The influence of a hip extension strengthening programme on gait performance in individuals following stroke

Submitted by:

Monica Busse

BSc(Physiotherapy) BSc Med Hons (Biomedical Sciences)

School of Physiotherapy, St George's Hospital Medical School and Kingston University, United Kingdom

Main Research Supervisor

Professor CL Vaughan

Hyman Goldberg Professor of Biomedical Engineering, University of Cape Town, South Africa

External Supervisor

Sarah Tyson

MSc MCSP

Stroke Association Research Unit, Manchester, United Kingdom

Abstract

Gait difficulties experienced by individuals following a stroke may be related to the commonly observed reduced hip extension in the stance phase of gait. The aim of this initial exploratory study was to evaluate the effects of a home-based strengthening programme on hip muscle strength and gait performance in individuals following stroke.

Six chronic stroke patients (> 9 months duration) participated in this pretest-posttest group design which was composed of two six week phases, A and B, where B immediately followed A. No training or advice was given to the six subjects during phase A. During Phase B, the same six subjects participated in a "hip extension focused" home exercise programme aimed at improving hip extensor muscle strength and the range of anterior hip structures. The exercise programme consisted of functional strengthening, task related activities and stretching. At the end of this six-week period, the subjects were re-tested in order to evaluate the effects of the exercise programme. The outcome measures included isometric muscle strength, walking speed and range of the anterior structures of the hip. The walking section of the Motor Assessment Scale for Stroke and the Nottingham Extended Activities of Daily Living were also employed. In addition, clinical gait analysis was used to gather measures of gait velocity, step length and hip joint excursion.

Statistically significant increases were found in the study group ($n = 6$) for the identified parameter of hip extensor strength after the intervention ($p = 0.05$), although this change could not necessarily be attributed to intervention effects alone. Hip extension strength was significantly correlated with (1) step length ($r = 0.82$; $p = 0.04$) and (2) joint excursion ($r = 0.8$; $p = 0.05$) after the intervention. These correlations, although tentative and not conclusive, suggest that hip extensor strength may influence gait performance and therefore warrants further investigation.

While the results obtained from this exploratory study appear to suggest that the hip extensors play an important role in providing stability for the lower limb during gait, a randomised controlled study with a larger cohort of patients would be necessary to make any definitive conclusions.

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Chapter 1: Introduction

A widely accepted standard definition of stroke is that given by the World Health Organisation, namely "rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than that of vascular origin" (Sudlow and Warlow, 1996).

Stroke survivors often have continuing problems with mobility once discharged from rehabilitation. Decreased mobility is a fundamental obstacle limiting the autonomy of people in their activities of daily living (Mercier *et al.,* 1999). Although it is shown that up to 60% of individuals regain walking following a stroke, only 40 % of those have been found to recover their normal walking speed (Wade *et al.,* 1987).

Limited walking ability as a result of a hemiplegia may compromise independence in moving about the home and limit community independence (Perry *et al.,* 1995). Mobility problems include falls, difficulty with walking both inside and outside as well as climbing stairs (Green *et al.,* 1999). It has also been found that the gains initially achieved during rehabilitation are often not maintained, with a progressive decline in mobility following discharge (Richards *et al.,* 1993; Wade *et al.,* 1992; Lindmark and Hamrin, 1995). This progressive decline in mobility may be related to a reduced level of activity once discharged from rehabilitation. Continuing physiotherapy intervention post discharge has however been found to be useful in preventing deterioration in mobility improvement achieved during inpatient treatment and can promote further improvements in mobility (Paolucci *et al.,* 2001).

Evidence related to the rehabilitation of individuals following a stroke indicates that addressing specific problems with task specific training and the use of strengthening activities (Dean *et al.,* 2000a) are effective in reducing motor impairments. Mayston (2000) has stated that muscle strengthening when used as part of the process of achieving optimal functional ability of the person with stroke can be of value during the optimum rehabilitation process. In addition to the suggestion that muscle strengthening programmes may be valuable, the feasibility of a home-based exercise programme for individuals with stroke in maintaining or improving mobility and strength has been established (Duncan *et al.*, 1998; Baskett *et al.*, 1999; Wall and Turnbull, 1987). Wall and Turnbull (1987) state that the advantage of the home exercise programme is that the patient can be more effective with a frequent practice schedule that may maximise skill acquisition. The use of independent home exercise programmes may also be more cost efficient in terms of travel time and patient contact time.

Disturbed motor control and subsequent movement disorders in stroke are associated with reduced gait speed and accompanied by changes in timing and distance covered by each step (Richards *et al.*, 1999). Brandstater *et al.* (1983) completed an analysis of temporal variables in hemiplegic gait and found that motor function was a major factor in the quality of gait. In addition, they found that walking speed was related to the clinical status of the patient and stated that this was an important variable and an extremely useful component of hemiplegic gait analysis. Static strength of the involved lower extremity muscles has also been found to be an important determinant of hemiplegic gait performance (Bohannon, 1987). Mercier *et al.* (1999) found evidence of carry over between strength and gait ability following a motor re-education.

Clinical experience led this author to propose that some gait difficulties experienced by individuals following a stroke may be related to reduced hip extension in the stance phase of gait. This may either be due to hip extensor weakness or to restriction of the anterior hip structures. This proposal is supported by studies of hemiplegic gait which note that reduced hip extension (due to an inability to produce sufficient active tension with the hip extensors) in the stance phase of gait is a common observation in gait following a stroke (Mosely *et al.*, 1993). The hip flexor muscles are also prone to shortening if a person tends to be sitting and inactive for long periods during the day (Richards *et al.*, 1999).

This author suggests that if gait difficulties could be reduced as a result of addressing the specific problems related to hip extension, individuals with stroke could possibly achieve and maintain improved walking ability following a stroke. This study has therefore been developed to evaluate the effects of a "hip extension focused" home exercise programme consisting of functional strengthening and task related activities as well as stretching on hip muscle strength and gait performance in individuals following stroke.

The aim of this study was to evaluate whether the implementation of a "hip extension focused" home exercise programme would influence gait performance as measured by velocity, peak ground reaction forces, step length, joint excursion and walking function in the individual following stroke.

A "hip extension focused" exercise programme was defined as a programme that involved the training of the hip extensor muscles in a functional pattern. This meant that the exercise programme was designed to involve all hip muscles required to produce a stable extended hip in the stance phase of gait (see Appendix 1a for a description of the functional anatomy of the hip).

The objectives of this study were

i) To observe whether a relationship exists between hip extensor muscle strength and gait performance following stroke.
ii) To explore the feasibility of an unsupervised home exercise programme in addressing a specific strengthening component, namely hip extension.

The research question was:
Does a "hip focused" home exercise programme influence gait performance following stroke?

