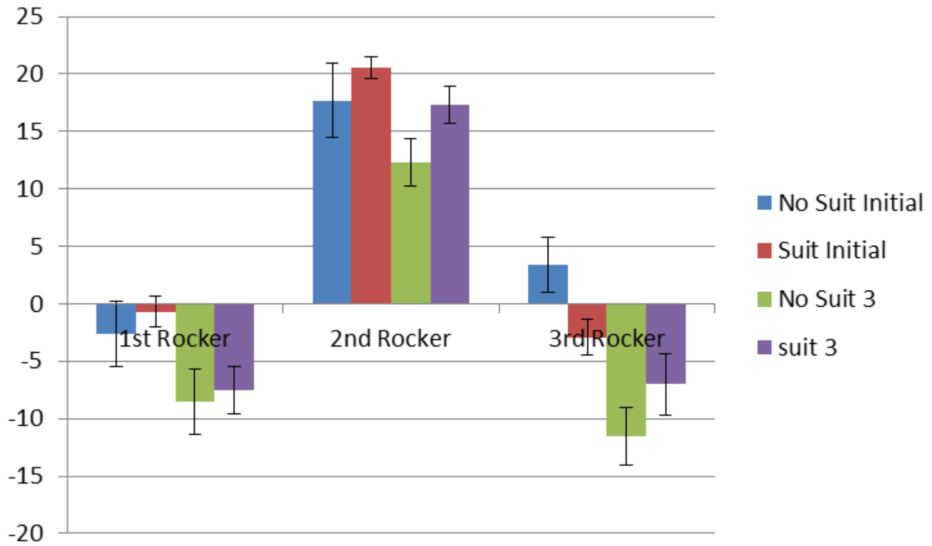
Hip Flexion at heel strike is around 55° during NIni, and reduces to 44° when the suit is worn during SIni. At 3 months hip flexion increases to 62° during NS3 and reduces to 46° during S3, all conditions are higher than the normal 41° flexion found at heel strike. The hip does not go into extension during any condition with flexion remaining between 14.58° during SIni and 19.97° during NIni, except for during S3 where flexion is reduced to 4.96°. Maximal flexion is found to be above the normal range during NIni at 64.35° and reduces to 51.47 during SIni°. At 3 months maximal hip flexion reaches 77.26° during NS3 (see graph 5.43), which is higher than the normal age-matched value of 57°. Flexion reduces to 54.72° during S3, which is closer to normal age-matched values (see figure 4.5f).



Graph 5.44 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

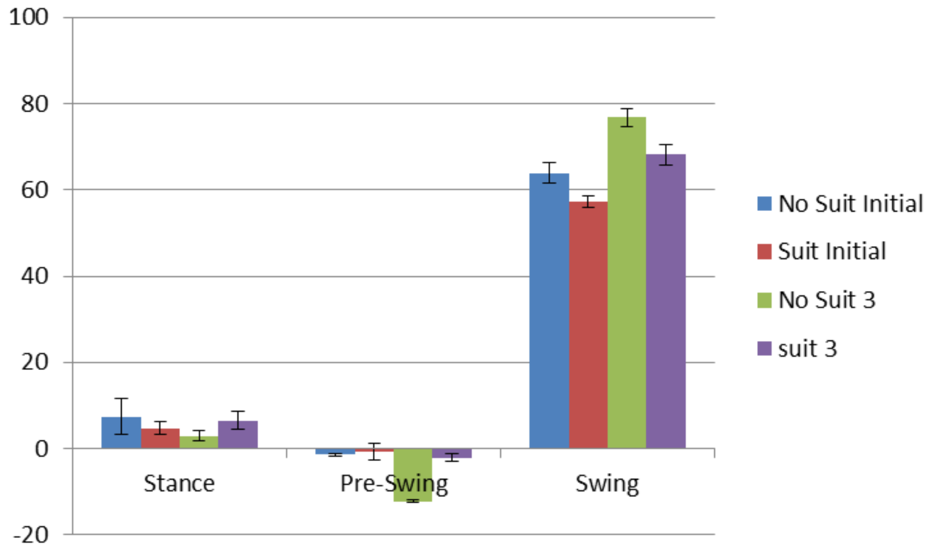
Hip ROM is below the normal age-matched value of 18° during NIni and is reduced further to 7.11° during SIni. After 3 months ROM increases during NS3 to 14.62°, which is closer to normal age-matched values, but is again reduced during S3 to 11.44° (see graph 5.44).

Left Leg-Affected



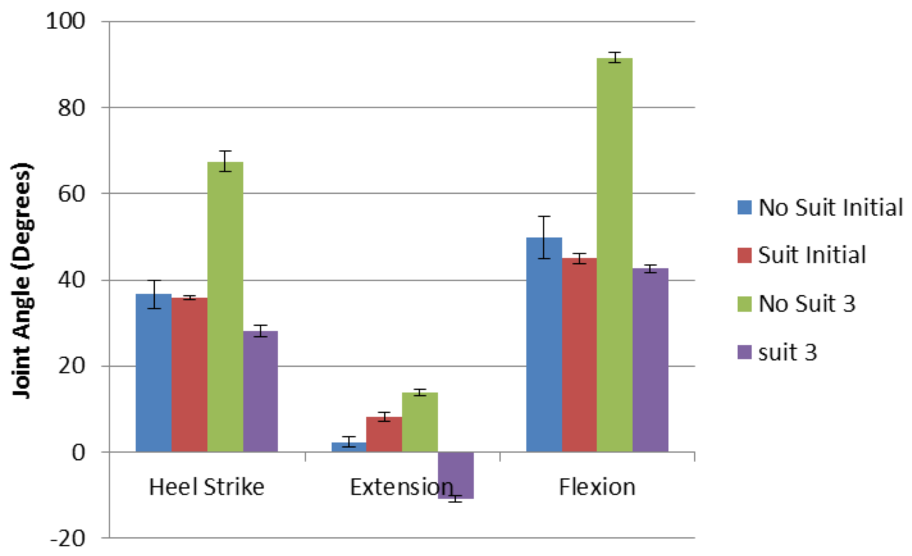
Graph 5.45 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Ankle plantarflexion during the 3rd rocker is within the normal range at -2.64° (see figure 4.5d) during NIni. SIni reduces planter flexion to -0.71°. At 3 months plantarflexion increases to -8.54° during NS3 and -7.54° during S3, both of which are above the range found in normal age-matched subjects. Dorsiflexion during the 2nd rocker is above normal at 17.7° during NIni and increases to 20.59° during SIni. At 3 months dorsiflexion is 12.27° during NS3 and 17.36° during S3. During the 3rd rocker the ankle does not plantarflex during NIni. When the suit is worn plantarflexion reaches -2.94°, which is much lower than the normal age-matched value of -18°. At 3 months, plantarflexion increases to – 11.54° during NS3 and -7.02° during S3 (see graph 5.45).



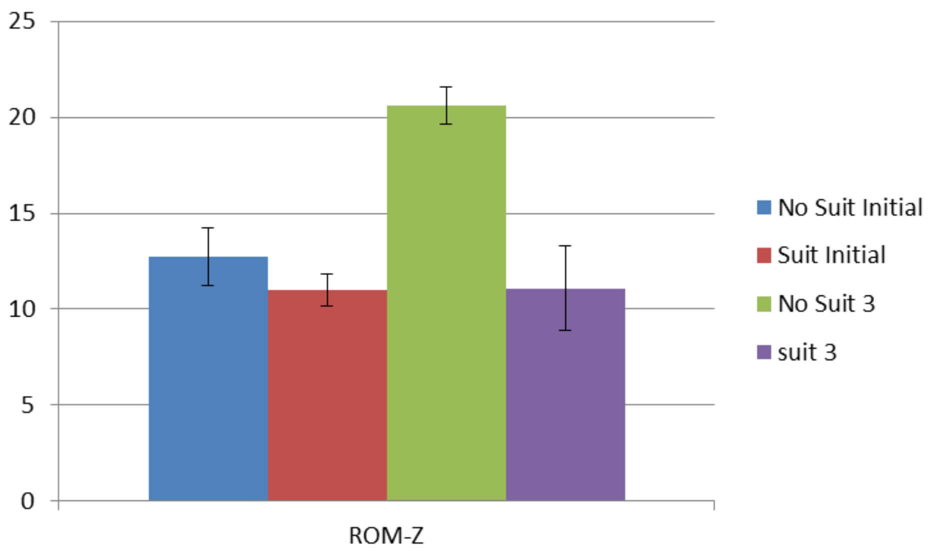
Graph 5.46 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance is lower than the expected 10° (see figure 4.5e) across all conditions. Extension during pre-swing is higher than the normal values of 0° across all conditions. Knee flexion during the swing phase is normal at 63.85° during NIni, and is reduced to 57.24° during SIni which is below normal values. At 3 months flexion has increased to 76.71° during NS3, reducing to 68.1° during S3 (see graph 5.46), which is within the normal age-matched range.



Graph 5.47 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike is below the normal range for both initial conditions. At 3 months flexion increases to around 67° which is much higher than the 41°found in normal populations (see figure 4.5f). The hip does not move into extension in all conditions except during S3. Extension reaches -10.82°, which is above the normal age-matched value of -4°. Maximal flexion is higher than normal across all conditions, especially during NS3 where flexion reaches 91.53° (see graph 5.47).



Graph 5.48 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM is found to be between 2° to 3° lower than the normal 18° across all conditions except during NS3 where ROM reaches 22.61°, which is higher than that found in normal age-matched subjects (see graph 5.48).

Table 5.6 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

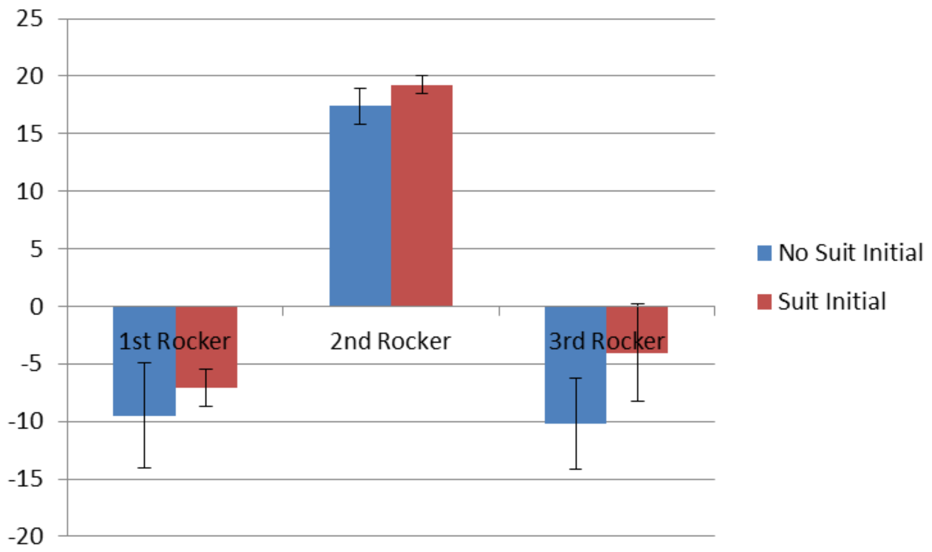
		Right Initial No	Right Initial Suit	Right 3mth No	Right 3mth Suit	Left Initial No	Left Initial Suit	Left 3mth No	Left 3mth Suit
Ankle	1st Rocker	-0.99	-1	-9.56	-12.75	-2.64	-0.71	-8.54	-7.54
	2nd Rocker	24.41	23.04	17	16.22	17.7	20.59	12.27	17.36
	3rd Rocker	9.25	4.23	-3.73	-9.34	3.43	-2.94	-11.54	-7.02
Knee	Stance	6.07	4.44	7.29	9.25	7.41	4.66	2.99	6.54
	Pre-Swing	-5.19	0.16	-11.89	-6.31	-1.41	-0.77	-12.19	-2.15
	Swing	63.27	58.58	77.07	70.21	63.85	57.24	76.71	68.1
Hip	Flexion	64.35	51.47	77.26	54.72	49.74	44.94	91.53	42.61
	Extension	19.97	14.58	19.36	4.96	2.39	8.1	13.79	-10.82
	ROM	8.3	7.11	14.62	11.44	12.71	11.01	20.61	11.08

Participant 6- Summary of Findings

Participant 6 is a 3yr old who has been diagnosed with developmental delay. Plantarflexion in the right ankle is below normal initially and little change is brought about by the suit at this point. After 3 months plantarflexion in both ankles increases a large amount to above normal in both conditions, this may be brought about by the higher levels of dorsiflexion during the swing phase to prevent tripping. Dorsiflexion during the 2nd rocker is higher than normal (see figure 4.5d) across all conditions on both sides. Initially neither ankle moves into plantarflexion during the third rocker, and although the suit brings about plantarflexion in the left ankle (see graph 5.45) it is much lower than normal levels and is not evident in the right ankle (see graph 5.41). After 3 months wear plantarflexion has increased both with and without the suit, but is still much below normal levels. Patterns of change in knee flexion are very similar in both knees. Flexion of the knee during stance phase is low across all conditions and is reduced further by the introduction of the suit. After 3 months wearing the suit flexion increases very slightly. Extension of 0° is expected during the pre-swing phase in children of 3yrs old (see figure 4.5e); though minimal extension is evident initially the introduction of the suit reduces this level to near 0°. After 3 months wear extension without the suit is increased to around -11° on both knees, this is reduced during S3, but is still found to be above normal levels. Knee flexion is found to be at normal levels initially on both sides, though this is reduced when the suit is worn. After 3 months flexion is increased to within normal levels in both conditions, reaching the highest levels during S3 (see graphs 5.41 and 5.46). Although the movement patterns are similar on both legs at ankle and knee level, there are differences found at the hip. The right hip is found to reach higher levels of flexion at heelstrike than normal across all conditions (see graph 5.43), though wearing the suit does reduce this at both time-points. In comparison the left hip is found to reach lower angles of flexion than the normal 41°, though this is greatly increased to 77.26° during NS3 (see graph 5.47). Maximal flexion was found to follow the same pattern also. The hip flexion angles could suggest instability around the joint, or the child could be over-compensating against the restriction brought about whilst wearing the suit. Hip rotation is found to be lower than the normal age-matched value of 18° across all conditions, although both legs see an increase in ROM during NS3 (see graph 5.44 and 5.48) only the left hip increases above normal age-matched values.

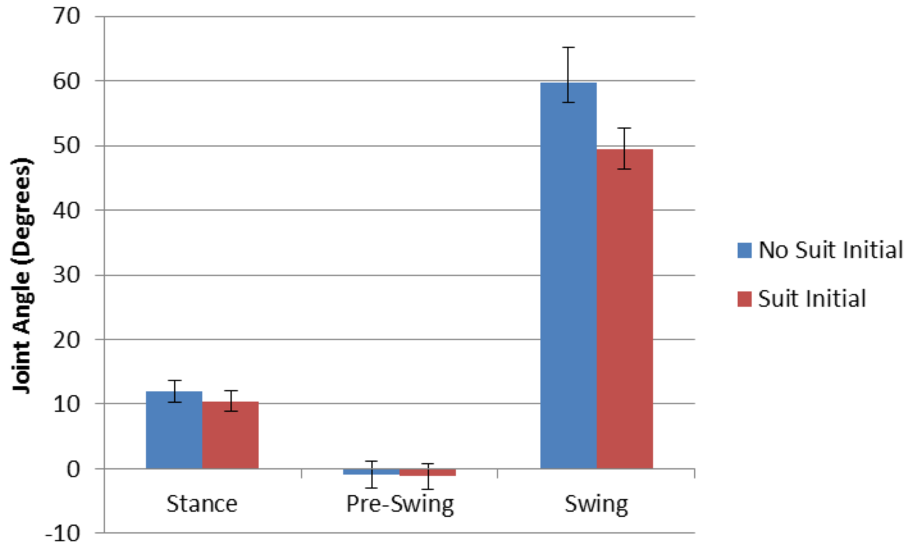
5.1.7 PARTICIPANT 7- AN 8YR OLD WITH SPASTIC DIPLEGIA

Right Leg- Affected



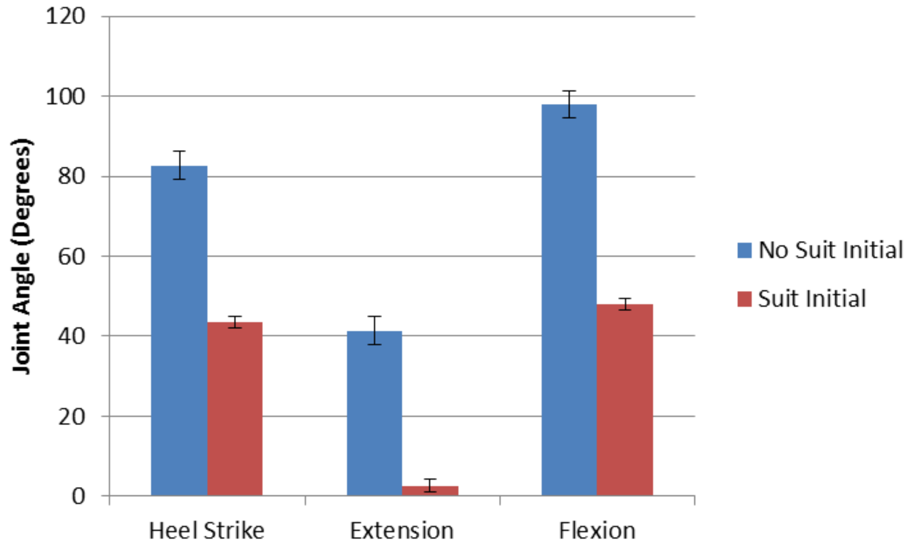
Graph 5.49 Maximum and Minimum affected (right) ankle joint angles at 1^{st}, 2^{nd} and 3^{rd} rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Ankle plantarflexion in relation to heel strike is higher than the normal age-matched range of -3° to -5° (see figure 4.5m) in both conditions, though the suit reduces plantarflexion by 3°. Dorsiflexion during the 2^{nd} rocker is higher than normal reaching 17.42° during NIni and 19.27° during SIni. Plantarflexion during the third rocker would be expected to reach -15° to -20°, but is -10.21° during NIni and reduced to -4.05° during SIni (see graph 5.49).



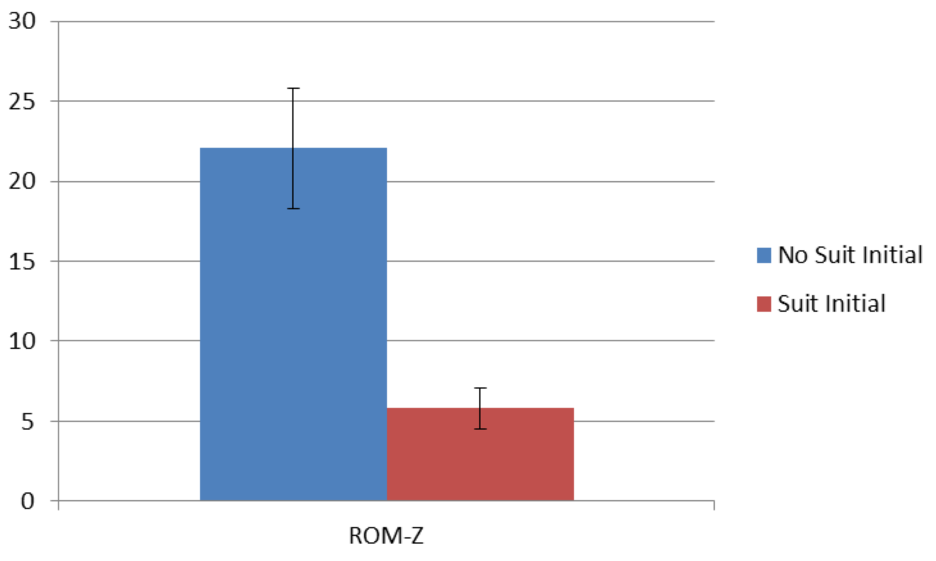
Graph 5.50 Maximum and minimum affected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance would be expected to reach 20° in relation to angle at heel strike (see figure 4.5n), but only reaches half this in both conditions. Extension during pre-swing is low reaching -0.95° to -1.19° in both conditions (see graph 5.50), where -5° to -10° is found in normal age-matched subjects. Maximal flexion during the swing phase is below the 65°-70° angles expected to be found at this point in the gait cycle.



Graph 5.51 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

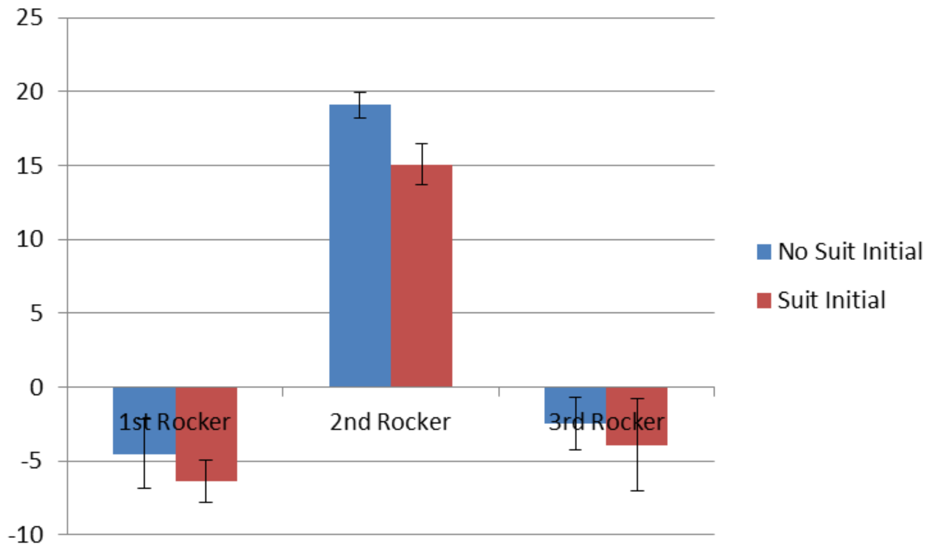
The introduction of the suit decreased movement by around 40° at all three points measured (see graph 5.51). Flexion at heel strike was reduced to around 42° which is much closer to the normal age-matched range of 30° to 40° (see figure 4.5o). The hip did not move into extension during either condition; however flexion was greatly reduced to around 2.66° during SIni. Maximal flexion was reduced from 97.92° to 48.09°, which is again much closer to the 30° to 40° found in normal age-matched subjects.



Graph 5.52 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

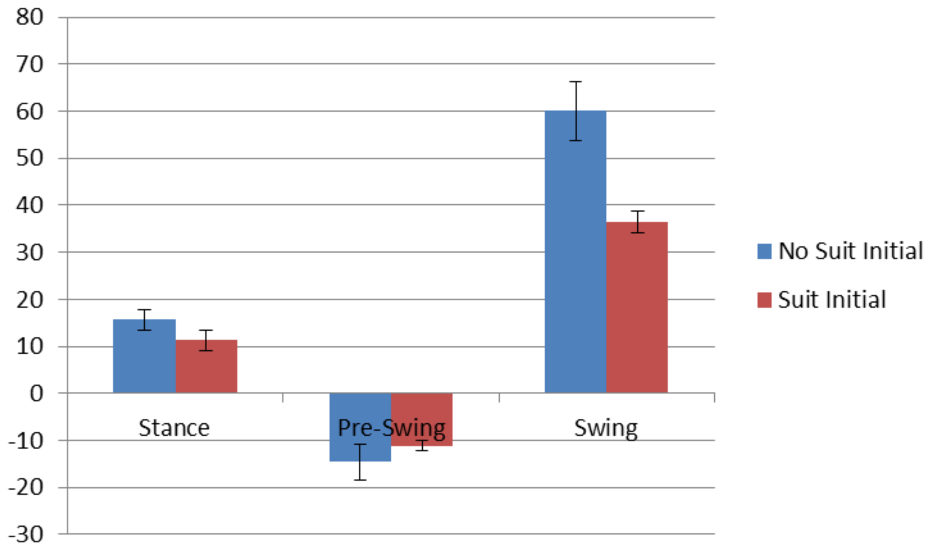
ROM in the coronal plane was reduced from 22.05° during NIni to 5.81° during SIni. The normal age-matched ROM is around 15° (see graph 5.52).

Left Leg- Affected



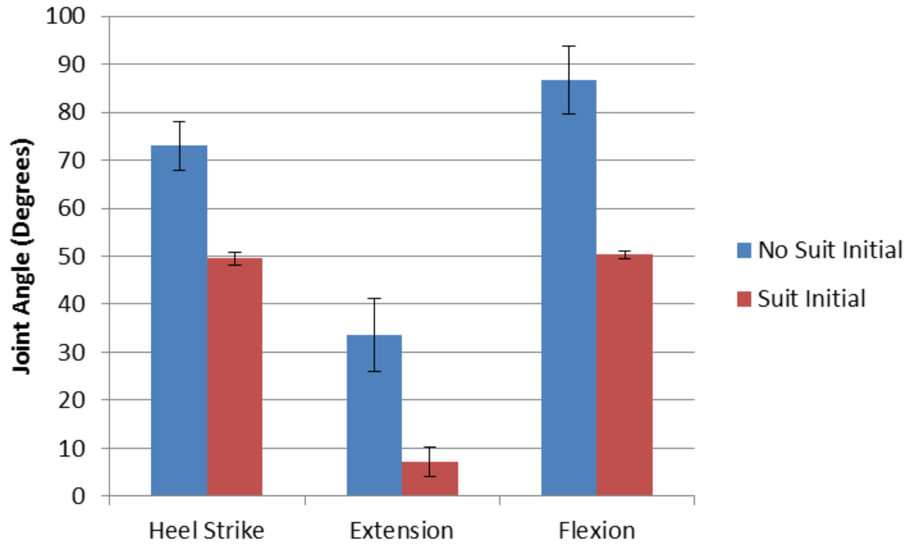
Graph 5.53 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion during NIni -4.54° which is within the normal age-matched range of -3° to -5°, plantarflexion increases to -6.37° during SIni, which is slightly above normal (see figure 4.5m). Dorsiflexion during the second rocker is reduced from 19.1° to 15.07° during SIni, which is still above the normal age-matched value of 10°. Plantarflexion during the third rocker would be expected to reach -15° to -20°, however the suit increases plantarflexion by nearly 2° to -3.93° (see graph 5.53).



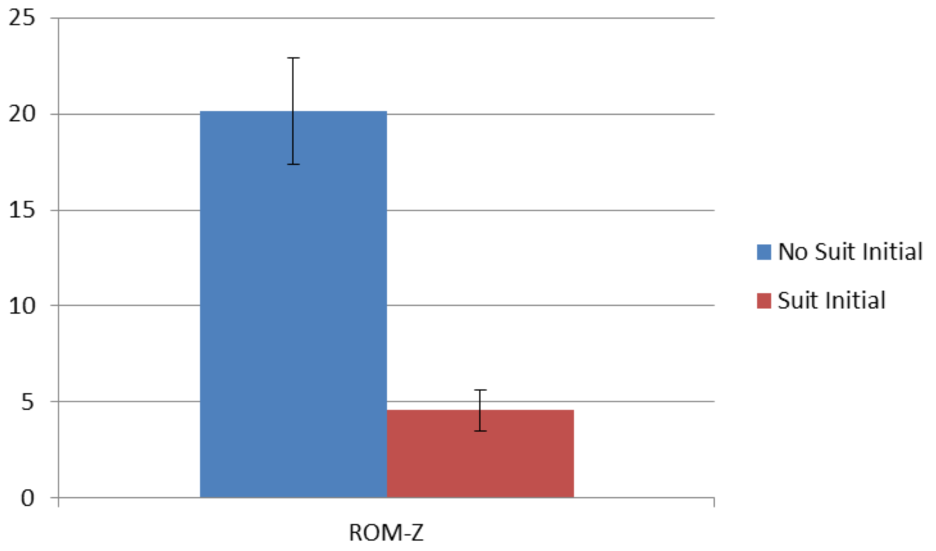
Graph 5.54 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion would be expected to reach around 20° during stance phase; however it reaches 15.66° during NIni and is reduced to 11.27° during SIni. Extension during the pre-swing phase is above the normal -5° to -10° at -14.62° during NIni, which is reduced to -11.16° during SIni (see graph 5.54). During the swing phase knee flexion is close to the 65° to 70° angle found in normal age-matched subjects (see figure 4.5n); however this is reduced to 36.45° whilst wearing the suit.



Graph 5.55 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion is higher than the normal 30° to 40° found at heelstrike (see figure 4.5o), but is reduced from 74° to 49° with the introduction of the suit. The hip does not move into extension at all throughout the gait cycle, though the suit reduces flexion from 33.64° during NIni to 7.24° during SIni. Maximal flexion is above the normal range of 30° to 40° at 86.66° during NIni and reducing to 50.26° during SIni (see graph 5.55).



Graph 5.56 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM of the hip in the coronal plane is 20.14° during NIni, which is higher than the normal age-matched value of 15°. ROM is reduced to 4.56° during SIni (see graph 5.56).

Table 5.7 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

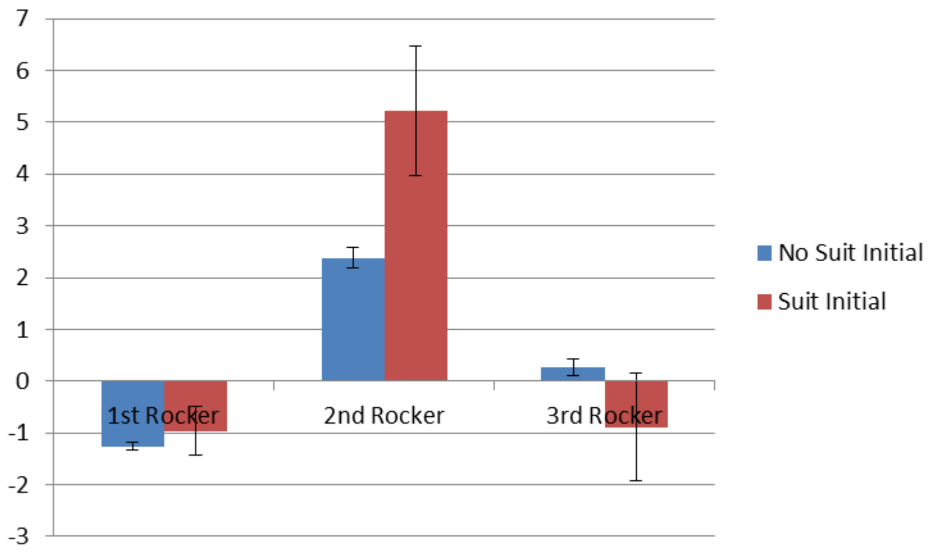
		Right Initial No	Initial Suit	Left Initial No	Initial Suit
Ankle	1st Rocker	-9.49	-7.11	-4.54	-6.37
	2nd Rocker	17.42	19.27	19.1	15.07
	3rd Rocker	-10.21	-4.05	-2.46	-3.93
Knee	Stance	11.91	10.42	15.66	11.27
	Pre-Swing	-0.95	-1.19	-14.62	-11.16
	Swing	59.71	49.46	60.08	36.45
Hip	Flexion	97.92	48.09	86.66	50.26
	Extension	41.41	2.66	33.64	7.24
	ROM	22.05	5.81	20.14	4.56

Participant 7-Summary of Findings

Participant 7 is an 8yr old presenting with spastic diplegia, data was not collected for the 3 month's time point. Plantarflexion of the right ankle in relation to ankle angle at heelstrike is higher than normal (see graph 5.49) even when the suit reduces it. In the left ankle plantarflexion is within the normal range during NIni (see graph 5.53), but is increased above normal level (see figure 4.5m) when wearing the suit. Similar results are found in levels of plantarflexion during the third rocker. Dorsiflexion in both conditions is higher than normal on both sides, though the suit brings about an increase in dorsiflexion on the right ankle and a decrease on the left. This may be to counteract the different effect the suit has during the first and third rockers, with the suit moving the ankle angle more towards dorsiflexion throughout the entire gait cycle. Knee flexion during the stance phase is around half the normal range (see figure 4.5n) in both conditions. Extension of the right knee is low at around -1° in both conditions (see graph 5.50), whereas it is found to be higher than normal in the left knee (see graph 5.54). Knee flexion during the swing phase is below the normal 65° to 70° at around 60° on both knees, this is reduced further during SIni. Flexion at heelstrike was higher than normal (see figure 4.5o) during NIni in both hips, reducing on both sides during SIni. The same pattern was followed with maximal flexion though normal levels are not reached. The hip does not reach extension in either condition, though the suit reduced levels of flexion markedly on both sides. The hip rotation is much higher than the normal ROM of 15° on both sides during NIni, though the suit brings this to below normal levels (see graphs 5.51 and 5.55). The suit shows very similar effects on both legs in this child, reducing movement at all points except during dorsiflexion of the ankle.

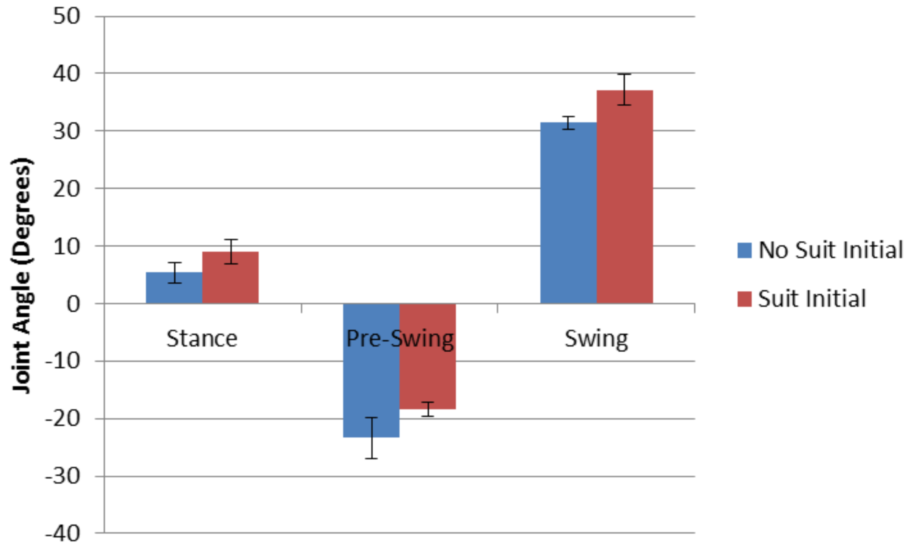
5.1.8 PARTICIPANT 8- A 4YR OLD WITH SPASTIC DIPLEGIA

Right Leg- Affected



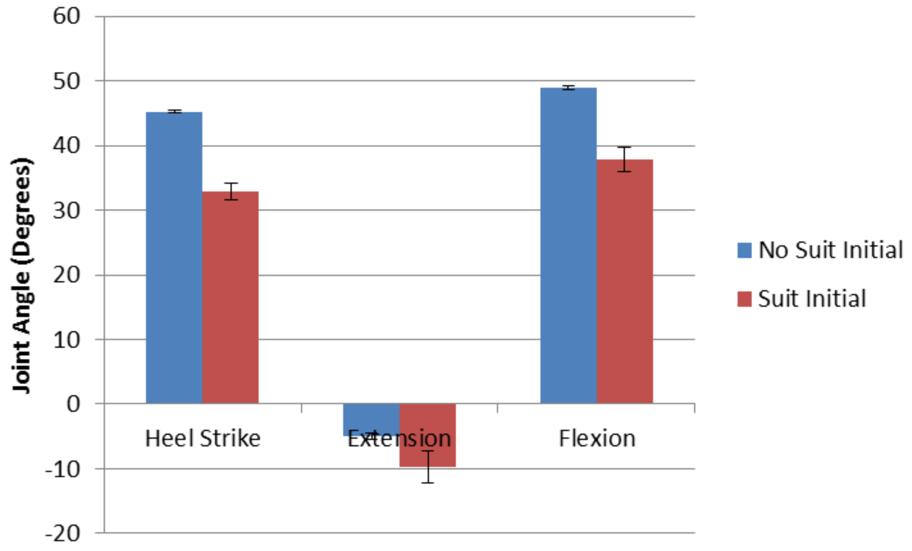
Graph 5.57 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion during both NIni and SIni is below the normal age-matched value of -2° at around -1° in both conditions. Dorsiflexion during the second rocker is also below the normal 13° (see figure 4.5g) at around 2.38° during NIni and increasing to 5.21° during SIni. Plantarflexion in the 3rd rocker does not occur during NIni, with the ankle remaining in 0.26° of dorsiflexion (see graph 5.57). Plantarflexion of -0.89° is reached during SIni, but this is still much lower than the -18° range found in normal gait patterns.