Although there are accepted research findings justifying the use of strength training in neurologically impaired individuals, it is still not a widely accepted practice in clinical settings. In addition, there is a paucity of research demonstrating the application of specific strength training principles in neurologically impaired individuals in an unsupervised home setting. This study was therefore intended to be an exploratory study, using applied strength training principles in neurologically impaired individuals in an unsupervised home setting, in order to answer the research question.

Chapter 2: Literature Review

2.1 Stroke

Stroke or cerebrovascular accident (CVA) constitutes a "burden of disability and misery for patients, their carers and the wider community" (Kings Fund, 1988). Stroke is the third largest cause of death and an important cause of hospital admission and long term disability in western countries (Bonita, 1992). The incidence rate per 1000 population standardised to the world populations is 0.82 and 1.25 standardised to the European population (Stewart *et al.,* 1999).

2.1.1 Muscle function following stroke

In order to understand the physiological and functional responses that may occur following a stroke, the main structural components relevant to movement, neuroplasticity, muscle strength and function need to be described. This background information is presented in Appendix 1(b).

Motor control problems occur following stroke (Woods-Duncan, 1997) and lesions of the motor areas in the cerebral cortex often result in symptoms of the upper motor neurone syndrome which is linked with involvement of the corticospinal tract (Burke, 1988). The positive features of the syndrome include abnormal proprioceptive (spasticity) and cutaneous reflexes while the negative signs seen in the presence of an upper motor neurone lesion reflect loss of function such as muscle activation problems, weakness and loss of dexterity (Burke, 1988). The major defects in function as a result of an upper motor neurone syndrome, are due to the negative, not positive features of the syndrome (Burke, 1988) and relief of the hypertonic spasticity does not necessarily infer enhanced performance (Katz and Rymer, 1989).

Reduced muscle force following stroke can occur as a result of both primary weakness due to loss of central control, residual cortical oedema, synaptic changes as well as secondary disuse atrophy due to immobility (Miller *et al.,* 1998). Changes at the nerve level, related to changes in peripheral nerve conduction, and muscle changes such as morphological, contractile and mechanical altered properties of the muscle have also been identified (Bourbonnais and Van den Noven 1989).

Ada *et al.* (2000) studied the effect of muscle length on strength and dexterity after stroke. In this study, peak isometric elbow flexion torque was measured at three angles of elbow flexion and compared with a control group of normal individuals. The researchers found the magnitude of the torque-angle curve to be not significantly different to that of the control group but found the shape of the torque-angle curve to be altered. They identified significant weakness at the shortest range of muscle length ($p<0.05$) and concluded that the provision of strength training at different muscle lengths could have functional benefits to an individual who has had a stroke.

In everyday life activities, low threshold, slow firing muscle units (Type I) are active for long periods of time while the fast twitch, high threshold units (Type II) are active in short and high frequency bursts (Edstrom and Grimby, 1986). Neurological weakness has been considered to be due to a loss of type II motor units, differing recruitment order of motor units and slower firing rates of motor units. There are however inconsistencies in the literature regarding the muscle fibre changes that may occur following hemiplegic stroke. Jakobsson *et al.* (1991) found a predisposition for transformation from type I to type II fibres as a result of selective disuse, while atrophy of type II fibres and hypertrophy of type I fibres have been shown in less active individuals following stroke with an inability to generate large muscle forces required for functional activity (Dattola *et al.,* 1993; Hachisuka *et al.,* 1997). Sunnerhagen *et al.* (1999) found no significant change of muscle fibre composition in both legs of stroke patients, although there was a trend towards less type II fibres on the affected side. It is worth considering that in this study, individuals who were studied were ambulatory and classified as having minor motor impairment. Sunnerhagen *et al.* (1999) suggested that these findings could be related to the relative high levels of activity of the subjects that they studied. Shamay and Shepherd (2000) also attribute secondary adaptations following brain injury to the inactivity and effects associated with ageing and immobility. It can therefore be suggested that muscle fibre changes following stroke could be related to the levels of physical activity and patterns of muscle activity that are employed as well as a result of disuse atrophy induced by the central effects of the lesion.

It has been suggested that immobilisation causes strength losses due to a reduced ability to fully activate the involved muscles (Herbert, 1993). In addition to the initial problems arising as result of a stroke, that person can often be less active than prior to their stroke which in turn can lead to secondary adaptation and disuse weakness of the involved muscles (Carr and Shepherd 1998). Disuse has also been shown to be an important contributing factor to weakness and atrophy of the lower limb muscles in individuals with longstanding hemiplegia (Hachisuka *et al.,* 1997). If the muscular system experiences a reduced demand for the production of large muscle tensions, its tension generating abilities decrease (Herbert, 1993). Functional activity can be limited by the absence of adequate muscle strength i.e. the ability of a group of muscles to generate and time the necessary forces (Carr and Shepherd, 1998).

2.1.2 Physiotherapy following stroke

The care of individuals who are functionally limited as a result of stroke is a major work commitment in rehabilitation units (Ashburn *et al.,* 1993). Physiotherapy is generally recognised as beneficial in the treatment of stroke patients and is valued by patients, who believe therapy to be crucial to their recovery of function (Pound *et al.,* 1994). Many of the clinical trials that have been published have been found to have methodological problems, however it seems that patients improve to some extent, all be it with differing rates of recovery, regardless of the approach taken by the treating therapist (Ashburn *et al.,* 1993; Miller *et al.,* 1998; Kwakkel *et al.,* 1999).

Intensity of therapy does seem to be linked with recovery rate, but to date, few clinical studies demonstrate clear differences in effectiveness between therapeutic approaches in stroke rehabilitation (Kwakkel *et al.,* 1999). The Motor ReLearning Programme and the Bobath Concept are two of the therapeutic approaches used in clinical neurophysiotherapy practice (Kwakkel *et al.,* 1999). See Appendix 2 for a comparison of the Bobath and Motor Learning Approach. With the increasing availability of research findings to support the work that therapists are doing, including the use of neuroplasticity as a practical concept to encourage activity (Lennon, 1996), re-educating function and encouraging activity are common themes in treatment (Ashburn *et al.,* 1993; Lennon, 1996).

2.1.3 Muscle strengthening programmes in physiotherapy

The effects of exercise on muscle fibres include adaptation to increased demands by a change in metabolic profile, a change in the muscle contractile properties and a higher level of performance (Edstrom and Grimby, 1984). Changes that occur in response to training are noted to be strength increases, accompanied by muscle hypertrophy (Herbert, 1993) as well as an increased ability to activate and co-ordinate muscles (Herbert, 1993; Sale, 1988). Strength can therefore be considered as being " not limited to the amount of force" produced by a muscle and including the "ability to produce and control muscle forces" (Giuliani, 1995). This suggestion that "central factors are decisive in the development of strength is supported by the observation that in the early stages of strength training, increases in strength or muscle activation can be achieved without related muscle hypertrophy" (Kerr, 1998). Electromyography studies monitoring motor unit activation following muscle strengthening programmes confirm this, indicating that following strength training, subjects demonstrate improved activation of the primary muscles as well as a specific cross training effect in associated muscle groups (Sale, 1988).

An effective training programme should be based on the principles of overload and specificity (Sale, 1988; Sale and MacDougall, 1981). The effectiveness of a strength training programme is dependent on frequency, volume and mode of training and for individuals with chronic diseases, single set programmes of up to 15 repetitions performed a minimum of twice weekly produce the required benefits of strength training (Feigenbaum and Pollock, 1999). According to Feigenbaum and Pollock (1999), single set programmes are less time consuming and translate into improved exercise programme compliance. When prescribing exercise programmes for an elderly population, sessions should begin at a lower intensity level (moderate rather than maximal intensity) and progress more slowly (Feigenbaum and Pollock, 1999).

In the past, neurological physiotherapy treatments involving muscle-strengthening programmes with individuals with an upper motor neurone lesion have been avoided due to the belief that this may exacerbate spasticity although research findings do not support this supposition (Teixeira-Salmela *et al.,* 1999; Sharp and Brouwer, 1997). Recent research suggests that the clinical focus on spasticity following stroke may not be justified (Shamay and Shepherd, 2000). Therapists are beginning to acknowledge that dealing with the positive aspects of the syndrome may be overemphasised in neurological rehabilitation programmes and that they may need to begin to address specific weakness in these individuals (Miller *et al.,* 1998).

Wolfe *et al.* (2000) found that the incidence rate of stroke rises significantly with age. Muscle weakness in the older population has been associated with functional limitations and there is a body of data that suggests that physical activity can reduce the progression of disability in older adults (Miller *et al.*, 2000). Carter and O'Driscoll (2000) suggested that physiotherapists have a role in developing safe programmes of activity for the elderly individuals as a means of achieving a reduction in the morbidity associated with ageing. As stroke patients are mostly from the older population and neural factors are primarily responsible for strength gains in the first 3-4 weeks of a training programme, particularly in older individuals, neural factors may be primarily responsible for strength improvements in stroke patients participating in strength training programmes (Miller and Light, 1997).

Numerous studies describing the relationship between muscle strength and function in individuals in the presence of an upper motor neurone syndrome have been documented in the literature (Damiano *et al.*, 1995a; Damiano *et al.*, 1995b; Sharp and Brouwer, 1997; Teixeira-Salmela *et al.*, 1999; Dean *et al.*, 2000a; Duncan *et al.*, 1998 and Weiss *et al.*, 2000).

Sharp and Brouwer (1997) showed that strength training had a beneficial effect in individuals with spasticity. They found improvements in strength ($p < .05$) with tone remaining consistent ($p > .87$) after a six week exercise programme (18 sessions) involving isokinetic strength training of quadriceps and hamstrings on the affected side only. The study was completed with 15 community dwelling individuals and although all subjects showed an improvement in absolute strength during the duration of the programme, there was little functional improvement or change in performance. These results could have been an indication of the need for task related training to improve functional ability.

Teixeira-Salmela et al. (1999) used a ten week (30 sessions) muscle strengthening and physical conditioning programme ($n = 13$) with chronic stroke which resulted in reduced impairment and disability ($p < .001$), and increases in strength ($p = .000$) in all major muscle groups with no increase in spasticity. A control group ($n = 6$) showed no change over a non-training ten week period following baseline measures and significant improvement in all measures following intervention which occurred in the randomised pretest and posttest control group designed study. The physical conditioning included graded walking, stepping as well as cycling. The strength training protocol incorporated progressive resistance training for hip flexors, extensors, abductors and knee flexors and extensors as well as dorsi-flexors. The subjects all showed improvements in quality of life scores, attributed to the beneficial effects of exercise as a form of intervention. A limitation of the study was that the sample consisted of motivated volunteers meaning that compliance was good. It may not always be possible to control for compliance in exercise programmes.

Rimmer *et al.,* (2000) found that a supervised exercise training programme for stroke patients was highly effective in improving fitness and reducing the risk of further disease and disability. As a result of this study, the researchers suggested that greater effort needs to be made to "increase access to community-based physical activity programmes for persons with stroke". This study comprised a lag-control group design ($n = 35$) with two 12 week training periods. Training included cardiovascular activity (30 minutes), strength training (20 minutes) and flexibility exercise (10 minutes). Participants trained three times per week during the study period. The treatment group subjects showed significant gains in strength ($p < 0.01$) and flexibility ($p < 0.01$). Members of the treatment group also showed fitness gains. The researchers in this study emphasised the need for supervision in the early stages of training programmes for individuals with stroke and indicated that these individuals must be taught the warning signs of when to stop exercising.

Most of the studies completed have been done involving individuals with chronic stroke. However, Cramp *et al.* (2000) completed a low intensity strengthening programme for lower limb muscles of early stroke patients. The subjects ($n = 10$) participated in twice weekly exercise sessions consisting of progressive and dynamic functional exercises. Increases in strength were seen after eight training sessions and no detrimental effects on tone or motor performance were noted. The conclusion of this study was that physical exercise and strength training programmes have a role in the rehabilitation of stroke patients (Cramp *et al.,* 2000).

Woods-Duncan (1997) reviewed a range of intervention trials designed to improve motor recovery after stroke. From this review, it was concluded that specifically designed exercise programmes in select populations could improve motor control beyond spontaneous recovery and that the most effective interventions involved active participation of the patient and task related training. More recently, Shamay and Shepherd (2000) reviewed literature relating to strength training in neurological physiotherapy and stated that resisted strengthening exercises and task specific training result in increased force-generating capacity of muscles and related performance benefits. They suggested the use of a progressive functional repetition maximum to optimise training intensity with progressive overload. They further stated that patients with stroke needed to take an active role in a "structured and intensive exercise training programme to address the impairments caused by the stroke as well as to minimise development of disuse weakness. The use of a hand-held dynamometer for measuring muscle strength and the use of functional measures to evaluate the effectiveness of the intervention was also advised (Shamay and Shepherd, 2000).

Further research into the specific protocols for strength training, as a form of intervention in neurological physiotherapy is needed. Miller *et al.* (1997) has stated that research directions should be towards finding "correlation of outcome and functional level, specific deficits of strength, determination of effectiveness in the sub-acute stage and establishment of the most effective strengthening protocols." Guiliani (1995) suggested that the "clinical assumption of deleterious effects of exercise training are probably unfounded and that although there is evidence that exercise training improves function, large population studies are necessary to allow "stratification by gender, diagnosis, side and site of lesion, impairment and functional ability."