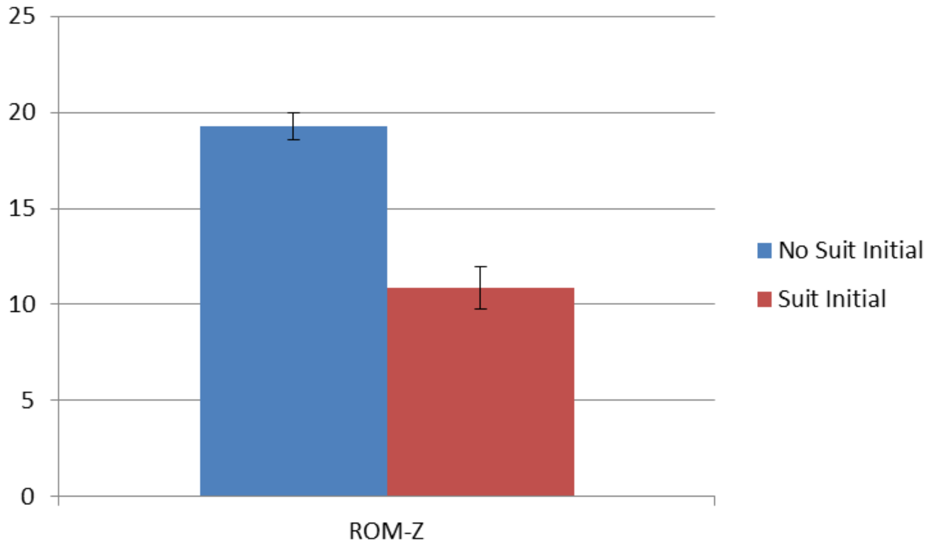
Graph 5.58 Maximum and minimum affected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion is expected to reach around 12° more than that found at heel strike during the stance phase (see figure 4.5h). The flexion found during NIni is 5.43° which is lower than normal age-matched values, and is increased to 9.02° during SIni. Extension during the pre-swing phase reaches -23.38° during NIni and -18.42° during SIni, both of which are higher than the normal age matched value of -1°. Flexion during the swing phase would be expected to reach around 66° in normal age-matched subjects; however flexion only reaches 31.45° during NIni and 37.85° during SIni (see graph 5.58).



Graph 5.59 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

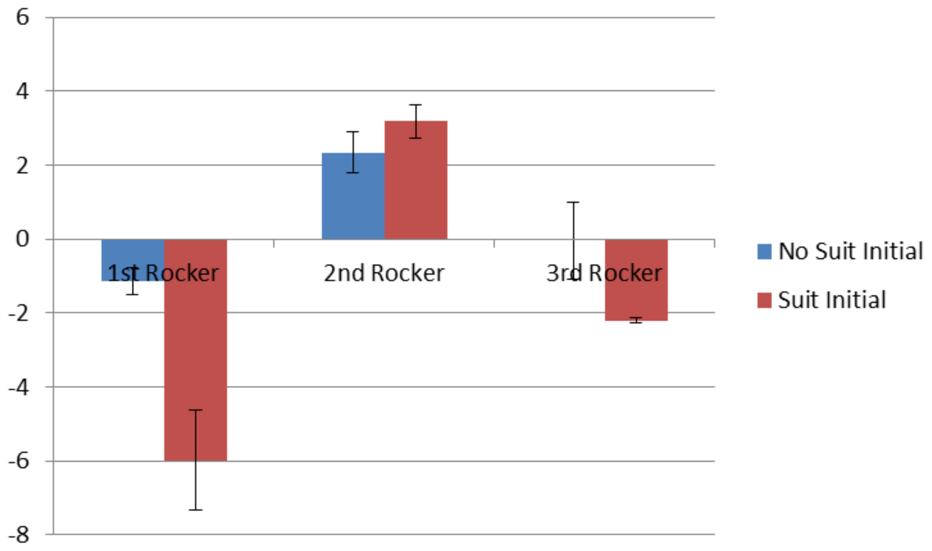
Hip flexion at heelstrike is 46° initially, which is above the normal range 42.5° found in 4yr olds gait (see figure 4.5i). The introduction of the suit reduces flexion to 33°, which is below the normal range. Extension is above the -3° found in normal age-matched subjects at -4.89° during NIni and -9.7° during SIni. Maximal flexion is close to the normal age-matched value range of 50° during NIni, but is reduced to 37.85° during SIni (see graph 5.59).



Graph 5.60 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle.

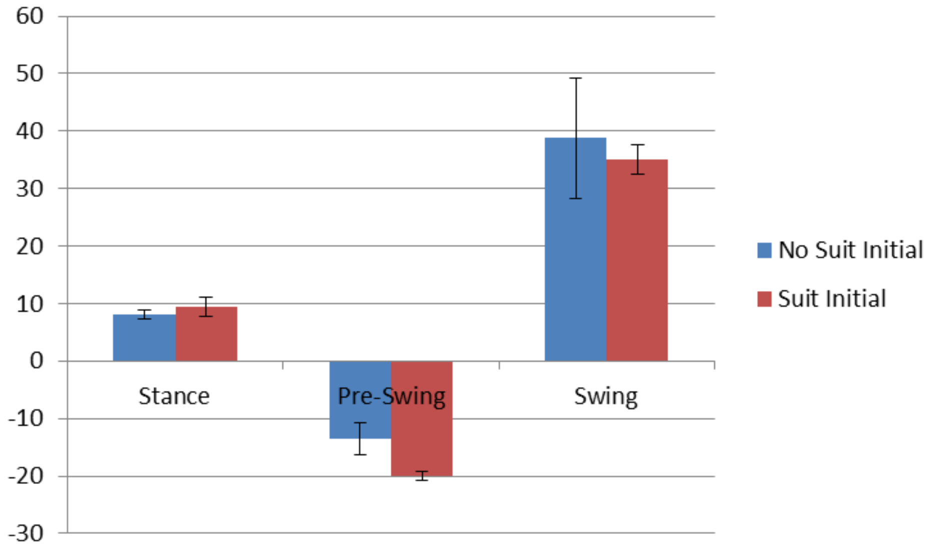
ROM in the coronal plane is above the normal age-matched value of 17° during NIni at 19.28° and below normal at 10.87° during SIni. Error bars show standard deviation across 9 gait cycles. (see graph 5.60)

Left Leg- Affected



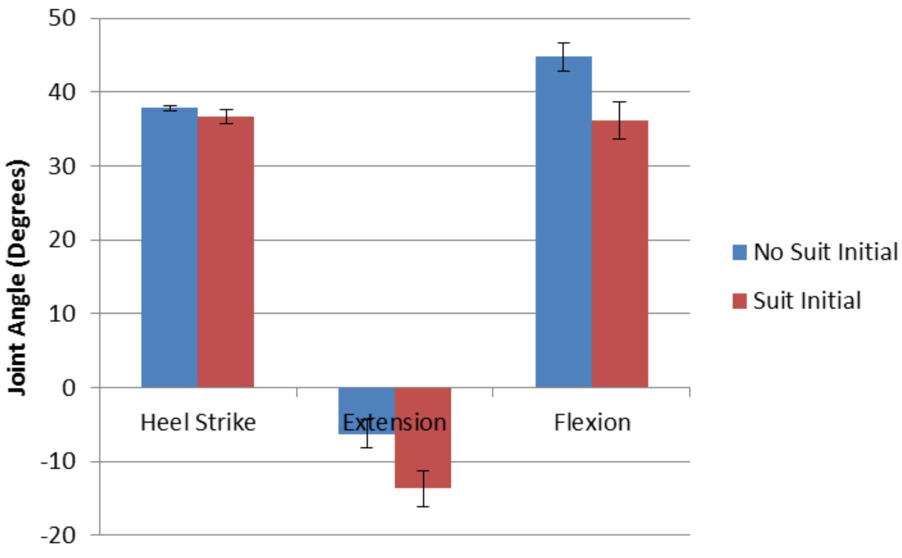
Graph 5.61 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion is -1.14° more than at heelstrike during the first rocker during NIni; this is lower than -2° value found in normal age-matched subjects (see figure 4.5g). This is increased to -5.98° during SIni. During the second rocker dorsiflexion would be expected to reach 13°, but is only 2.34° during NIni and 3.18° during SIni. Plantarflexion during the third rocker is also much lower than the -18° value found in normal age-matched subjects at -0.04° during NIni and -2.2° during SIni (see graph 5.61).



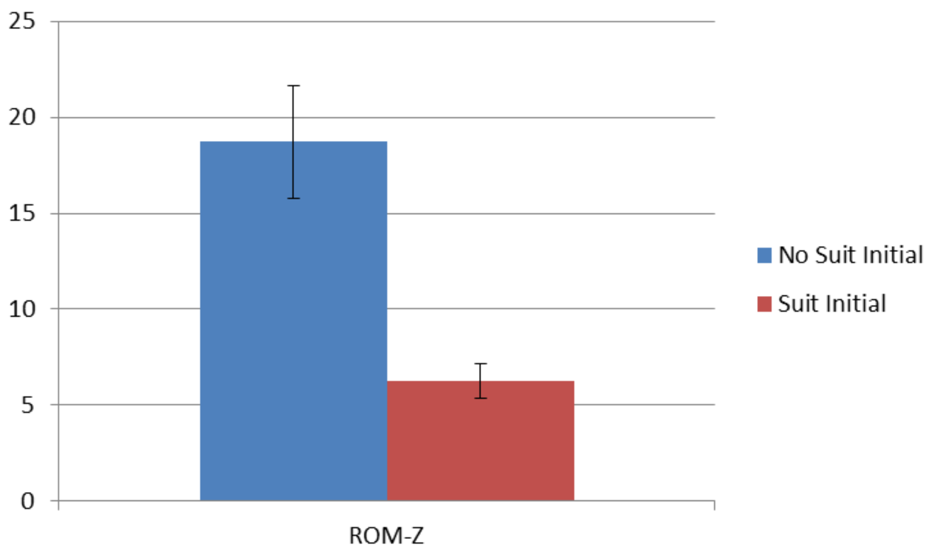
Graph 5.62 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during the stance phase is lower than the normal age-matched value of 12° (see figure 4.5h) in both conditions at 8.1° during NIni and 9.48° during SIni. Extension during pre-swing is above the normal age-matched value of -1° in both conditions measuring -13.45° during NIni and -20.06° during SIni. Flexion during the swing phase would be expected to reach 66° in normal age-matched subjects, but is much lower here. Maximal flexion reaches 38.75° during NIni and is reduced further to 35.01° during Sini (see graph 5.62).



Graph 5.63 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip flexion at heel strike is slightly below the normal age-matched vale of 42° (see figure 4.5i) in both conditions. Maximal extension is above the normal value of -3°, measuring -6.28° during NIni and -13.66° during SIni. Maximal flexion is below the normal age-matched 50° during NIni at 44.78°. The introduction of the suit during SIni reduces flexion to 36.13° (see graph 5.63).



Graph 5.64 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM in the coronal plane is above the normal age-matched 17° during NIni at 18.72°. This reduced to 6.28° during SIni, which is below the normal age-matched value (see graph 5.64).

Table 5.8 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

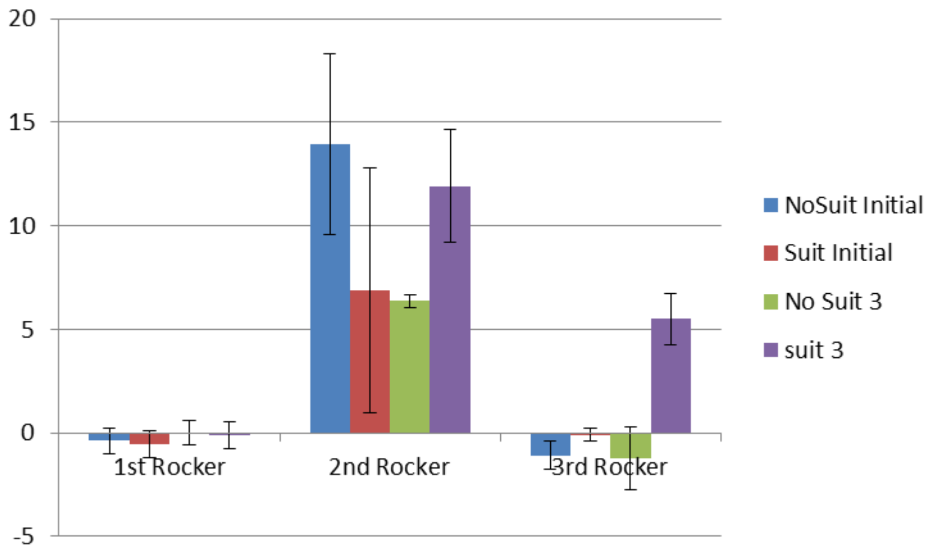
		Right		Left	
		Initial No	Initial Suit	Initial No	Initial Suit
Ankle	1st Rocker	-1.26	-0.96	-1.14	-5.98
	2nd Rocker	2.38	5.21	2.34	3.18
	3rd Rocker	0.26	-0.89	-0.04	-2.2
Knee	Stance	5.43	9.02	8.1	9.48
	Pre-Swing	-23.38	-18.42	-13.45	-20.06
	Swing	31.45	37.18	38.75	35.01
Hip	Flexion	48.98	37.85	44.78	36.13
	Extension	-4.89	-9.7	-6.28	-13.66
	ROM	19.28	10.87	18.72	6.28

Participant 8-Summary of Findings

Participant 8 is a 4yr old child diagnosed with spastic diplegia. Motion data was only captured for the initial time point. Plantarflexion is lower than normal in both conditions on the right ankle (see graph 5.57), and though it is found to also be low initially, it rises above normal levels to -5.98° on the left during SIni (see graph 5.61). Dorsiflexion during the 2nd rocker is very similar on both sides at around 2.35° during NIni. The suit increases dorsiflexion on both sides, but to a much higher degree on the right ankle, though this is still much lower than the 13° found in normal age-matched subjects (see figure 4.5g). Plantarflexion during the 3rd rocker is only reached during SIni on the right ankle, and although the suit increases this on both ankles the angles are still far below normal age-matched values. Knee flexion during stance is below normal in both conditions even though SIni does bring about a small increase. Extension during the pre-swing phase is higher than normal across all conditions on both sides, though SIni brings about a reduction in extension on the right knee (see graph 5.58), and an increase on the left (see graph 5.62). Maximal knee flexion during the swing phase is below the normal level of 66° across all conditions on both sides, though SIni causes an increase in flexion on the right knee, and a decrease on the left, which is a shift in the same direction of movement found during pre-swing. Hip flexion at heelstrike is below normal in both conditions on the left side (see graph 5.63). Flexion is higher than the normal 42.5° during NIni on the left side, though SIni reduces this to 33° which is much lower. Extension is above normal on both sides during NIni at -4.89° to -6.28°, this is increased further during SIni. Maximal flexion is slightly below the normal range initially on both sides, and is reduced further when the suit is worn. Overall the suit tends to shift movement in the sagittal plane towards extension in both hips (see graphs 5.59 and 6.63). Rotation at the hip is similar on both sides initially and is slightly above the normal 17°. The suit reduces the ROM to below normal at 11° on the right hip (see graph 5.60) and 6° on the left (see graph 5.64_. The response to the suit is clearly different between both sides.

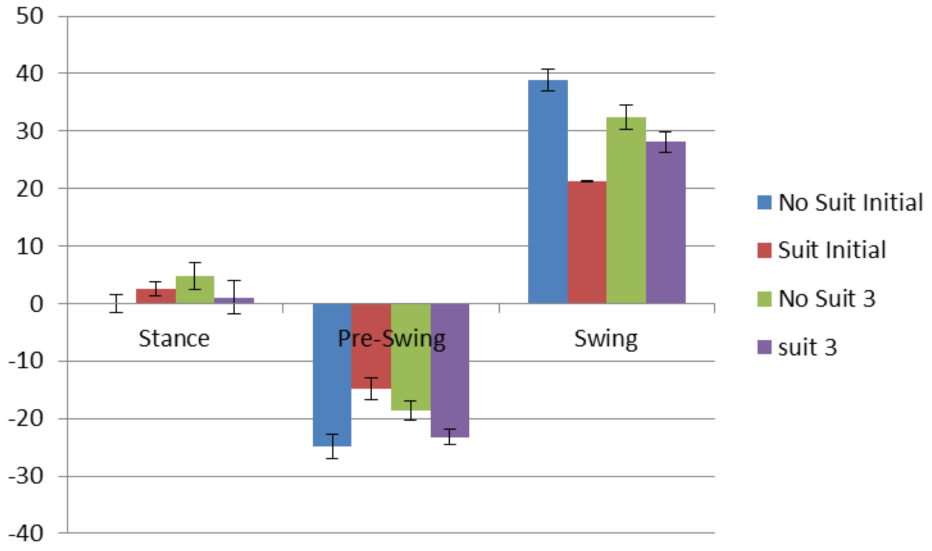
5.1.9 PARTICIPANT 9- A 3YR OLD WITH SPASTIC DIPLEGIA

Right Leg- Affected



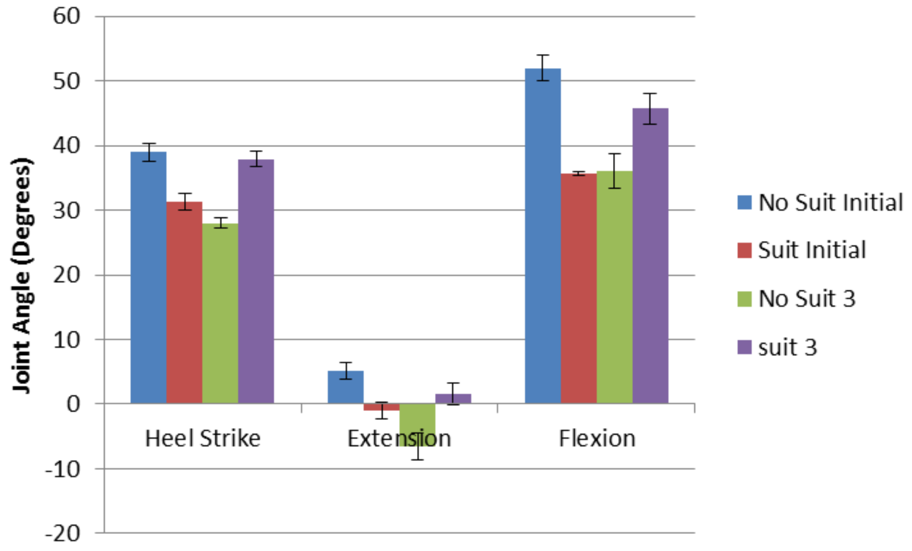
Graph 5.65 Maximum and Minimum affected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion is around the normal -2.5° (see figure 4.5d) during initial testing in both conditions, but this is reduced to nearly 0° after 3 months. Dorsiflexion during the 2nd rocker is above the normal 10° during NIni at 13.96°, but is halved during SIni to 6.9°. After 3 months flexion is increased to 11.92 during S3°, which is still below NIni. Plantarflexion during the 3rd rocker reaches a maximum of -1.24°, which is much lower than the normal age-matched value of -18°. Plantarflexion during NIni is very low at -1.1°, and dorsiflexion of 5.5° occurs during S3 (see graph 5.65).