2.1.4 Stroke rehabilitation in the home environment

Jones and Mandy (2000) state that rehabilitation following stroke that occurs in a hospital setting can be considered to be a "situation in which patients have limited opportunities for control" and this can lead to them feeling "powerless." Prompt discharge combined with home rehabilitation has been found to have a link with a greater degree of higher level function, life satisfaction and community re-integration (Mayo *et al.*, 2000). Although the issue of independent practice and exercise training for individuals following stroke is not straightforward, particularly with respect to safety considerations (Jones and Mandy, 2000), there is an increasing need to develop rehabilitation that can be focused on the individual in their own home environment. This may encourage transfer of learning and development of autonomy. Baskett *et al.* (1999) have found that a home-based programme is "as effective as outpatient or day hospital therapy ($p = 0.003$)." This randomised controlled trial of 100 patients involved a control group who received outpatient or day hospital therapy upon discharge from hospital and an experimental group who were prescribed a programme of exercises and activities following a once weekly visit by a physiotherapist or occupational therapist. The researchers stated that where possible, the stroke patient should be given the opportunity to take control of their recovery programme with a range of activities suiting the emotional and social needs of the individual whilst being appropriate to the level of impairment.

Wall and Turnball (1987) published their work looking at the use of home exercise programmes in stroke patients to address gait asymmetry. Although they did not find that their prescribed exercise programme improved gait symmetry in their experimental group any more than their control group, they highlighted some issues pertaining to the use of home exercise programmes with stroke patients, particularly with respect the nature of the prescribed programme. Wall and Turnbull (1987) suspected that in some instances the exercises were incorrectly performed with the possibility that the exercise regime was rendered ineffective. They suggested further development of feedback devices and methods to ensure correct execution of the prescribed programs. Motivation appeared to be problematic and it was noted that the group who were involved in a combination of independent home exercise and therapist supervised exercise appeared to demonstrate the most improvement in gait speed over the intervention period. Some of their suggestions for motivating the patients and facilitating compliance were to provide instructional videotapes, involve family members and include progression and variation of the programme to minimise boredom. They also suggested higher frequency of exercising of shorter duration and stated that in order to ensure compliance with home based exercises programmes, the programmes must be "challenging, effective and enjoyable."

Rodriguez *et al.* (1996) applied a home based training model with 18 subjects who were at least one year post stroke, where training extended over a period of 22 months. They found an improved perception of well being and quality of functional activities ($p < 0.05$) and a reduced fear of falling ($p < 0.05$). The training programme emphasised weight-bearing, balance, segmental control, stretching and bracing. Although the researchers could not refute that the changes were not due to passage of time, they noted that the subjects who were included in the study were beyond the suggested point at which spontaneous recovery is considered to occur. The researchers concluded from this study that the post acute period may be a better time for patients to focus on specific goals when family and community support is well developed and the patient has returned home (Rodriguez *et al.,* 1996).

Duncan *et al.* (1998) investigated the feasibility of a home-based exercise programme for individuals with mild to moderate stroke. The experimental group ($n = 10$), having completed in-patient rehabilitation, received a three times per week, eight week long therapist supervised exercise programme and then progressed to a 4 week independent home exercise programme, while the control group ($n = 10$) received care as prescribed by their physician. The experimental group showed significant improvement in motor function of the lower extremity ($p < 0.02$) and changes in gait speed. No difference was found in functional status as measured by scales of activities of daily living. This may be due to a lack of sensitivity to change in the outcome measures. Another possible explanation for the lack of functional benefits following the exercise programme is that strength in older individuals is mainly associated with lower extremity function in the lower portion of the strength range and that there is a non-linear relationship between measures of muscle strength and performance (Ferruci *et al.,* 1997). Follow up testing was done after the 12 week intervention period and the researchers do not discuss whether the change from supervised to non-supervised exercise programme in the last 4 weeks may have had an impact on the compliance and performance of the subjects. The authors of this study did note that they had used a small sample and had no knowledge of the subject's site or size of lesion. They also acknowledged that they did not identify an ideal time to initiate a home exercise programme in individuals following stroke, i.e. early or late after stroke, but stated that this study has demonstrated that the use of a home based intervention programme is feasible.

2.2 Gait

Locomotion, in the form of walking, is considered to be the result of the co-ordinated activity of muscles acting across many joints (Winter, 1991). The gait cycle is the fundamental unit of locomotion and is defined as the sequence of events that starts with activity of a lower extremity and continues until that same activity is repeated at the contralateral limb (Craik and Dutterer, 1995). Functional anatomy of the hip is presented in Appendix 1 (a). The normal gait cycle and hip muscle function during the stance phase of gait is described in Appendix 1 (c).

2.2.1 Hemiplegic gait

The typical adaptive motor behaviour that may occur following stroke is a decreased amplitude of movement, a decreased stride length and step length. Uneven step lengths, increased stride width, increased time spent in double support and decreased walking velocity have also been documented (Moore *et al.,* 1993; Moseley *et al.,* 1993). Moseley *et al.* (1993) published a comprehensive description of hemiplegic gait kinematic deviations in the stance phase of gait. Their main findings related to the hip extension in the stance phase of gait are shown in Figure 1.

Figure 1: Possible causes of reduced hip extension in the stance phase of gait.

Source: Moseley *et al.* (1993)

Deviation	Possible Causes
Decreased peak hip extension in late stance phase	**Inability to produce sufficient active tension with the hip extensors in early stance phase**
	Adaptive shortening of the hip flexor muscles
	Production of excessive tension within the hip flexor muscles in stance
	Production of excessive active tension within the hip flexor muscles late in stance
	Adaptive shortening of plantarflexors
	Inability to produce sufficient active tension with the hip flexors late in stance
	Inability to produce active tension with the knee extensors throughout stance
	Inability to produce sufficient active tension in the ankle plantar flexors in stance

Bohannon (1987) found that static strength of lower extremity muscles of the involved side was an important determinant of hemiplegic gait performance, although no relationship between the non-paretic muscle strengths and any gait variable was found. In this study (n = 20), static strength was measured with a hand-held dynamometer and normalised to body weight. Velocity and cadence were calculated from a timed gait trial. Correlations ($p < 0.05$) were found between the gait variables and normalised strength of hip extensors, knee flexors, ankle dorsi and plantar flexor muscle groups. The results suggested that strength of lower extremity muscle groups are important indicators of gait in individuals who have had a stroke.

Peat *et al.* (1976) found that hemiplegic subjects showed a loss of the phasic muscle patterns usually associated with normal locomotion. The mean stance of the affected leg was 67% and the mean swing time was 33%, while the unaffected limb showed a longer stance time and shorter swing phase. This illustrated as an unwilling dependence on the paretic leg as a stable weight-bearing support. Strengthening and task related training is appropriate to address the lower extremity function in order to effect a change in gait performance following stroke.

2.3 Strengthening and Activities to Improve Hemiplegic Gait

Dean *et al.* (2000a) completed a randomised controlled pilot study, which established evidence for the efficacy of a task-related circuit class in improving locomotor function in chronic stroke. In this study, the experimental group ($n = 4$) completed a 4 week (12 sessions) strength and functional training programme, while the control group ($n = 4$) completed an upper limb programme. The experimental group showed improvements in walking speed and endurance as well as force production in the affected leg ($p < .05$). The subjects in the control group did not show similar improvements in lower limb function or strength. This study demonstrated that group exercise classes are one way to provide ongoing programmes to maintain, and/or improve performance after discharge from rehabilitation. The small numbers of subjects involved in this trial and the potential for errors arising from the statistical comparisons indicate that this study should be replicated with large numbers. The researchers recommended that that future studies should include measures of quality of life and community participation.