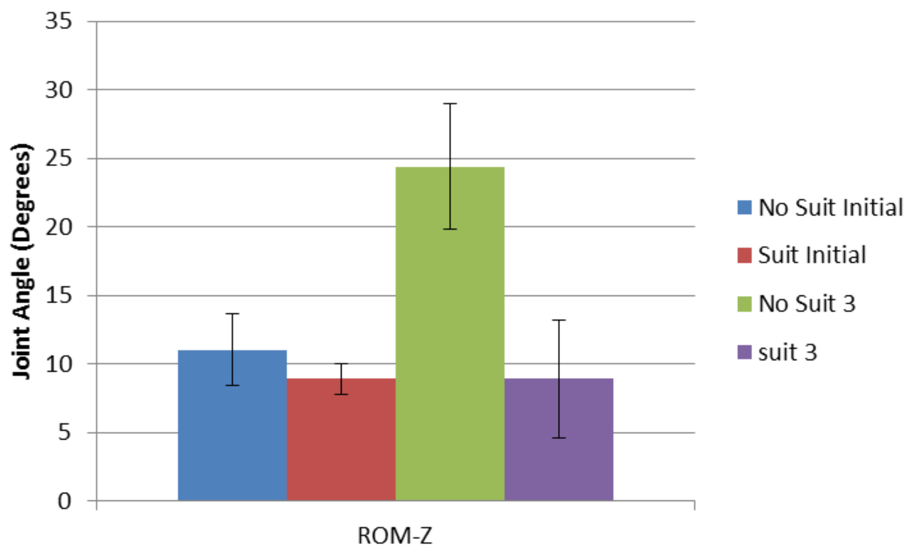
Graph 5.66 Maximum and minimum affected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Flexion during the stance phase is much lower than the 10° found in normal 3 yr olds (see figure 4.5e). Extension during pre-swing would not be expected, with the knee remaining at 0°, however it is much higher here, reaching up to -24.89° during NIni. This is reduced to -14.8° during SIni, but this increases again after 3 months wear. Flexion during the swing phase would be expected to reach 64°, but is much lower across all conditions, reducing further whilst wearing the suit at both time points (see graph 5.66).



Graph 5.67 Angles at heel strike, maximum flexion and extension at the affected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

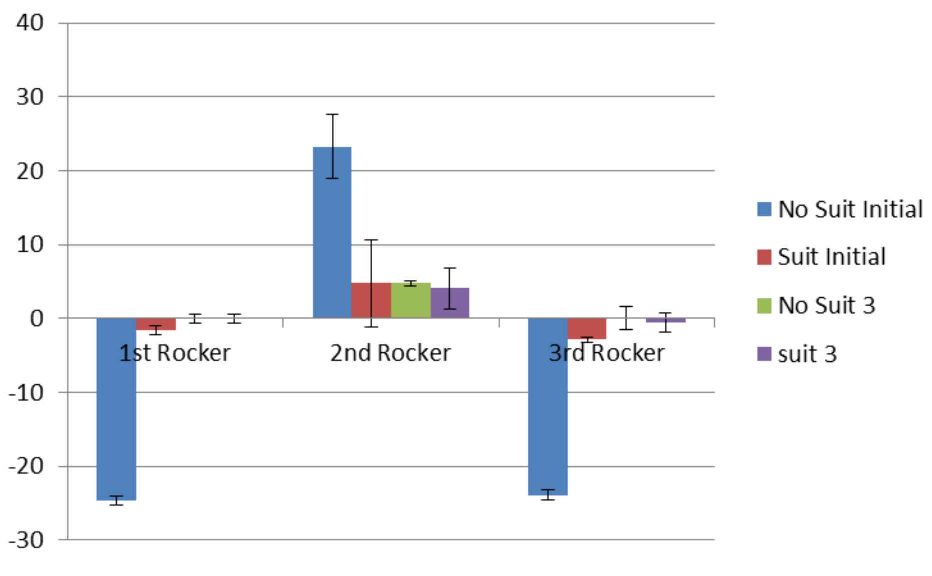
Flexion is close to the normal age-matched value of 41° at 39° (see figure 4.5e) during NIni, this is reduced to 31° during SIni. After 3 months Flexion is reduced further, but increases to 39° during S3. The hip does not move into extension during NIni, remaining flexed at 5.11°, extension of -1.05° is reached during SIni, after 3 months this is increased to -6.62° during NS3, but the hip remains in flexion at 1.58° during S3. Maximal flexion reaches 52° during NIni, which is slightly below the 57° found in normal age-matched subjects. Flexion is reduced to 35° when the suit is worn. After 3 months flexion remains around 36.05° during NS3, and increases to 45.68° during S3 (see graph 5.67).



Graph 5.68 Range of motion of the affected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

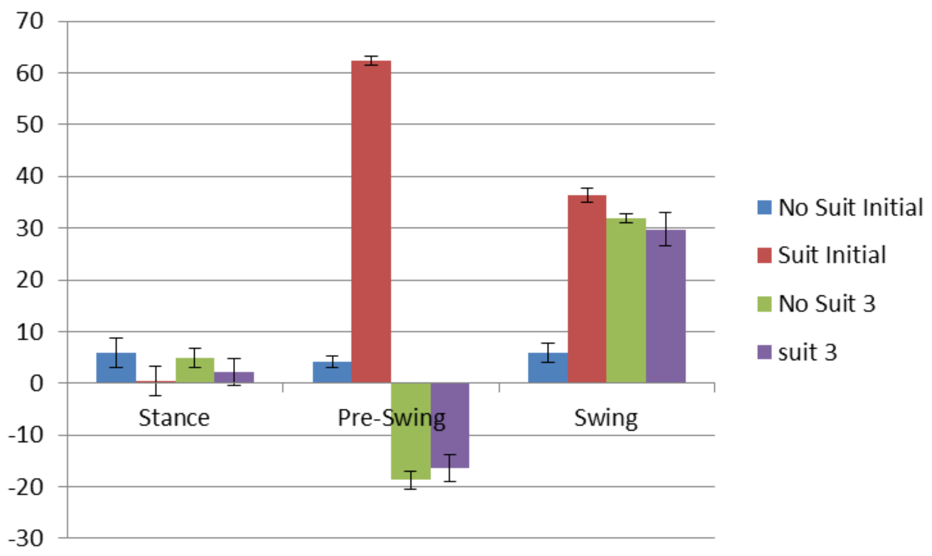
ROM at the hip is lower than the normal 18° across all conditions except during NS3, where it reaches 24.38°. No data was captured during NIni (see graph 5.68).

Left Leg- Affected



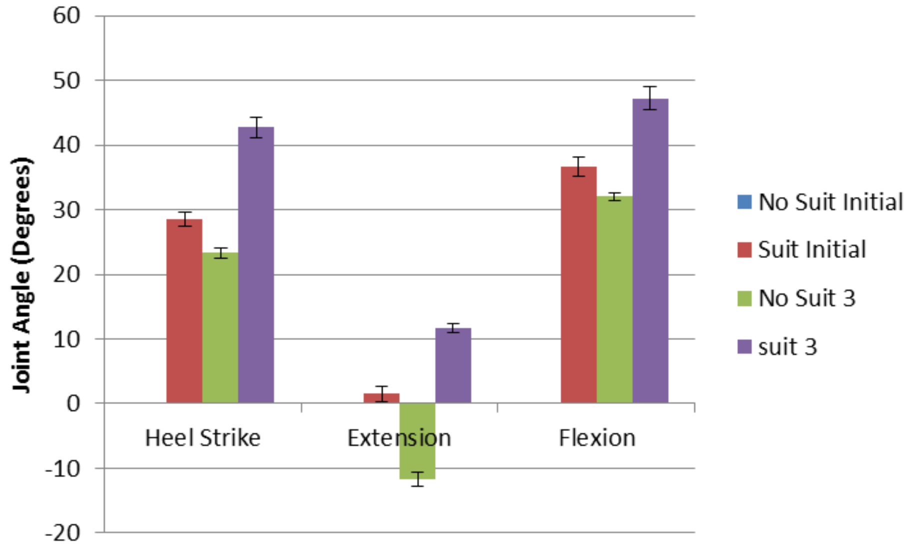
Graph 5.69 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion is much higher than the normal -2.5° during NIni at -24.66°; this is reduced markedly to -1.58° during SIni, which much closer to the normal age-matched range (see figure 4.5d). Ankle angle is the same during 1st rocker and heel strike in both conditions after 3 months. Dorsiflexion during the 2nd rocker reaches 23.26° during NIni, which is higher than 10° found in normal age-matched subjects. Dorsiflexion is reduced to between 4.06° and 4.77° across all other conditions, which is lower than normal. Plantarflexion during NIni is also higher than normal at -23.9° in comparison with -18° (see graph 5.69). Plantarflexion is greatly reduced in all other conditions to between 0° and -3°, which is much lower than found in normal age-matched subjects.



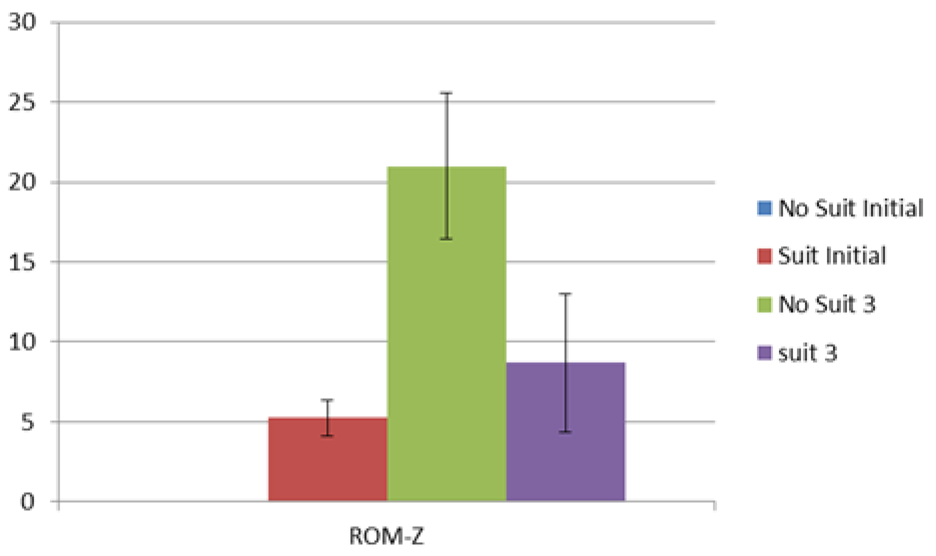
Graph 5.70 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during swing phase would be expected to reach 10° above that at heel strike (see figure 4.5e), but is lower across all conditions and reduced further when wearing the suit. The knee does not reach extension during NIni and a sharp rise to 62.39° occurs during SIni. Extension is evident after 3 months, reaching -18.74° during NS3 and -16.36° during S3, which is above the 0° found in normal age-matched subjects. Flexion of 64° would be expected during the swing phase in normal populations. Flexion during NIni is only 5.96°, and is increased to 36.37° during SIni. Knee flexion remains around 30° in both conditions after 3 months (see graph 5.70).



Graph 5.71 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip data was not captured for the initial no suit trial. Hip flexion at heel strike would be expected to reach 41° (see figure 4.5f). Flexion reaches 28° during NIni, increasing to 42° after 3 months. Flexion decreases to 23° when the suit is removed after 3 months. Extension is only reached whilst not wearing the suit after 3 months, but at -11.69° is much higher than -4° found in normal age-matched subjects. Maximal flexion is lower than the normal 57° across all conditions, reducing further during NS3 to 31.99° (see graph 5.71).



Graph 5.72 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Data was not captured at the hip for the initial no suit condition. ROM is lower than the normal age-matched value of 18° whilst wearing the suit at both time points. ROM increases to 20.98° during NS3, which is closer to normal even though slightly higher (see graph 5.72).

Table 5.9 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait. Amber indicates that there was no change. Where Initial No data was unavailable green indicates the condition closest to normal gait.

		Right Initial No	Right Initial Suit	Right 3mth No	Right 3mth Suit	Left Initial No	Left Initial Suit	Left 3mth No	Left 3mth Suit
Ankle	1st Rocker	-0.39	-0.57	0	-0.1	-24.66	-1.58	0	0
	2nd Rocker	13.96	6.9	6.37	11.92	23.26	4.77	4.74	4.06
	3rd Rocker	-1.1	-0.1	-1.24	5.5	-23.9	-2.88	0.06	-0.52
Knee	Stance	0	2.59	4.74	1.07	5.83	0.51	4.97	2.18
	Pre-Swing	-24.89	-14.8	-18.61	-23.25	4.15	62.39	-18.74	-16.36
	Swing	38.89	21.29	32.37	28.11	5.96	36.37	31.96	29.78
Hip	Flexion	52	35.66	36.05	45.68	0	36.68	31.99	47.23
	Extension	5.11	-1.05	-6.62	1.58	0	1.53	-11.69	11.69
	ROM	11.04	8.91	24.38	8.91	0	5.23	20.98	8.68

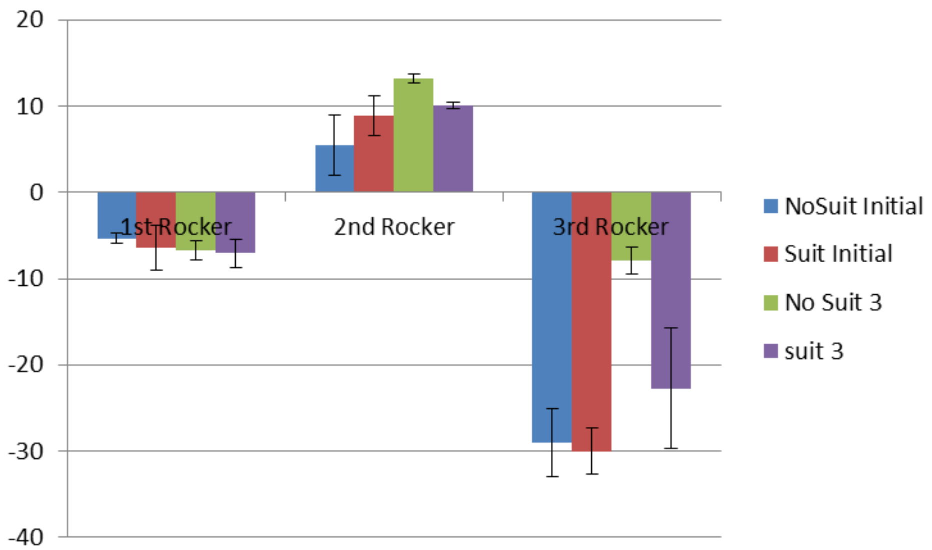
Participant 9-Summary of Findings

Participant 9 is a 3yr old child with spastic diplegia. Motion data for the left hip was not caught for the initial condition. As this was used as a baseline measure hip data for the left hip has been reported by assuming the closest condition to normal measures is 'positive'.

Large angular differences are apparent between the ankles during the initial condition. Plantarflexion during the 1st rocker is very high in the right ankle at -22.66°; this is reduced to -1.58° during SIni, which is close to normal (see graph 5.65). After 3 months plantarflexion in relation to angle at heelstrike is almost non-existent in both conditions on both sides. This indicates the child has a flatfooted floor contact. Dorsiflexion is higher than normal in both sides during NIni, and is especially high on the left ankle at 23.26° (see graph 5.69). Dorsiflexion is reduced to 4-5° across all other conditions on the left ankle, which is lower than normal. Similar results are found on the right ankle, though wearing the suit at the 3 month point increases dorsiflexion to 11.92° which is slightly above that found in normal age-matched subjects. This suggests that the suit has a greater effect on the left ankle after 3 months than it does on the right. Plantarflexion of the left ankle during the 3rd rocker is also higher than normal, and is reduced to below normal levels across all other conditions (see graph 5.69). The right ankle has low levels of plantarflexion across all conditions, and is decreased further whilst wearing the suit. After 3 months the ankle remains in 5.5° of dorsiflexion, which suggests that movement into plantarflexion is being inhibited throughout the gait cycle (see graph 5.65. Knee flexion during the stance phase is much lower than the normal age-matched value of 10° (see figure 4.5e) across all conditions on both sides. The right knee does not move into extension initially, and the flexion is greatly increased to 62.39° when the suit is introduced, indicating the right leg remaining in crouch position (see graph 5.66). The left leg moves into extension during all conditions (see graph 5.70), when an angle of 0° would be expected in normal age-matched subjects. During the swing phase flexion is initially very low on the right side, and increases across the other conditions, but is still less than half the normal 64°. Initial flexion on the left side is higher, but still low compared to normal. The initial introduction of the suit reduces this, and although flexion increases after 3 months it still remains below initial levels. The responses to the suit vary widely between right and left sides despite the child being diplegic. Flexion at the right hip is close to normal initially and is then reduced when the suit is worn, the reduction remains after 3 month without the suit, and wearing the suit at this time point returns hip flexion to near normal levels. The same pattern occurs during maximal flexion. Extension does not occur initially, or whilst wearing the suit after 3months. It appears that although the suit has an initial impact on movement in the sagittal plane at the right hip (see graph 5.71), this moves angular motion away from normal measures. After 3months wear little difference is found between initial measures and wearing the suit. At the left hip the condition that reaches closest to normal measures is 3 months with the suit for flexion (see graph 5.71), and 3 months without the suit for extension and rotation ROM (see graph 5.72). The rotation found at the right hip is low across all conditions except after 3months without the suit where it is close to normal.

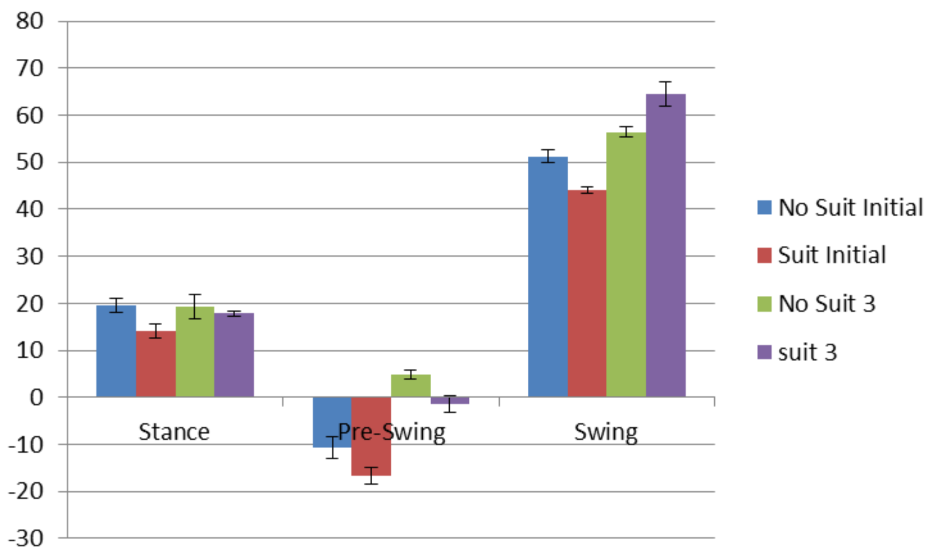
5.1.10 PARTICIPANT 10- A 9YR OLD WITH HEMIPLEGIA AFFECTED ON THE LEFT SIDE

Right Leg- Unaffected



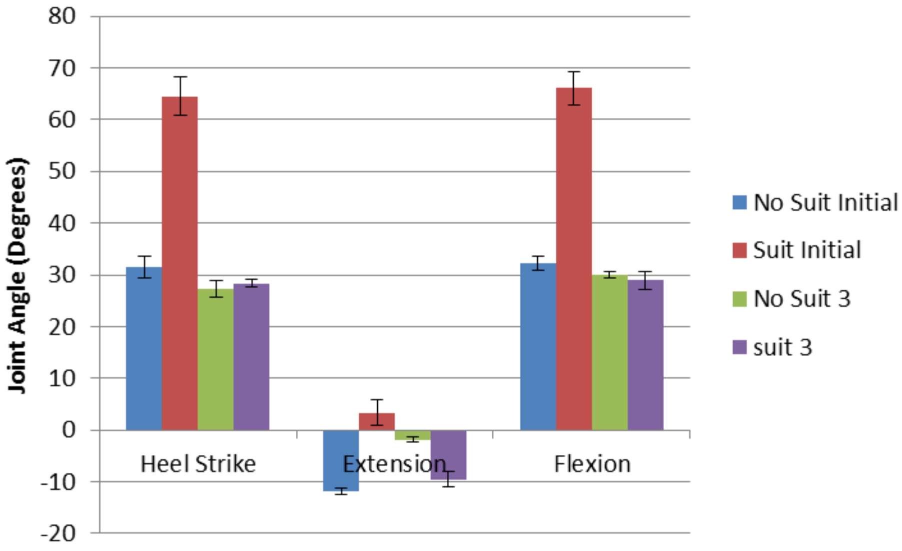
Graph 5.73 Maximum and Minimum unaffected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion during the 1st rocker is close to the normal age-matched range of -3° to -5° (see figure 4.5m) during NIni, but increases above this across the other conditions. Dorsiflexion during the 2nd rocker is half the normal 10° during NIni and increases to 8.84° during SIni. After 3 months dorsiflexion increases to 13.2° during NS3, this is reduced to 10.07° during S3. Plantarflexion during the 3rd rocker is above the normal 20° in both conditions initially. After 3 months this reduces to -7.91° during NS3, increasing to -22.71° during S3 (see graph 5.73).



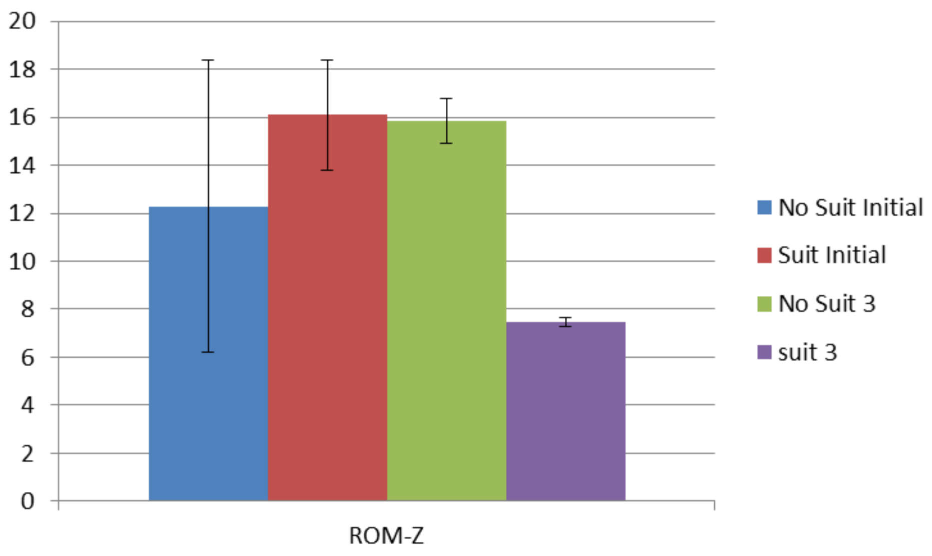
Graph 5.74 Maximum and minimum unaffected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance is at the normal 20° without the suit at both time-points. Wearing the suit reduces this to below normal age-matched values. Extension during pre-swing is close to the normal -10° at 10.67° during NIni, and increases to -16.77° during SIni. Extension is not reached during NS3, with the knee remaining in 4.81° of flexion. Wearing the suit brings about -1.47° of extension during S3 (see graph 5.74). Knee flexion is below the normal 65° to 70° across all conditions, except during S3, where it reaches the normal 64.55° (see figure4.5n).



Graph 5.75 Angles at heel strike, maximum flexion and extension at the unaffected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

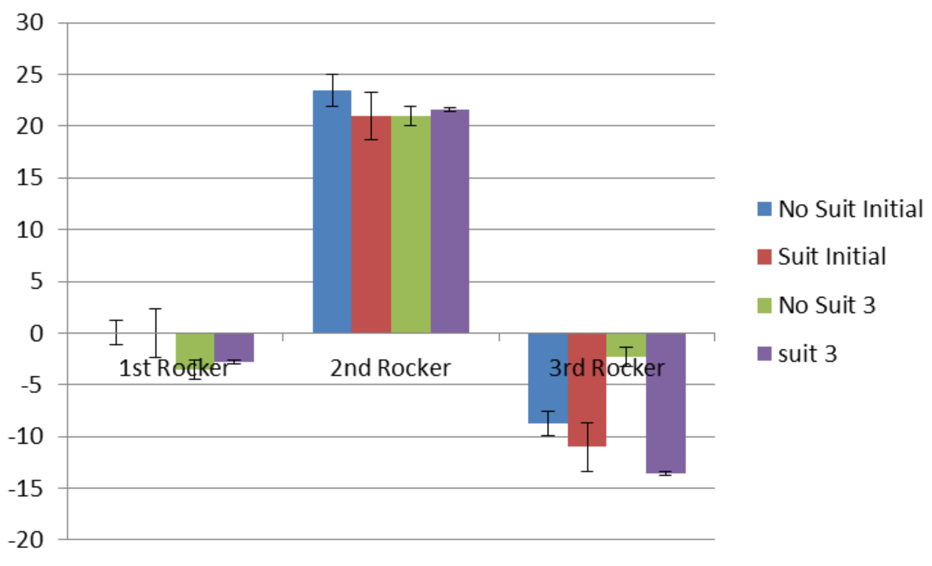
Hip flexion at heel strike reaches 30° during NIni, which is at the lower end of the 30° to 40° range found in normal age-matched subjects (see figure 4.5o). This is greatly increased during SIni to 65°. After 3 months the flexion is found to be below normal in both conditions. Extension is within the normal age-matched range of -5° to -12° during NIni, the introduction of the suit at SIni causes the hip to remain at 3.37° of flexion. After 3 months extension is below normal during NS3 and within the normal range at 9.54° during S3 (see graph 5.75).



Graph 5.76 Range of motion of the unaffected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

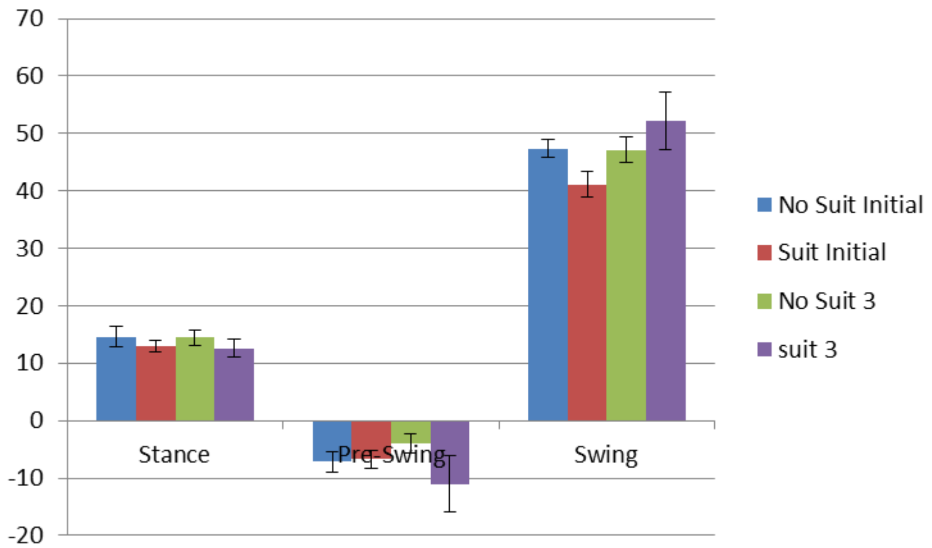
ROM reaches around 15° in normal age-matched subjects. The ROM is found to be much below this at 7.45° during S3 (see graph 5.76).

Left Leg- Affected



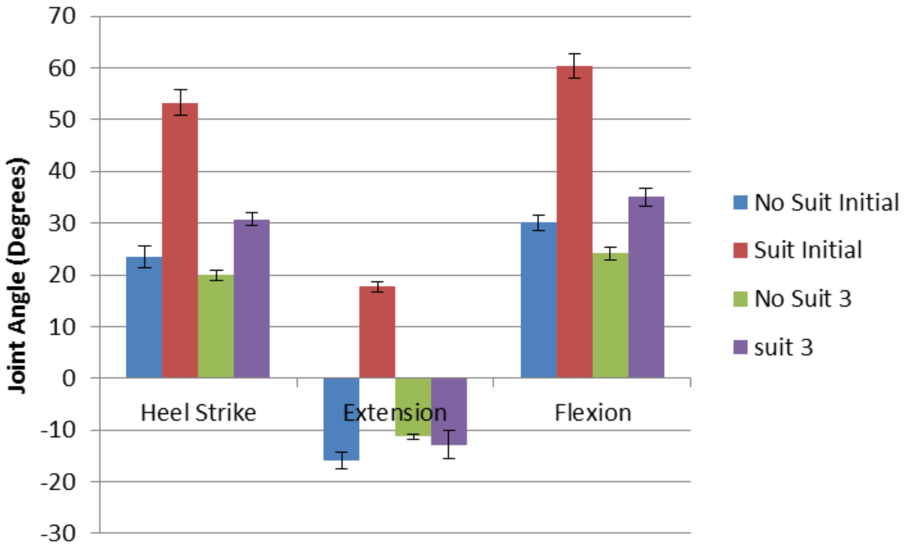
Graph 5.77 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Ankle angle during the first rocker is the same as at heel strike in both initial conditions. After 3 months both conditions are within the normal age-matched -3° to -5° range (see figure 4.5m). Dorsiflexion is more than double the normal 10° found within normal age-matched subjects across all conditions. Plantarflexion is below the normal range of -15° to -20° during NIni, rising to -11.03° during SIni. After 3 months wear plantarflexion during NS3 is reduced to -2.26°, and increases to -13.55° during S3 (see graph 5.77).



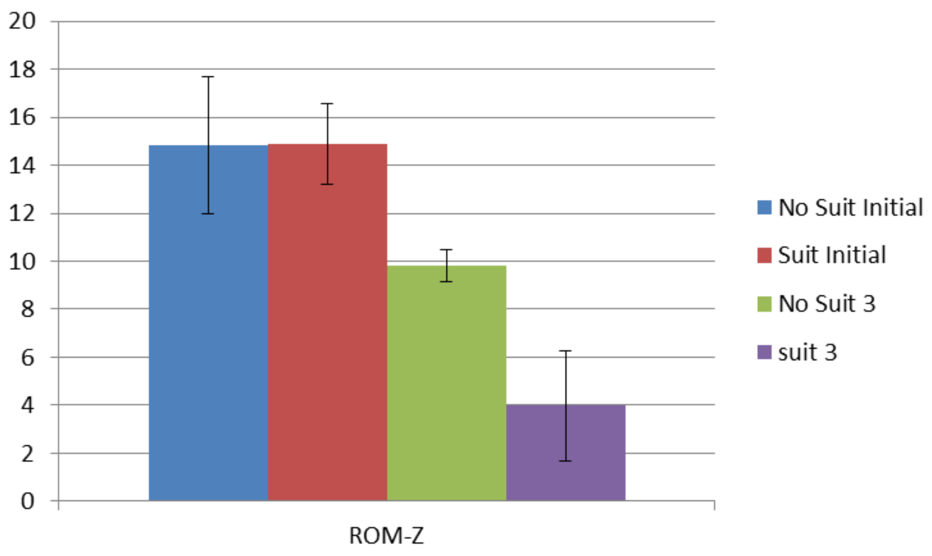
Graph 5.78 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion at stance is expected to be around 20° in normal age-matched subjects (see figure 4.5n), but is lower than this across all conditions. Extension during the swing phase is within the normal -5° to -10° during NIni at -7.15°, reducing slightly to -6.68° during SIni. After three months flexion reduces to -3.95° during NS3, and increases to -11.03° during S3, both of which are outside of the normal range. Maximal flexion during the swing phase is below the normal age-matched range of 65° to 70° across all conditions (see graph 5.78).



Graph 5.79 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

Hip angle at heel strike is below the normal age-matched range of 30° to 40° (see figure 4.5o) at 23° during NIni, rising above normal to 53° during SIni. Flexion reaches normal at 30° during S3. Extension is above the normal age-matched range of -5° to -12° during NIni at -15.87°. SIni sees the hip remain in 18° of flexion. After 3 months the hip is within normal range during both conditions. Maximal hip flexion is normal at 30.08° during NIni, but doubles to 60.35° during SIni. After 3 months it reduces to below normal, but is within the normal range of 30° to 40° at 35.04° during S3 (see graph 5.79).



Graph 5.80 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM is around the normal 15° in both initial conditions. After 3 months ROM is reduced below this to 9.81° during NS3 and further again to 3.97° during S3 (see graph 5.80).

Table 5.10 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait. Amber indicates that there was no change.