Malouin *et al.* (1992) found that intensive, graded locomotor activities could be well tolerated in the early period following stroke. A criticism of their study is that in their report they did not discuss their patient selection, response and any physiological characteristics and limiting factors. It is imperative that in any intensive training programme, especially with the acute stroke patient, that there is adequate monitoring to ensure safe participation of the patients.

Mercier *et al.* (1999) described a single case study of a motor re-education programme for the paretic lower limb using a static dynamometer measuring force output at the ankle with feedback to guide force production. This intervention was carried out in 18 sessions over a six-week period and resulted in the subject having an improved ability to produce linear forces in all directions. In addition improvements in functional measures of gait speed, endurance and timed up and go test were noted. This is evidence of the possibility for carry over between strength and gait ability.

Dean *et al.* (2000b) reported a small multiple single case design study to investigate the effect of a locomotor circuit training programme with a specific component designed to increase push-off in walking and muscle strength in chronic stroke. They found that all subjects showed improvement in functional tests during the training phase and maintained the improvement in the second non-training phase. Changes were also shown in power generation at the ankle during push off, increased stride length, improvement in step length ratio and reduction in step width. There were, however, minimal strength changes in hip flexor, ankle plantar flexor and dorsiflexor muscles. This may be an indication of the non-linear relationship between measures of muscle strength and performance which has been identified in older populations of healthy women (Ferruci *et al.*, 1997).

2.4 Outcome Measures

2.4.1 Functional outcome measures in stroke rehabilitation

Responsive and reliable outcome measures need to be used in order to demonstrate treatment effects following rehabilitation (Kwakkel *et al.*, 1999). Following rehabilitation after stroke, it has been found that patients are able to improve their functional performance as demonstrated by changes in their motor assessment scale (MAS) scores (Dean and Mackey, 1992). The MAS is a disability based assessment of eight items of motor function with each item being scored on a scale of 0-6 (Dean and Mackey, 1992). Reliability has been tested by rating individual physiotherapist scores made while observing videotapes of patients against the criterion rating and the scale has been found to have inter and intra-test reliability (Carr *et al.,* 1985). It also has been found to have face and concurrent validity (Poole and Whitney, 1988). The advantage of the test is that it is intended to measure each item independently and each item has no particular relationship to each other (Carr and Shepherd, 1998). The assessment of locomotor related tasks is an important part of the functional assessment of patients after stroke (Richards *et al.,* 1999) and the walking item of the MAS can be used as a measure of gait function. The MAS was found to have a ceiling effect where patients may have scored the highest possible score on the scale, but still require intervention (Dean and Mackey, 1992). In this case the use of additional outcome measures such as timing of walking speed, step length or base of support were suggested.

Timing of walking can be done over a short distance to assess gait speed or over a long distance to assess gait endurance. The 10 metre walk test and the 2 or 6 minute endurance test are examples of these timed walking tests. It may be more relevant to use tests of walking speed that assess comfortable speed over a longer distance rather than maximum speed over a shorter distance (Teixera-Salmela *et al.,* 1999; Wade and Rossier, 2001). Dean et al. (2000c) suggested that walking speed over 10 metres overestimates locomotor capacity after stroke. They found that stroke patients ($n = 14$) where not able to maintain their 10 metre speed during a 6 minute endurance test and had significant reductions ($p < 0.05$) in walking speed compared with healthy subjects ($n = 12$), They recommended that both speed and endurance be tested and trained during rehabilitation. Walking tests have ceiling effects when the subject reached normal speed and endurance (Wade, 1992), but have been found to have face validity and are reliable when performed by a single observer (Rossier and Wade, 2001). In a study of reliability of walking speed, one particular subject showed a large difference in times for the 10 metre walk between test 1 and test 2 with no difference in functional scores and neurological examination (Rossier and Wade, 2001). The researchers reported that the patient mentioned feeling particularly tired on the day of the test. This is an indication of the problematic issue of controlling for individual performance versus capacity. With any tests involving performance, it is therefore important to give consistent instructions and directions to the patient to ensure consistent performance (Wade, 1992). It is also important to acknowledge that performance may be affected by uncontrollable factors such as illness.

2.4.2 Assessment of strength in the presence of spasticity

The validity and clinical inferences of strength measures when used in neurological practice are yet to be established (Miller *et al.,* 1998). Hand-held dynamometers can be used to assess muscle strength in both normal individuals and individuals with spasticity and have in most cases been found to have reasonable inter and intra-rater reliability. In order to ensure this reliability, they must be used with strict criteria, standardised testing positions and procedures (Bohannon and Andrews, 1987; Livesley, 1992; Kilmer *et al.,* 1997, Richardson *et al.,* 1998). In terms of standardising testing positions, goniometry can be used to ensure reliability of limb position prior to measurement of force output and in the same way, force output can be standardised when measuring passive range of motion (Gajdosik and Bohannon, 1987). With specific reference to reliability of goniometric measurements at the hip, visual estimates and goniometric measurements at the hip have been shown to have high reproducibility with good agreement between visual and goniometric estimates and high reliability (Holm *et al.,* 2000). This study was done with patients with osteoarthrosis and may therefore have limited application in other populations.

Riddle *et al.* (1989) studied intersession reliability of dynamometry in brain injured individuals and found that when repeated measures were separated by a time interval, the measures from the paretic limbs were highly reliable, however the measures from the non-paretic limb were not reliable. They attributed this poor reliability of the non paretic limb to the fact that forces generated by the non-paretic limb were more variable than those generated by the paretic limb due to the presence of stereotypic patterns. This study was limited by the small number of subjects, the use of one tester and one type of dynamometer with resulting poor generalisability, however there is an issue with comparing the force output between affected and non-affected side, that needs to be considered if using dynamometry in clinical practice.

Miller *et al.* (1998) reviewed the literature for and against strength testing and training in patients with hemiparesis. They concluded that patients with hemiparesis are able to modulate force in the sub-maximal range of force production but found that strength deficits may differ according to the location of the infarct and related prognostic factors. Lennon and Ashburn (1993) discussed the fact that it is not possible to guarantee maximal exertion during testing in clinical practice as the contraction produced is dependent on motivational and co-operational factors. In addition, reference values are essential for establishing the degree to which an individual's strength is impaired (Bohannon, 1997).