		Right Unaffected				Left Affected			
		Initial No	Initial Suit	3mth No	3mth Suit	Initial No	Initial Suit	3mth No	3mth Suit
Ankle	1st Rocker	-5.34	-6.5	-6.78	-7.1	0	0	-3.52	-2.81
	2nd Rocker	5.41	8.84	13.2	10.07	23.48	20.96	20.95	21.59
	3rd Rocker	-28.99	-30.01	-7.91	-22.71	-8.73	-11.03	-2.26	-13.55
Knee	Stance	19.48	14.11	19.29	17.81	14.61	12.96	14.45	12.6
	Pre-Swing	-10.67	-16.77	4.81	-1.47	-7.15	-6.68	-3.95	-11.03
	Swing	51.25	44.02	56.42	64.55	47.38	41.1	47.16	52.25
Hip	Flexion	32.23	66.12	29.96	28.9	30.08	60.35	24.14	35.04
	Extension	-11.9	3.37	-1.89	-9.54	-15.87	17.68	-11.29	-12.84
	ROM	12.29	16.09	15.85	7.45	14.85	14.9	9.81	3.97

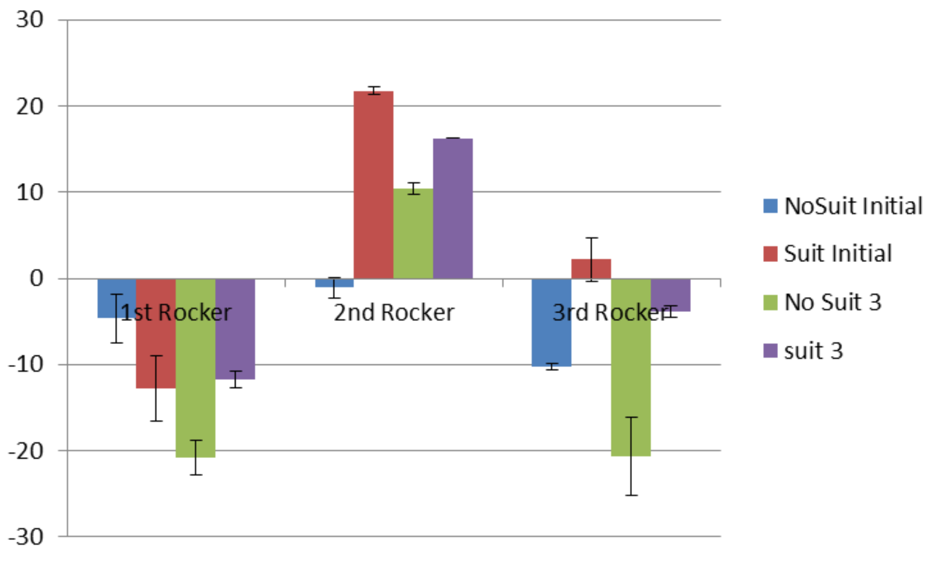
Participant 10-Summary of Findings

Participant 10 is a 9yr old hemiplegic who is affected on the left side.

Initially a flatfooted floor contact is seen in both conditions at the left ankle (see graph 5.77), after 3months plantarflexion reaches normal range in both conditions. At the right ankle the plantarflexion during the 1st rocker is close to normal during NIni, but increases slightly above this across the other conditions (see graph 5.73). Dorsiflexion on the unaffected (right) side during the 2nd rocker is more than double normal across all conditions with little variation throughout. Dorsiflexion on the affected (left) side is initially half the normal, and increases slightly with the introduction of the suit, after 3months dorsiflexion has increased to slightly more than normal during NS3, but is within the range during S3. Dorsiflexion during the third rocker is below normal during NIni on the affected side, but increases with the suit, and further again with the suit after 3 months (see graph 5.77). Dorsiflexion on the unaffected (right) is above normal during both initial conditions, reaching the closest to normal with the suit after 3months (see graph 5.73). It appears that the suit is bringing the unaffected knee into a normal range after 3months of wear, though this does not carry over when the suit is removed. Knee flexion during stance is below normal on the affected (left) side across all conditions (see graph 5.78), and around normal on the unaffected (right) side except when wearing the suit (see graph 5.74). Extension during pre-swing is normal in both initial conditions on both sides also. After 3 months of wear extension on the affected (left) side is below normal without the suit and above normal with the suit. The unaffected (right) knee no longer reaches extension without the suit, and is greatly reduced with it. Although the suit has initial effects moving knee flexion and extension towards normal levels, the same cannot be said after 3months of wear, where the opposite is true. Maximal flexion during swing phase is below normal across all conditions on both sides, except during S3 on the unaffected (right) side where it reaches lower normal levels at 65° (see graph 5.74). Hip flexion responses are similar between affected and unaffected sides. Both sides are slightly below normal flexion levels during heelstrike and see large increases when the suit is introduced to above normal levels. Flexion is below normal during NS3, but increase to normal levels on the affected side during S3. The suit has a greater impact on the affected side at hip level, which is the opposite of what happens at the knee (see graphs 5.75 and 5.79). Hip rotation is found to be close to normal on the affected (left) side (see graph 5.80), and slightly below on the unaffected (right) side (see graph 5.76). This may be due to compensatory measures developed to assist walking. After 3months ROM has decreased on the affected side and is below normal levels whilst wearing the suit on the unaffected side.

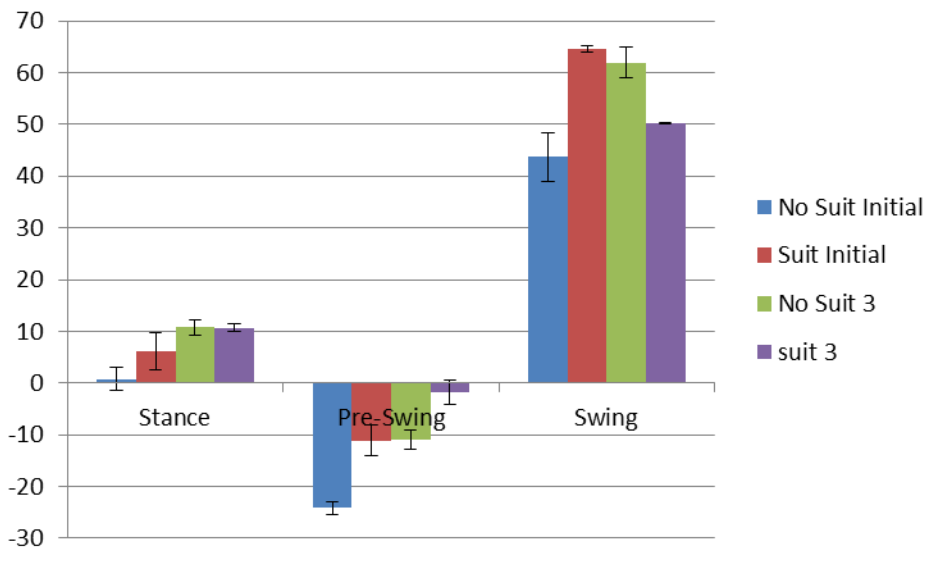
5.1.11 PARTICIPANT 11- A 2YR OLD WITH HEMIPLEGIA-LEFT SIDE AFFECTED

Right Side- Unaffected



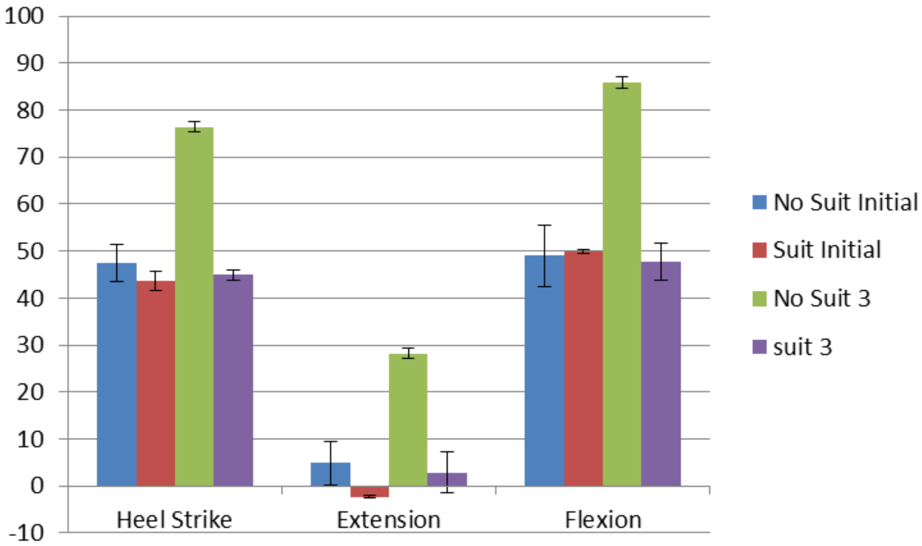
Graph 5.81 Maximum and Minimum unaffected (right) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Plantarflexion during the first rocker is above the normal -2° range at -4.65° during NIni. This increases to -12° to -13° in both suit conditions and further again to -20.78° during NS3. During the 2nd rocker the ankle does not dorsiflex from the heelstrike position during NIni, remaining in -1.09° plantarflexion. SIni sees the ankle dorsiflex by 21.76°, which is much higher than the 11° found in normal age-matched subjects (see figure 4.5a). Dorsiflexion during S3 is reduced to 16.27°, and is within the normal age-matched range at 10° during NS3. Ankle plantarflexion would be expected to reach -15° during the 3rd ankle rocker, but only reaches -10.22° during NIni. During SIni plantarflexion is not reached, with the ankle dorsiflexing to 2.19°. After 3 months dorsiflexion is measured at -20.66° during NS3 and -3.85° during S3 (see graph 5.81).



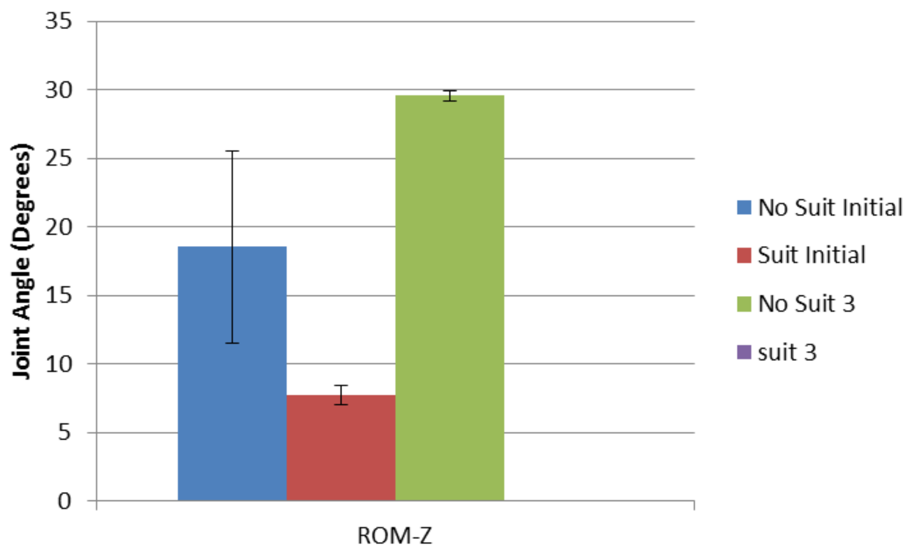
Graph 5.82 Maximum and minimum unaffected (right) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Knee flexion during stance phase would be expected to increase by 8° over that found at heelstrike in normal age-matched subjects (see figure 4.5b). During NIni flexion reaches 0.79°, and is increased to 6.2° during SIni. After 3 months flexion is measured at 10° both with and without the suit, which closer to the normal age-matched range. Extension during pre-swing is -24.13° at NIni, which is much higher than the normal range of -2°; this reduces to -11.1° during SIni. After 3 months -11.01° of extension still occurs during NS3, and is reduced to -1.76° during S3. Maximal flexion during swing phase is 43.66° during NIni, increasing to 64.57° during SIni, which is above the normal 60° found in 2yr olds. After 3 months flexion reduces to 61.94 during NS3° and further to 50.22° during S3 (see graph 5.82).



Graph 5.83 Angles at heel strike, maximum flexion and extension at the unaffected (right) hip throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

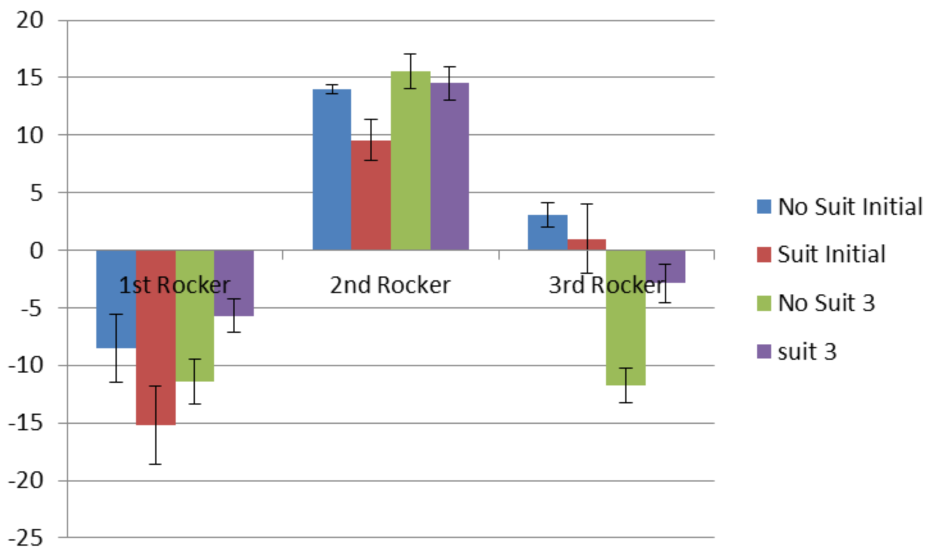
Hip flexion at heel strike is above the normal age-matched value of 41° during NIni at 47°, reducing slightly to 44° during SIni. After 3 months, flexion increases dramatically to 76° at NS3, again being reduced to 45° during S3. Extension only occurs during NIni, reaching -2.29° which is above the 0° found in normal age-matched subjects (see figure 4.5c). Maximal flexion is higher than the normal 30° to 40° across all conditions, rising sharply to 85.88° during NS3 (see graph 5.83).



Graph 5.84 Range of motion of the unaffected (right) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

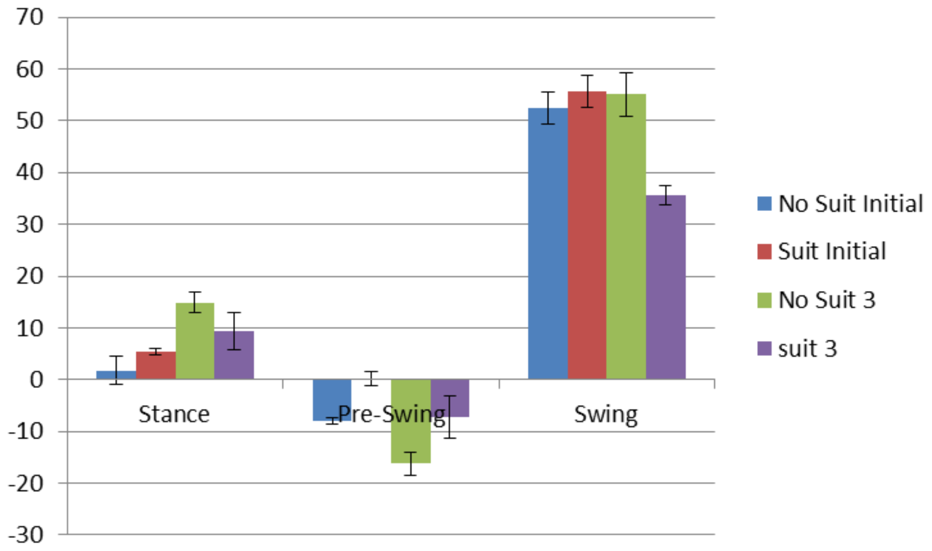
ROM is normal at18.83° during NIni, reducing to 7.74° during SIni. After 3 months flexion raises to 29.5°. Data for the 3 month with suit condition was not captured. (see graph 5.84)

Left Side- Affected



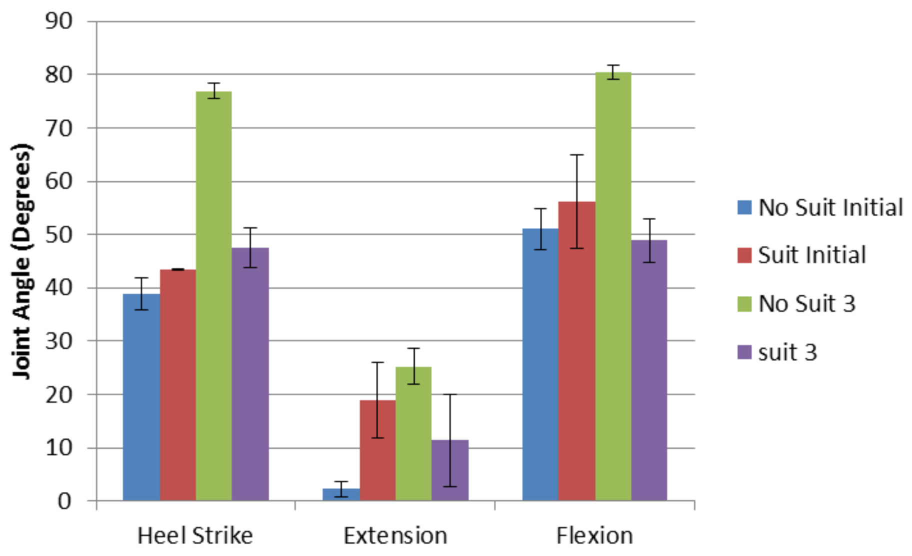
Graph 5.85 Maximum and Minimum affected (left) ankle joint angles at 1st, 2nd and 3rd rockers in relation to ankle angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Ankle plantarflexion during the 1st rocker is expected to reach -2° above that at heelstrike (see figure 4.5a), plantarflexion was found to be much higher amongst all conditions, with the most reduction during S3, where it reached -5.68°. Dorsiflexion during the 2nd rocker was above the normal age-matched value of 11° during NIni, reducing to below normal at 9.59° during SIni. After 3 months dorsiflexion was above normal age-matched values in both conditions. Plantarflexion during the third rocker does not occur in both initial conditions. After 3 months plantarflexion reaches -11.74° during NS3 and -2.85° during S3 (see graph5.85), both being lower than the normal -15°.



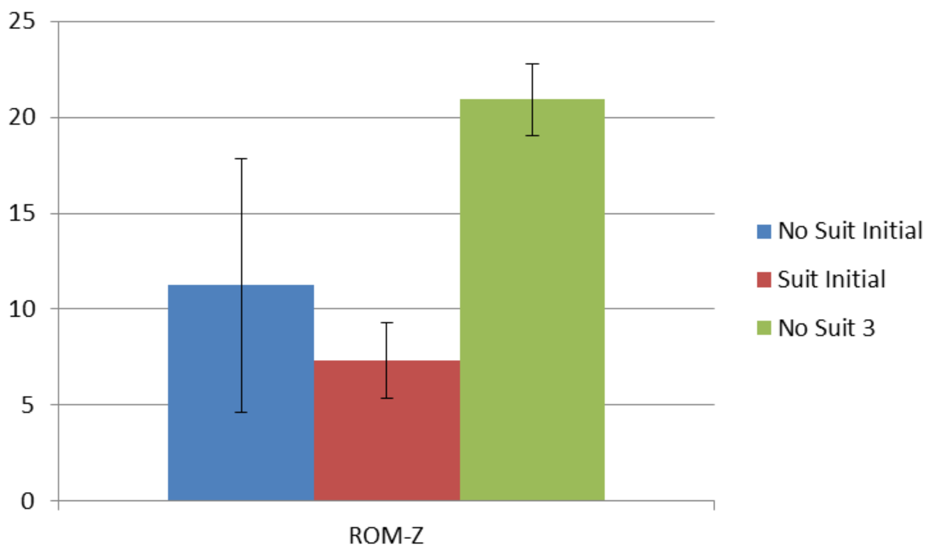
Graph 5.86 Maximum and minimum affected (left) knee joint angles during stance, pre-swing and swing phases in relation to knee angle at heel strike. Error bars show standard deviation across 9 gait cycles.

Flexion during the stance phase is below the normal age-matched value of 8° during NIni, and increases to 5.43° during SIni. After 3 months flexion is much higher than normal at15° during NS3, decreasing to 9.46° during S3. Knee angle during the pre-swing phase would be expected to reach no more than 2° (see figure 4.5b), but it is much higher across all conditions, except at NIni where it remains at 0°. During swing phase flexion reaches between 52.52° and 55.68° except for the 3month suit condition where it is reduced to 35.57° (see graph 5.86).



Graph 5.87 Angles at heel strike, maximum flexion and extension at the affected (left) hip throughout the gait cycle.

Hip flexion at heel strike is slightly below the normal 41° at 39°, increasing to 43° with the introduction of the suit. After 3 months there is a sharp rise to77° without the suit, wearing the suit reduces this to 48°. Maximal extension is expected to reach 0° in 2yr old gait (see figure 4.5c). Extension is 2° during NIni, decreasing to 18.92° during SIni. After 3 months extension decreases further to 25.22°, this is increases to 11.4° during S3. Maximal flexion is higher than the normal age-matched value of 47° across all conditions, increasing to 80.41° during NS3 (see graph 5.87).



Graph 5.88 Range of motion of the affected (left) hip in the Z-plane throughout the gait cycle. Error bars show standard deviation across 9 gait cycles.

ROM is below the normal age-matched value of 18° in both initial conditions. After 3 months ROM raises to 20.92° during NS3, which is above normal. No data was collected for the with Suit 3 condition (see graph 5.88).

Table 5.11 Summary of changes in joint angles from Initial No condition (Baseline measures). Green indicates a change towards normal gait while red indicates a change away from normal gait.

		Right Unaffected				Left Affected			
		Initial No	Initial Suit	3mth No	3mth Suit	Initial No	Initial Suit	3mth No	3mth Suit
Ankle	1st Rocker	-4.65	-12.78	-20.78	-11.74	-8.5	-15.18	-11.4	-5.68
	2nd Rocker	-1.09	21.76	10.38	16.27	13.98	9.59	15.55	14.5
	3rd Rocker	-10.22	2.19	-20.66	-3.85	3.11	1	-11.74	-2.85
Knee	Stance	0.79	6.2	10.73	10.67	1.75	5.43	14.89	9.46
	Pre-Swing	-24.13	-11.1	-11.01	-1.76	-8	0.18	-16.28	-7.21
	Swing	43.66	64.57	61.94	50.22	52.52	55.68	55.09	35.57
Hip	Flexion	49.02	49.9	85.88	47.82	51.06	56.11	80.41	48.86
	Extension	4.86	-2.29	28.23	2.83	2.28	18.92	25.22	11.4
	ROM	18.53	7.74	29.55	0	11.24	7.31	20.92	0

Participant 11-Summary of Findings

Participant 10 is a 2yr old child with hemiplegia. The left side is affected. Plantarflexion at the ankle during the first rocker is above normal during NIni on both sides. The introduction of the suits sees this increase further. After 3 months the unaffected (right) ankle increases again during NS3, moving even further from normal range (see graph 5.81), whilst the affected (left) side is reduced to near initial levels without the suit and again when the suit is worn (see graph 5.85). Dorsiflexion does not occur during NIni on the unaffected (right) side with SIni causing dorsiflexion double the normal 11° (see figure 4.5a). Dorsiflexion reaches close to normal during NS3.

During the 3rd rocker the unaffected (right) ankle reaches a lower level of plantarflexion during NIni, and is moved to dorsiflexion during SIni. After 3 months plantarflexion is above normal during NS3 and below normal during S3 (see graph 5.81). On the affected (left) side the ankle does not reach plantarflexion in either initial condition (see graph 5.85), after 3 months the response is the same as found in the unaffected (right) side. Knee flexion during stance phase is low in both initial conditions on both sides, after 3months this is seen to increase to slightly above normal across all conditions. Extension during the pre-swing phase would be expected to reach around -2° (see figure 4.5b) but is higher on the affected (left) side (see graph 5.86), and higher again on the unaffected (right) side (see graph 5.82). The introduction of the suit at SIni sees the extension reduce on both sides, though this is to a much greater effect on the affected (left) side where 0° is apparent. After 3 months extension is above normal, only reaching normal levels during S3 on the unaffected (right) side. Maximal flexion during swing phase is below normal across all conditions on the affected side (see graph 5.86). The unaffected side reaches normal levels without the suit after 3 months, but this is reduced again while not wearing the suit (see graph 5.82). The affected (left) hip is only slightly below normal flexion levels during heel strike initially, the introduction of the suit rises this slightly at both time-points. The largest increase in flexion is found at NS3, this is also apparent in maximal flexion and during extension, where the hip was found to remain in flexion throughout (see graph 5.87). The same pattern occurs on the unaffected (right) side also, with large increases in hip flexion witnessed throughout the gait cycle (see graph 5.83). It may be possible that the suit is causing muscular fatigue in the hip and pelvic area during prolonged wear, or that the muscles have become dependent on the suit for support and weakened as a result. Hip rotation also increases during NS3 above all other conditions, bringing the affected (left) hip to above normal levels (see graph 5.87), and the unaffected (right) to much higher again (see graph 5.83).

5.2 SUMMARY OF GROUP FINDINGS.

Looking at the individual results for the participants it is clear to see that there is a great deal of variability. The changes brought about by the suit differ widely between all subjects, in all conditions, when comparing affected and unaffected limbs and also at different joints. Despite this, some slight patterns did occur within the data when the group is split into hemiplegics and diplegics.

5.2.1 HEMIPLEGIC RESULTS

A greater amount of change towards normal gait was found in the hemiplegics when compared to the diplegics. The unaffected leg saw SIni change towards normal joints angles at the hip, knee and ankle. This change then increased again at NS3, but decreased slightly at S3; however the level of change still remained higher than at NIni.

The greatest degree of positive change was found at the ankle joint during NS3, which is particularly interesting as the suits end at the ankle, with just a stirrup under the foot to hold the garment in place. The knee joint was also found to change towards normal gait more often than not, which was the case across all conditions. Interestingly the least amount of change towards normal joint angles was at the hip. Change around the hip, in flexion, extension and rotation was found to be more variable, and to a lesser degree than that found at the knee and ankle.

The affected leg showed the same amount of changes towards normal joint angles as the unaffected leg at SIni. This regularity of change decreased at NS3 to below the SIni level, and was then returned to the SIni level at S3, though one child increased further again during this condition. Most improvement at the ankle was found during the 2^{nd} rocker, but overall the changes are more sporadic on the affected side at knee and hip. Most overall change was found to occur at the ankle during the 2^{nd} and 3^{rd} rockers on both affected and unaffected sides.

5.2.2 DIPLEGIC RESULTS

Any patterns across the diplegic participant's results are even less obvious than those in the hemiplegics. SIni brings about varying levels of change in both limbs in all participants. A further change towards normal joint angulation is found after 3 months, but occurs at a similar regularity both with, and without the suit, at this timepoint. Most regular change towards normal joint angles is again at the ankle during the 2nd and 3rd rockers.

6. DISCUSSION

There is currently a paucity of research carried investigating effects of lycra suits, with most focus on postural control, stability and upper limb movement. The aim of this study was to provide a description of angular kinematic alterations brought about at the hip, knee and ankle joints. These were measured throughout the gait cycle whilst wearing the lycra suit, both initially and after a 3 month period of wear. There was found to be a great deal of variability in the effect of the lycra suits, both within subjects and across the group as a whole. This reflects the findings of previous studies investigating the effects of lycra garments on postural and motion control (Rennie et al, 2000; Nicholson et al 2001).

6.1 CHANGES IN ROM AT THE HIP

ROM was found to decrease in six of the eleven children whist wearing the suit at both time points. When decreases in ROM were observed there was also a change towards a normal age-matched gait pattern in all but two children. These children were all associated with an increase in ROM above normal during NS3, which may suggest muscle weakness as they come to rely on the suit for support, further investigation would be needed to find out if this is indeed the case. In children 7 and 8 the decrease in ROM moved them away from a more normal gait pattern. It is worth noting, however, children 7 and 8 were only captured for the initial testing period, so it is unknown whether a 3 month period of wear may have brought about a different response. This decrease in ROM showed that the suit was preventing the excessive internal rotation at the hip found in cerebral palsy crouch gait (Rab, in Howlin and Udin, 2002). The primary function of ROM at the hip is to keep the feet along the midline of forward and backward limb motion, and to allow the pelvis to turn on top of the femur. Both of these aspects help to conserve energy throughout the gait cycle (Miller, 2007). Reduction in internal rotation at the hip would provide stability around the thigh and prevent collapse during weight-bearing. Mechanical efficiency would also be improved as the knee joint axis would be brought closer to the forward line of motion (Miller, 2007). The reduction in ROM would be expected as the suits are designed with a strong panel of material sewn around the thigh to restrict internal rotation at the hip.

Three of the children did display an increase in ROM around the hip. Child 9 saw a decrease in ROM during the suit conditions, which moved them away from a normal age-matched range. However, the ROM during the NS3 condition increased and was closer to normal than all other conditions. This shows that despite the suit having what could be seen as a restrictive quality during wear it is having a positive carry-over effect whilst not being worn. This response may be preferential as it may mean that the child could reduce hours of wear and see benefits whilst not wearing the suit.

Child 10 saw an increase in ROM during SIni on both the affected and unaffected side, which is unexpected as the suits are made to restrict ROM, however this increase did bring them closer to normal age-matched values. After 3 months ROM had become more restricted than NIni levels. This suggests that prolonged wear in this particular child was having negative effects on their hip movement, which is in contrast to the other children tested.

It is clear that most children did see changes towards more normative gait measures throughout the study, but during different conditions and to varying degrees. This was not true of all children and relates closely to the varied findings of previous studies investigating the effects of lycra garments (Rennie et al, 2001; Nicholson et al, 2001; Coghill & Simkiss, 2010).

6.2 CHANGES IN HIP FLEXION AND EXTENSION

Flexion and extension at the hip were found to move towards normal age-matched values during at least one condition in all children except child 8. However, this was achieved by differing effects brought about by the suit. Flexion was reduced in the suit conditions at both time-points in all children, except child 9 and child 10 on the unaffected (right) leg. In these two children flexion increased to bring the joint angles closer to normal age-matched values. Maximal hip flexion during gait is often found to be high in children with cerebral palsy; this can be the result of either an increased anterior pelvic tilt which is very common in those with crouch gait (Rab, in Howlin and Udin, 2002), or the thigh being lifted higher than normal during swing phase to prevent tripping caused by equinus (Perry, 1992). This again leads to a more inefficient gait as the limb effort at the hip and knee is increased above normal levels. A reduction in anterior pelvic tilt would mean reduced lordosis of the spine, and the thighs would be brought further under the body during standing and gait, reducing crouch gait patterns and improving weight bearing.

Flexion increased during NS3, sometimes to above NIni levels, again suggesting there is no cross-over effect from the suit after long-term wear, and that the children may be becoming reliant upon the suit for support during gait to a detrimental effect.

6.3 CHANGES IN KNEE FLEXION AND EXTENSION

An extremely varied response was found across all conditions at the knee. During the stance phase there is a small amount of flexion in comparison to knee angle at heel-strike in normal gait. This flexion serves to absorb force caused by weight bearing before full extension is reached at pre-swing (Miller, 2007). Knee flexion at heel-strike is above normal age-matched levels in the children due to weak gastrocsoleus or flat-footed and toe-strike floor contact (Miller, 2007). As a result extension during stance is lower than normal values as the leg would be fully extended in non-pathological subjects. Knee flexion during crouch gait is found to be above normal throughout the gait cycle, placing higher stress on the quadriceps and, along with internal rotation of the thigh, causes collapse at the knee. The primary causes of crouch gait include knee flexion contracture, hamstring contracture and gastrocsoleus weakness, with the most common secondary cause being hip flexion contracture (Miller, 2007). All of the children showed some change towards normal levels of knee flexion during stance, but this occurred at different levels and during different conditions. This change could be caused by the suit providing continuous stretch in the hip and knee flexors and hamstrings which may inhibit tone and soft tissue contractures (Rennie et al, 2000). Child 9, who has spastic diplegia showed improvements across all conditions on the right side, yet the opposite was true on the left side, with knee flexion moving away from normal age-matched gait in all conditions. In contrast children 7 and 8, both of whom also have spastic diplegia were affected in the same way on both legs, though child 7 moved towards a normal level of flexion, and child 8 moved away from normal age matched levels. Child 10 moved away from normal age-matched levels during all conditions.

Responses to the suit during pre-swing were also extremely varied across all children and all conditions. All children did see a movement towards normal age-matched values, and children 2,4,5,8 and 9 this occurred during all conditions. How the suit achieved this effect is unknown as in children 4,5 and 9 this was due to a decrease in knee extension, and in child 8 this was due to an increase in knee extension. This suggests that the suit is not bringing about a change in knee angle by actively restricting or supporting movement at the knee. It is more likely that the changes here may be cause by proprioceptive feedback (Karem et al, 2001), or more effective positioning being allowed by improvements in flexion at the hip.

The Effect of the suit during the swing phase was also extremely varied. Children 1, 2,3,7,8 and 9 all moved towards a normal level of flexion on one leg, but the opposite occurred on the other leg. Child 6 had negative changes in knee flexion across all conditions on both sides. Again child 9 who has spastic diplegia saw different responses on both sides with a decrease in flexion on the right knee in all conditions, especially whilst wearing the suit. The left knee however saw a large increase in flexion, by around 25° to 30° across all conditions, though this still left flexion at half of the normal 64° age-matched value. Knee flexion during the swing phase is important as it allows foot clearance over the floor and adequate pre-positioning of the leg and foot for heel-strike. Although improvements were witnessed in 6 of 11 children, these were not always on both sides, or to a fully normal range. Flexion also increased again without the suit during NS3 suggesting reliance upon the suit for maximal improvements. The other 5 children tested saw knee flexion moving away from normal.

6.4 CHANGES IN ANKLE DORSIFLEXION AND PLANTARFLEXION

Directly following heelstrike the ankle would be expected to move further into plantar flexion during the 1st rocker, to bring the foot flat onto the floor. Most of the children presented with a flat-footed or toe contact during NIni. All of the children wore their usual AFOs, which are to prevent equinus, during all testing conditions so plantarflexion was restricted as a result. However, a heelstrike floor contact would still be preferential as it would result from more normative movement around the hip and knee during the swing phase. Flat-footed toe contact whilst wearing AFOs to prevent equinus is caused by a lack of knee flexion and a shortened swing phase (Miller, 2007). Plantarflexion was found to move towards normal in four of the eleven children across all conditions, a further four children had more normal levels of plantarflexion in both conditions after 3 months only. Children 3, 7 and 8 all saw plantarflexion move away from normal levels, though it is worth noting that children 7 and 8 were only tested at the initial time point.

During the 2nd rocker dorsiflexion occurs as the leg moves over the foot during stance phase. Nine of the eleven children saw a move towards normal during the 2nd rocker suggesting greater control during stance at the ankle. Three of these children were only tested during the initial time point, so it is unclear whether they would have continued to see a change towards normative gait patterns after 3 months.

Plantarflexion as the foot rises up onto the toe during pre-swing is found to move towards normal values in ten of the eleven children. The improvements are seen across all conditions. The improvements are achieved by both increases and decreases in plantarflexion, depending on what is required by that child. Overall the findings at the ankle have been particularly interesting as most change towards normal age-matched gait values has occurred at this joint. The suits do not cover the ankle; they stop just below the malleoli and have a stirrup under the foot to hold the leg of the garment in place. This means that the suits provide the least amount of support at the ankle, so the resultant changes at the ankle must be from either increased proprioceptive feedback allowing for greater limb control, positive knock-on effects from changes at the hip and knee, or a mixture of both. This is in stark contrast to findings in previous studies which have found changes in proximal joint stability to have little or no effect on the distal joint stability (Rennie et al, 2000)

6.5 PATTERNS OF CHANGE FOUND IN CEREBRAL PALSY SUB-GROUPS

As seen in this study and those carried out previously (Rennie et al, 2000; Nicholson et al, 2001) there is great deal of variability across the participant group. Splitting the group into subgroups by Cerebral Palsy type did reveal some evidence of pattern within the results, though with such a small cohort it is unclear whether this pattern reflects the entire cerebral palsy population or is merely coincidental.

Hemiplegics displayed the greatest amount of change towards a normal gait pattern, with this being most apparent on the unaffected side during SIni at the hip, knee and ankle. This improved further during S3. The improvements on the affected side were found to be more sporadic at the knee and hip, which reflects the earlier findings of Rennie and colleagues (2000) regarding distal joint stability. Cerebral Palsy is found to cause muscular weakness, stiffness and poor coordination (Goodman in Howlin & Udwin, 2002). The decreased muscle innervation on the affected side could result in lower levels of proprioceptive feedback from the suit, reducing any possible learning effect. This could explain why the affected side did not show the same level of change towards normal as the unaffected side, and why this became more apparent after 3 months of wear.