A few studies have described normative values for strength as measured by dynamometry (Andrews *et al.,* 1996) and most of these do not present data for hip extension strength. Smith et al. (1996) studied hip extensor strength in twenty elderly women (mean age 84 +/- 3.1 years). They used the prone lying testing position and measured force output using a myometer clamped to an external rig. The mean values for hip extensor strength in this group was 145 N +/- 51. As the study group were healthy elderly women, the usefulness of these normative values is limited in younger individuals with neurological impairment. Livesley (1992) has presented the reference value of 8.45 kg (SD = 1.53) for isotonic hip extension strength as measured with a hand held dynamometer. This study was completed with a small number of healthy subjects (n=10) and therefore has limited application with this particular study population. In addition, there was not a range of ages tested, the mean age of the subjects tested being 38 years (SD 8.7). Further to this, the values obtained were not normalised to body weight to control for size differences in subjects. In contrast to the values presented by Livesley (1992), Bohannon (1986) presented values for paretic isometric hip extensor strength normalised to body weight for 20 hemiparetic subjects. The range of strength scores was 13.8 kg to 52.3 kg and the mean 33.5kg. In this study, the researcher used the maximum force produced rather than the average of tests as well as a gravity eliminated position with 90 degrees of hip flexion. The differing positions and testing techniques prevent any comparison of presented values. Based on these identified issues relating to the use of dynamometry, this strength measure should not be the only measure used to assess capacity, performance or outcome and it is important to consider that the value of these measures in the discussion of group effects may be limited.

2.4.3 Assessment of activities of daily living

Assessment of activity of daily living (ADL) function is useful when considering how individuals function within their wider community and at home as well as whether the intervention has been of benefit (Wade, 1992). The Nottingham Extended ADL Test (mobility section) can be used as a measure of community participation (Nouri and Lincoln, 1987). Gomperts *et al.* (1994) evaluated the construct validity and sensitivity of the Extended Activities of Daily Living Scale (EADL). They found it to be a valid and sensitive measure although Wade (1992) suggested that scoring and sensitivity may be more useful if used 0-3 in line with potential answers.

Additional information can be gathered by direct questioning which can be directed to the patient or relatives (Wade, 1992). Questionnaires can also be used to seek specific information from the study subjects (Polgar and Thomas, 2000). A closed choice response format is particularly useful to assist in the gathering of qualitative data regarding an intervention or particular situation, as they do not discriminate against less articulate or those with higher level cognitive problems (De Vaus, 1991). When designing questionnaires, it is important to avoid bias, leading questions and ambiguous questions (De Vaus, 1991; Polgar and Thomas, 2000) as individuals with poor memory or insight may over rate their abilities (Lincoln, 1981).

2.4.4 Clinical gait analysis

Quantitative gait analysis is a useful clinical tool for the prescription and evaluation of treatment outcome (Kadaba *et al.*,1990). Computerised gait analysis consists of 3D motion analysis, dynamic electromyography and force plate data acquisition (Ounpuu, 1995). Computerised gait analysis does not replace the more traditional tools used in clinical decision making such as joint range of motion and muscle strength, but should be used in conjunction with these tools to provide a more complete description (Ounpuu, 1995).

Data which can be gathered during a clinical gait assessment include kinetic, kinematic and temporal-distance parameter (Kadaba *et al.*, 1990). Temporal variables provide a comparative value when compared to measured standards and include velocity, cadence and stride length. Kadaba *et al.* (1990) described an external marker system used for computing lower extremity joint angle motion (kinematics) for gait analysis during level walking. This is known as the Helen Hayes Marker Set. They noted limitations of the process as error due to the placement of the body surface markers, but acknowledged that in the sagittal plane, the effect is small.

Kinetics are defined as the "motion of a body under the action of a given force" (Nordin and Frankel, 1980). Joint kinetics are "fundamental to the understanding of movement and the moments of force represent the net effect of the agonist and antagonist" muscle activity at that point in the gait cycle (Winter, 1984). Kinetics are determined mathematically from the force data obtained via a force platform. A complicating factor in the calculation of joint kinetics is the need for making assumptions regarding the body segment masses in the inverse dynamic approach for final moment calculations i.e. indeterminacy (Winter, 1985) and assumptions regarding the estimated joint centre of rotation (Ounpuu, 1995). It has been noted that in human gait, a wide range of force patterns at the hip and knee due to variability and compensating effects can result in identical joint angle patterns during stance phase (Winter, 1984). Hesse (1994) has in fact suggested that kinetics should be considered to be an independent measure of outcome, a view supported by Lennon (2001) following a study of gait re-education using clinical gait analysis as a measure of outcome.

2.5 Hip Extensor Activity and Gait Performance

There is a reported relationship between strength and gait performance in normal, elderly and hemiplegic gait. Bohannon (1986) found that the strength of hip extensors, knee flexors, ankle plantar flexors and dorsiflexors were correlated with walking speed and cadence in stroke patients.

Nugent *et al.* (1994) investigated the influence of a weight bearing leg extensor exercise on walking outcomes following stroke. They based their premise on the functional requirements for a stable, extended leg in the stance phase of gait and found a dose related response between the amount of practice done and walking outcome in individuals who were able to practice the exercise independently. In this study, they did not investigate any strength changes and only measured change according to the functional outcome.

Weiss *et al.* (2000) found that high intensity strength training improved bilateral lower limb strength and functional performance at least one year after stroke. Subjects participated in a twelve week long resistance-training programme and trained twice a week during that time (24 sessions, no documentation of length of individual sessions). The training intensity was set at 70 % of each individual's repetition maximum. The researchers found that nearly all strength improvements were achieved by the eighth week of training, after which there were no additional significant gains. Relative muscle strength gains were similar on the affected (68%) and less affected (48%) side with largest strength increases observed with hip extension on both affected and less affected side. There was a significant improvement in walking function as measured by the walking section of the Motor Assessment Scale, but not in terms of gait speed or leg stance time. This may be related to the type of training programme as well as differences in subjects. The researchers do not discuss a relationship between hip extension and walking function although most strength changes were measured in bilateral hip extensors.

Experimental subjects (n=4) involved in a 4 week long randomised controlled pilot study investigating task –related circuit class aimed at improving locomotor function were found to have an improvement in hip extension in stance and improved power generation at the hip following the intervention (Dean *et al.*, 2000a). Training incorporated strength and functional activities. No relationship was identified between hip extensor activity and gait performance.

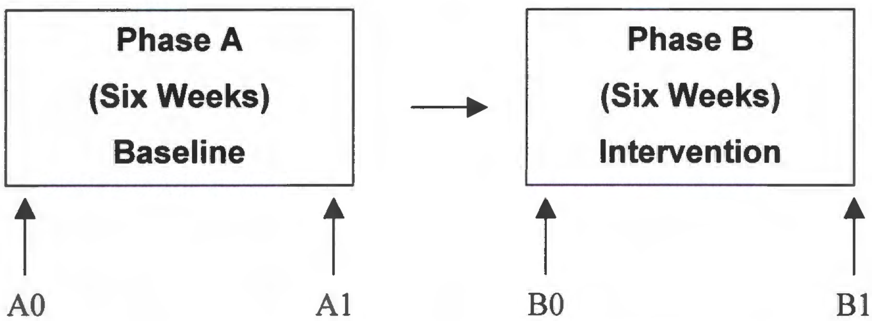
Rodriguez *et al.* (1996) found the greatest mean change in step length, stance time and hip extension ($p<0.05$) following a home based gait-training model for individuals with chronic hemiplegia. They also found an associated reduced fear of falling and improved perception of function in the study subjects. Kerrigan *et al.* (2001) found that reduced peak hip extension during walking in the healthy elderly was more evident in those with a history of falling. They found consistently low peak hip extension which implied that the hip joint was unable to achieve full extension during walking. A reduction in hip extension is significant as functional hip tightness will cause a reduced stride length which in turn is a limiting factor in walking performance. These researchers stated that based upon their findings, addressing hip extension is worthy of investigation in order to improve walking performance.

Single leg support in stance phase is an important determinant of stable gait (Brandstater *et al.,* 1983). One of the problematic events in the hemiplegic stance phase is the lack of sufficient hip extensor muscle activity at the initial heel strike to mid-stance phase (Moseley *et al.,* 1993). This may result in stance phase on a flexed hip with an inability to maintain single leg support in stance and consequently achieve the required push off for the swing phase of gait. Although specific, task related training is considered to be necessary in hemiplegic gait training and lower limb strength is considered to be a performance indicator in gait, there appears to be a paucity of published research addressing the individual, specific effect that reduced hip extension has on hemiplegic gait performance. The researcher therefore asks whether a "hip focused" exercise programme will have an effect on gait performance in individuals with stroke.

Chapter 3: Materials and Methods

3.1 Study design

The method used in this research was a quasi-experimental pretest-posttest group design. This research was considered to be quasi-experimental as random selection of the involved subjects was not possible. The study was composed of two six week phases, A and B, where B immediately followed A.



Phase A: This phase was a baseline measurement phase. It was needed in order to establish that the subjects' gait and function were not changing (to establish a stable baseline). No training or advice was given to the subject. Baseline measures were obtained in week 1 of phase A (at time A0) with repeated measures at the end of phase A (six weeks later). This data was recorded at time A1.

Phase B: Measures were taken at the end of phase A (at time A1). This coincided with the beginning of phase B (where time A1 = time B0). During this second phase, subjects participated in a functional "hip focused" strength training home exercise programme aimed at improving hip extensor muscle strength and range of anterior hip structures. At the end of this six week period, the subjects were re-tested in order to evaluate the effects of the exercise programme (time B1). Transport costs to the laboratory were covered by the researcher in order to ensure attendance at the testing sessions and all subjects were given written and telephonic reminders in the week prior to any testing session.

The gait laboratory is situated at Queen Mary's Hospital-Roehampton and is operated as a joint venture between the hospital and the Biomedical Engineering Group of the University of Surrey. This was the main testing site for the subjects. All other interaction with the subjects took place in their own homes.

3.2 Subjects and Recruitment

The subjects had to meet the following inclusion criteria in order to participate in the study:

1. First stroke resulting in hemiplegia.
2. Aged between 40 and 80 years.
3. At least six months post-stroke.
4. Not receiving any active physiotherapy aimed at addressing balance or lower limb function.
5. Living in an area local to the study.
6. Able to participate in an exercise programme without supervision of the therapist and attend measurement sessions in the gait laboratory at the beginning and end of each phase over the study duration.
7. Able to walk 10 metres independently with or without assistive devices.

Subjects were excluded from the study if they had any medical condition preventing participation in an exercise-training programme. The subjects were also excluded if they were unable to give informed consent or unable to communicate sufficiently to be able to follow the instructions for completing the training programme.

Contact details of individuals who met the inclusion criteria were obtained from discharged physiotherapy patient records within St George's NHS Trust, London (1999/2000). Fifteen of these individuals met the criteria and were provided with information about the study and an invitation to participate (see Appendix 3b). From this initial group, six individuals consented to participate in the study. Those who declined to participate in the study gave their reasons as being due to the time commitment involved as well as difficulty with travel. One individual declined for health reasons.

3.3 Ethical Approval

Ethical approval for this study was obtained from Wandsworth Local Research Ethics Committee (LREC) on 11 December 2000 (see Appendix 3a). Written consent was obtained from all the participants of the study and all subjects were provided with a written information sheet (see Appendix 3b) explaining the nature and purpose of the study as well as the required involvement. All data collected was kept anonymous to outside parties and used only for the purposes of this study. Subjects were made aware that their participation was voluntary and that they were free to withdraw from the study at any time.

3.4 Intervention

3.4.1 Exercise programme

During phase B of the study, the subjects undertook a minimum of 3 exercise sessions per week in their own home for six weeks. All the exercises were designed to be suitable for a home exercise programme. The equipment was portable and suitable for use in each subject's home environment. The researcher visited each subject at home at the start of the session to teach the correct execution of the prescribed programme. At this stage, each subject was provided with a weekly training diary, instructions for the safe completion of the programme (see Appendix 4) and diagrammatic representation of the individual exercises. The individual exercises specifically addressed the hip muscles of the lower limbs and the subjects were asked to perform the exercises bilaterally due to the possibility of associated ipsilateral impairments (Kim and Pohl, 2000).

There is lack of consensus in the literature on the most appropriate time span of intervention for an exercise programme in stroke patients. Strength training research has involved studies lasting a range of durations from 4 to 20 weeks (Damiano *et al.*, 1995a; Damiano *et al.*, 1995b; Sharp and Brouwer, 1997; Teixeira-Salmela *et al.*, 1999; Dean *et al.*, 2000a; Duncan *et al.*, 1998 and Weiss *et al.*, 2000). In strength training, the early increases in voluntary strength are attributed to neural adaptation and motor learning (Sale, 1988; Miller and Light, 1997). As it seems that neural adaptation and motor learning produces a response to strength training, the programme was designed to last over a six week period, which has been found to be sufficient to allow for neural adaptation to strength training (Sale, 1988).

3.4.2 Compliance with the intervention

In order to monitor compliance with the exercise programme, each subject was required to keep a complete record of each exercise session which was facilitated by the provision of a training diary (see Appendix 5).

In addition, each subject was visited at least three times and a maximum of five times over the six-week period by the researcher to ensure the correct execution of the programme, progression of strength training and completion of the training diary by each subject.

3.4.3 Content of exercise programme

A "hip focused" exercise programme was defined as that which involved the training of the hip extensor muscles in a functional pattern. This meant that the exercise programme addressed all hip muscles required to produce a stable extended hip in the stance phase of gait (see Appendix 1a for a description of the functional anatomy of the hip). In order to incorporate the principles of both overload and specificity (Sale, 1988; Sale and MacDougall, 1981, Kerr, 1998), the exercises were designed to incorporate a progressive range of 6 exercises with the emphasis on functional activities (related to the different positions in which the hip extensors are functionally active, see Figures 3 – 12).