Diplegic participants have a far more sporadic response to the suit. Patterns suggest a further improvement towards normal after 3 months of wear both with and without the suit. Interestingly this is most evident at the ankle joint, which is not covered by the suit. This may be due to increased proximal control allowing for improved foot positioning and a more controlled transfer of weight over the foot during stance.

6.6 HOW THE STUDY FINDINGS RELATE TO PREVIOUS RESEARCH

The only previous known study to investigate the effect of lycra suits on lower limb function was carried out by Rennie and colleagues (2000). The study investigated proximal and distal stability around the pelvis and legs, as opposed to angular changes, however the findings of the study also found a wide level of variety across the group tested, as was found here. Rennie and colleagues (2000) found that proximal stability increased in 5 of the 8 children tested, but to widely varying degrees within this group. Variation was clearly evident during this study also both between participants and within participants. For example participants 4 and 6, show similar patterns of change to knee and hip angles despite being diagnosed as diplegic. Whereas participants 7 and 8 both show decreased extension in the right knee, and increased extension in the left knee, which may appear similar, but is in fact taking them in the opposite directions of 'normal' knee angles. Responses around the hip are found to be similar in the participants of this study and that carried out by Rennie and colleagues (2000)

Nicholson and colleagues (2001) discovered that lycra garments improved trunk stability in 5 out of 12 children, but shoulder stability was decreased as a result. Although this study was investigating the effects on upper limbs similar 'knock-on' effects could be seen in the results of the gait analysis. Many of the participants showed vast changes in ankle motion despite the suits stopping at the ankle and not covering the joint as a whole, and all participants wearing AFOs on both ankles. Participant 1 is an example of such with both the hips and knees moving towards more normal joint angles, yet the right and left ankle both respond differently, with the left foot moving away from normal ankle angles after 3 months without the suit.

6.7 STRENGTHS AND LIMITATIONS

Accuracy of the Qualysis 3D motion capture system was optimised by calibrating the capture area prior to each testing session. Calibration was carried out using the small calibration wand provided by Qualysis; the distance between the markers is known to be 300mm. The smaller wand was chosen to ensure the cameras were placed sufficiently to capture the smaller markers which were being used on the younger children.

The marker placement followed those outlined by the CAST (as described in chapter 4). As the placement of the anatomical markers used to define joint centres involves palpation of anatomical landmarks the same person placed the markers on all children during all stages of testing. Previous studies have found that experienced examiners are able to produce the same levels of reliability in day-to-day marker placement as functional methods (Pohl et al, 2010).

During initial testing with the first participant it was discovered that the individual anatomical markers were falling off during movement as the double sided tape used did not stick to the lycra suits securely. As a result the markers were exchanged for those which were attached to a plastic disk, allowing more surface contact, and a stronger one sided tape could be used.

The manner in which footstrike and toe-off were identified may act as a limitation in the current investigation. Detection of gait events using force platform information is considered to be a gold standard for kinematic analyses and identification using alternative methods is known to be associated with error (Fellin et al, 2010). However, given that the participants were children who suffered from pathology they had difficulty striking a force platform consistently without altering their gait pattern, thus it was deemed most appropriate to identify events using the current manual technique.

As stated in chapter 2 it is important that the suits are placed correctly when being put on. To ensure this all parents/carers were shown how to dress the child in the suit by Kathryn Fisher, the representative of DM Orthotic Ltd, when they were first introduced to the suit. Nikki Salter, the physiotherapist who recruited the children from the Burnley clinic where she works reminded the parents/carers of how to do this during the children’s regular physiotherapy sessions between test dates. Nikki Slater also regulated the day-to-day wear of the Lycra Suits for each child and was to report if there were any problems.

No subjective data were recorded during the study, which meant that despite the angular changes being recorded at the joints it could not be truly established if this was of benefit or hindrance to the child whilst walking. In future it would be beneficial to carry out questionnaires to investigate whether the suits make walking and movement easier for the children, or harder. Physiological tests such as efficiency of movement could also be taken.

6.8 CONCLUSION AND FURTHER WORK

It is clear from the findings that there is a great deal of variability in change brought about by lycra suits within the CP population. There does not seem to be any clear relationship between CP type, presentation or level and the changes that are observed. There is also no clear trend between the length of time the suits are worn for, and any change towards or away from normal gait. In conclusion it is however clear that the responses to the lycra garments are as varied and individual as the presentations of Cerebral Palsy itself. With this in mind therapists should ensure continuing observations are carried out during periods of wear, ensuring physical ability both with and without the suit are not being reduced as a consequence.

The study, however, does only look at a small minority of the CP population, and with larger cohorts it may be possible to find trends through utilization of statistical analysis rather than the case-study design undertaken in the current investigation. It is also important to gain the subjective measures of the garments as changes in joint angles may appear more 'normal' in a biomechanical sense, but normal gait patterns are not being dealt with so in reality this may not be beneficial to, or comfortable for, the CP patient.

Future work should involve a larger cohort, preferably with 'similar' presenting CP patients who could be grouped together more easily. Along with this questionnaires and/or physiological measures such as walking efficiency should be used in conjunction with motion analysis to gain a more holistic view of whether the suit are beneficial to patients or not.

6.8 IMPLICATIONS OF THE FINDINGS

- The effects of lycra suits on joint angle at the hip, knee and ankle varies widely both across and within subjects.
- Most positive results were found around the hip with the largest change in degrees occurring during flexion, extension and ROM. This is in agreement with previous studies (Rennie et al, 2000; Blair et al, 1995; Hilton et al, 1997) that lycra suit have a greater sized effect on proximal joint stability.
- The effect of lycra suits on individual children is as wide and varied as the presentations of cerebral palsy. Prescription of lycra suits and garments should be undertaken with caution, with continuous monitoring of the patients to ensure the positive benefits outweigh any adverse effects that may occur.

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APPENDICES

APPENDIX 1- Patient Information Sheet- Parent /Carer Version

PATIENT INFORMATION SHEET Parent/carer Version

Study title: Functional Benefits of Lycra Suits in the management of Cerebral Palsy.

Your child is being invited to take part in a research study. Before they decide whether to take part it is important for them to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with your child and other people such as family, friends or your GP if you wish. Please ask us if there is anything that is not clear, or if your child wishes to take part. Thank you for taking the time to read this.

What is the purpose of the study?
Lycra Suits are often used to help people with Cerebral Palsy (CP) to walk. In this study we will look at how well they work when different people with CP are standing up from a normal chair, stepping up and down a single step and walking.

Why has my child been chosen?
Your child was chosen to take part in this study as they have Cerebral Palsy and are able to stand and walk independently without support, and they also have no visual or auditory disturbances that affect their walking.

Does my child have to take part?
No. It is up to them to decide whether or not to take part. If they do decide to take part both you and your child will be given this information sheet to keep. You will both also be asked to sign a consent form, or if this provides your child with difficulties they will be asked to communicate their consent through yourself or their carer who will sign on their behalf.

If your child decides to take part they are still free to withdraw at any time. They do not have to give a reason if they decide not to take part, or if they decide to withdraw later on, it will make no difference to the standard of care they will receive.

What will happen to my child if they take part?
Firstly your child will need to visit the Paediatric Physiotherapy Service at Reedley Hall, Burnley to be measured for their suit. Your child will be required to change into shorts so that your body measurements may be taken accurately. From this a Lycra Suit will be made specifically for them, Figure 1

Figure 1: Lycra suit. Image from promotional material by Gilbert and Mellish- manufacturers of the Lycra Suit.

Your child will then be required to visit the Movement Analysis Laboratory in the University of Central Lancashire 4 times. If they need your self, or a carer or interpreter to come with them they can. Each visit will take no more than 1 hour.

When your child makes the second and final visits they will need to change into shorts. This will allow reflective markers to be placed onto their bare legs and feet which will be attached with a Velcro type fastening, so it should not be uncomfortable. The markers will allow us to measure the movements of their legs and feet, Figures 2 and 3.

Figure 2: Movement Analysis Laboratory

Figure 3: Lower limb reflective markers

Your child will be asked to do three tests:

1) standing up from a normal chair,
2) walking 10 meters,
3) stepping up and down a single step.

They will need to do each of these activities five times. Their movements will be measured but they will not be recognisable as no video information will be recorded.

Your child will be asked to wear the Lycra suit at home for 6-8 hours per day over a period of 14 weeks. At the end your child will be able to keep the Lycra Suit that has been made for them. They will need to come to the movement analysis laboratory at the University of Central Lancashire to be tested 4 times.

Week 1 – The first visit their speech will be assessed without the Lycra suit. This will be carried out by a specialist Speech and Language Therapist, using pictures and toys.

Week 2 – Your child will be asked to stand up from a normal chair, step up and down a single step and walk in the movement laboratory, without and then with the Lycra Suits.

Week 13 – After 3 months of wearing the Lycra Suit their speech will be reassessed whilst wearing the suit.

Week 14 – Your child will be assessed in the movement laboratory first with and then without the Lycra Suit. Again they will be asked to stand up from a normal chair, step up and down a single step, and walk.

What does my child have to do?
Apart from coming to have the Lycra Suit fitted and coming for the tests they can do whatever they would normally do.

What are the possible disadvantages and risks of taking part?
Your child will have to travel to the University of Central Lancashire in Preston four times for the testing sessions. You will be paid back the cost of travelling there, however you will not be reimbursed any travelling costs incurred during the visit to Reedley Hall in Burnley. Your child will not be asked to do any activities that are harder than they do in everyday life. So it is very unlikely that taking part will cause them any pain or discomfort, but it will involve some time and effort.

What are the possible benefits of taking part?
At the end of the study your child will be able to keep the Lycra Suit that they have tried out for us. We will also give you a written report to tell them how the suit has worked for them. A total of 20 adults and 20 children will be tested throughout this study. The information that we get from this study may help to treat people with Cerebral Palsy better in the future. We can send you a summary of what we have found out from the study if you so wish.

Will my child's taking part in this study be kept confidential?

All the information which we collect about your child during the course of this research will be kept strictly confidential and any information about them which leaves the hospital will have their name and address removed so that they cannot be recognized from it. If we write about the results of the study their name and details will be removed completely. Any recording of them doing the tests in the laboratory will also be kept strictly confidential. If we show a picture or film of their movements they will not be recognisable.

Who is organising the research?
The Allied Health Professional Research Unit at the University of Central Lancashire and Paediatric Physiotherapy Service at Reedley Hall, Burnley are organising the research.
The research is being funded by Gilbert and Mellish who manufacture the Lycra Suits, however all research will be conducted without any involvement from the company. The costs include staff and laboratory time and the provision of the Lycra suits.

The results of the study will be published in peer reviewed journals and presented at conferences and user group meetings.

The study has been reviewed by the South West Research Ethics Committee.

Contact for further information
Professor Jim Richards
Allied Health Professions Unit
University of Central Lancashire
Preston

JRichards@uclan.ac.uk
01772 894560

Thank you for taking time to read about this study, if you have any questions please do not hesitate to ask. If your child agrees to take part you will both be given a copy of this information sheet as well as the consent form to take with you.

APPENDIX 2- Patient information Sheet- Child's Version

Functional Benefits of Lycra Suits in the management of Cerebral Palsy.

Do you want to join in our research study?
We want to tell you more about it and see if you have any questions.

Why are we doing this research?
Wearing a suit made out of a special material called lycra can help people with Cerebral Palsy (CP). You can wear your own clothes on top!
We want to see if lycra suits help people who have CP

- to walk,
- to stand up,
- to go up and down steps
- and to talk more clearly.

Do I have to take part?
You can choose if you want to do this and you can choose if you want to stop before the end of the study.
Someone can help you to sign the form if you decide you want to take part.

What will happen to me if I take part?
You will have a new lycra suit made just for you and it will be yours to keep.
You have to wear the suit for at least some time every day for 14 weeks.

You will go to Reedley Hall at Burnley to be measured for your suit. And you will come 4 times to the University in Preston. Sometimes you will wear shorts and we will put some stickers on your legs, like in this picture. It won't hurt you. You will be able to see the special cameras there.

This is what you will do when you come to the University:

4) standing up from a normal chair,

5) walking 10 meters,
6) stepping up and down a single step,
7) talking about some pictures.

You don't have to do anything that is harder than you do everyday.

What happens at the end of the research study?
At the end of the study you can keep the lycra suit you have tried out for us. And you will get a report to tell you how the suit has worked for you.

A total of 20 grown-ups and 20 children will be in this study, so we hope this will help people in the future who have CP. If you want, you can have a copy of that report at the end of the study too. We won't put your name and address in any reports and no-one will be able to recognise your face in any pictures.

Who is doing this research?
The Allied Health Professional Research Unit at the University of Central Lancashire and Paediatric Physiotherapy Service at Reedley Hall, Burnley are organising the research. The people who make the lycra suits are paying for the research, but you won't meet them.
At the end of the research, the research team will write some reports and talk about this at some conferences and meetings for people who have CP.

You can have a copy of this letter to keep.

If you want to ask us some more questions, you can talk to:
Professor Jim Richards
Allied Health Professions Unit
University of Central Lancashire
Preston

JRichards@uclan.ac.uk
01772 894560

Centre Number::
Study Number:

APPENDIX 3- Consent Form

Patient Identification Number for this trial:

CONSENT FORM

Title of Project: Functional Benefits of Lycra Suits in the management of Cerebral Palsy

Name of Researcher: Professor Jim Richards

Please initial box

1. I confirm that I have read and understand the information sheet dated .... (ve

2. I understand that my participation is voluntary and that I am free to withdraw at any time, wit

3. I understand that sections of any of my medical notes may be looked at by responsible individuals from [company name] or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records.

4. I agree for my speech to be recorded on both audio and video.

5. I agree to take part in the above study.

Name of Patient	Date	Signature
Name of Person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

1 for patient; 1 for researcher; 1 to be kept with hospital notes

APPENDIX 4- GMFCS-CP

CanChild Centre for Childhood Disability Research
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GMFCS – E & R
Gross Motor Function Classification System
Expanded and Revised

(Reference: Dev Med Child Neurol 1997;39:214-223)

INTRODUCTION & USER INSTRUCTIONS

The Gross Motor Function Classification System (GMFCS) for cerebral palsy is based on self-initiated movement, with emphasis on sitting, transfers, and mobility. When defining a five-level classification system, our primary criterion has been that the distinctions between levels must be meaningful in daily life. Distinctions are based on functional limitations, the need for hand-held mobility devices (such as walkers, crutches, or canes) or wheeled mobility, and to a much lesser extent, quality of movement. The distinctions between Levels I and II are not as pronounced as the distinctions between the other levels, particularly for infants less than 2 years of age.

The expanded GMFCS (2007) includes an age band for youth 12 to 18 years of age and emphasizes the concepts inherent in the World Health Organization's International Classification of Functioning, Disability and Health (ICF). We encourage users to be aware of the impact that **environmental** and **personal** factors may have on what children and youth are observed or reported to do. The focus of the GMFCS is on determining which level best represents the **child's or youth's present abilities and limitations in gross motor function**. Emphasis is on usual **performance** in home, school, and community settings (i.e., what they do), rather than what they are known to be able to do at their best (capability). It is therefore important to classify current performance in gross motor function and not to include judgments about the quality of movement or prognosis for improvement.

The title for each level is the method of mobility that is most characteristic of performance after 6 years of age. The descriptions of functional abilities and limitations for each age band are broad and are not intended to describe all aspects of the function of individual children/youth. For example, an infant with hemiplegia who is unable to crawl on his or her hands and knees, but otherwise fits the description of Level I (i.e., can pull to stand and walk), would be classified in Level I. The scale is ordinal, with no intent that the distances between levels be considered equal or that children and youth with cerebral palsy are equally distributed across the five levels. A summary of the distinctions between each pair of levels is provided to assist in determining the level that most closely resembles a child's/youth's current gross motor function.

We recognize that the manifestations of gross motor function are dependent on age, especially during infancy and early childhood. For each level, separate descriptions are provided in several age bands. Children below age 2 should be considered at their corrected age if they were premature. The descriptions for the 6 to 12 year and 12 to18 year age bands reflect the potential impact of environment factors (e.g., distances in school and community) and personal factors (e.g., energy demands and social preferences) on methods of mobility.

An effort has been made to emphasize abilities rather than limitations. Thus, as a general principle, the gross motor function of children and youth who are able to perform the functions described in any particular level will probably be classified at or above that level of function; in contrast, the gross motor function of children and youth who cannot perform the functions described in any particular level should be classified below that level of function.

APPENDIX 5- GMFM

GROSS MOTOR FUNCTION MEASURE (GMFM)
SCORE SHEET (GMFM-88 and GMFM-66 scoring)

Version 1.0

Child's Name: ______________________________ ID #: ____________

Assessment date: ____________________
year / month /day

Date of birth: ____________________
year / month /day

Chronological age: ____________________
years/months

Evaluator's Name: ____________________

____

GMFCS Level [1]

☐ I ☐ II ☐ III ☐ IV ☐ V

Testing Conditions (eg, room, clothing, time, others present)

____

____

The GMFM is a standardized observational instrument designed and validated to measure change in gross motor function over time in children with cerebral palsy. The scoring key is meant to be a general guideline. However, most of the items have specific descriptors for each score. It is imperative that the guidelines contained in the manual be used for scoring each item.

SCORING KEY
0 = does not initiate
1 = initiates
2 = partially completes
3 = completes
NT = Not tested [used for the GMAE scoring*]

It is now important to differentiate a true score of "0" (child does not initiate) from an item which is Not Tested (NT) if you are interested in using the GMFM-66 Ability Estimator Software.

*The GMFM-66 Gross Motor Ability Estimator (GMAE) software is available with the GMFM manual (2002). The advantage of the software is the conversion of the ordinal scale into an interval scale. This will allow for a more accurate estimate of the child's ability and provide a measure that is equally responsive to change across the spectrum of ability levels. Items that are used in the calculation of the GMFM-66 score are shaded and identified with an asterisk (*). The GMFM-66 is only valid for use with children who have cerebral palsy.

Contact for Research Group:
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[1] GMFCS level is a rating of severity of motor function. Definitions are found in Appendix I of the GMFM manual (2002).