The subjects were asked to perform the prescribed exercise programme at least three times weekly over the six week period as the effectiveness of a strength training programme is dependant on frequency, volume and mode of training (Feigenbaum and Pollock, 1999). For individuals with chronic diseases, single set programmes of up to 15 repetitions performed a minimum of twice weekly have been shown to produce the required benefits for strength training (Feigenbaum and Pollock, 1999). Each session took approximately 30 minutes to complete.

When prescribing exercise programmes for an elderly population, sessions should begin at a lower intensity level (moderate rather than maximal intensity) and progress more slowly (Feigenbaum and Pollock, 1999). The number of repetitions that each subject performed was established according to the ability of each individual to perform the exercises correctly and without discomfort, whilst requiring moderate effort. Progression was based on a protocol in which when the subjects could complete 2 sets of ten repetitions through the available range, the resistance was increased. This form of functional resistance had been used effectively in a previous intervention study (Duncan *et al.,* 1998). Either increasing the resistance of the theraband or progression of the level of functional task to a more difficult task or position involving a reduced level of upper limb support or an increased level of work against gravity achieved this progression. Theraband resistance is limited in that the resistance that it provides only loads the muscle in the outer limits of the active range of motion. Functional exercises that incorporated body weight as a form of resistance was therefore necessary so as provide a more uniform resistance.

The stretching exercises provided could be performed in both a supine position and a standing position. The reason for the optional use of the supine position, was that some of the subjects were unable to achieve a suitable stretch in the standing position due to the nature of their impairments. Each stretch was maintained for a maximum of 30 seconds and a minimum of 15 seconds (Shrier and Gossal, 2000; Roberts and Wilson, 2000).

The following equipment was provided to each of the subjects for completion of the exercise programme:

- 15 cm high step (manufactured according to specific specifications of 15cm (height) x 56cm (width) x 37cm (depth) by the carpentry workshop at St George's NHS Hospital)
- Resistive rubber exercise bands providing five levels of resistance, namely extra thin, thin, medium, heavy and extra heavy (Theraband GmbH, Mainzer Landstrabe 19, D-65589, Hadamar, Germany)
- Training Diary (compiled by researcher using Physio-Tools Exercise Software)

Figure 2: Exercise equipment provided to each subject.

Clockwise from front left is theraband, wooden step and exercise handbook

The prescribed strengthening exercises with progressions included:

1. Active hip extension in prone and crook lying

   Level one: prone, isometric

   Level two: prone, isotonic, gravity included, knee flexed

   Level three: prone, isotonic, gravity included, knee extended

   Level four: bridging

Figure 3: Prone hip extension

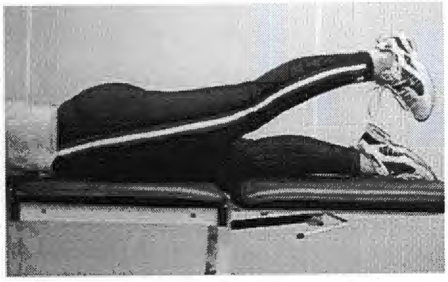
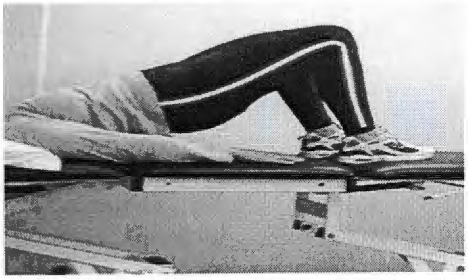
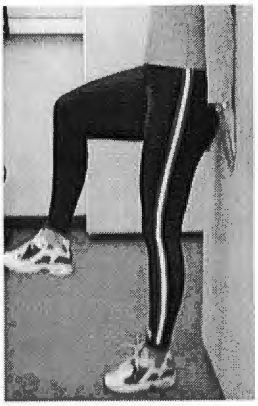


Figure 4: Bridging



2. Weight transfer (gait training) in standing against a wall

Figure 5: Weight transfer in standing



Level one: do not lift the non-weight bearing leg from the ground

Level two: progress to single leg stance leaning against the wall

3. Squats

Figure 6: Squats

Level one: use a stable chair for upper limb support

Level Two: Complete the activity with no upper limb support

4. Step ups

Figure 7: Step ups

Level one: Step ups onto wooden step (use upper limb support)

Level Two: Complete the activity with no upper limb support

5. Chair stands

Figure 8: Chair Stands

Level one: Stand up and sit down from a chair, using hands for assistance

Level two: Complete the activity with no upper limb support

6. Wall slides

Figure 9: Wall slides

Level one: slide down the wall until 30 degrees of knee flexion,

Level two: progress until knee flexion is 80 degrees

7. Hip Extension in standing

Figure 10: Theraband hip extension

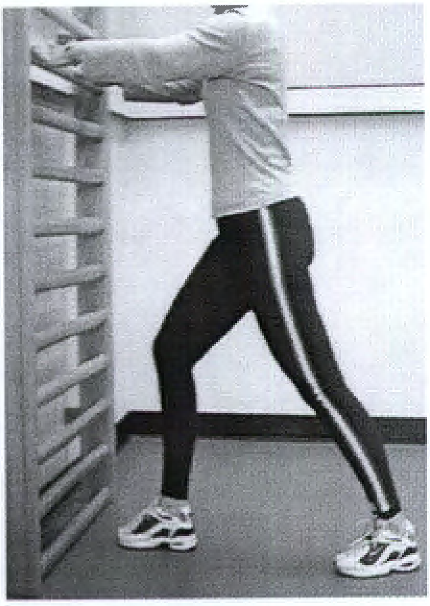
Level one: free active hip extension with upper limb support

Level two – four: add and progress rubber bands to resist hip extension

The prescribed stretching exercises included:

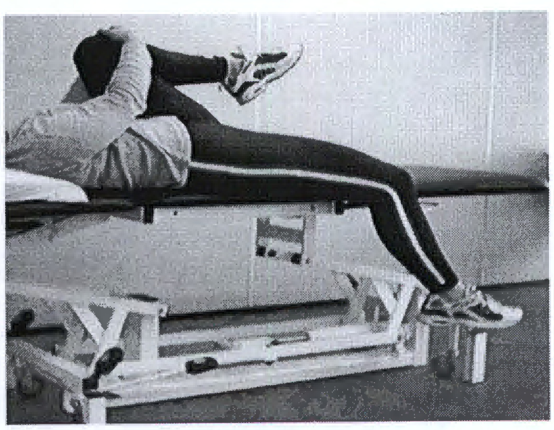
1. Supine hip extension with knee extension over the edge of the bed and opposite leg remaining in neutral
2. Stride standing facing a wall

Figure 11: Stride standing hip stretch



3. Supine hip extension with knee flexion and opposite hip and knee flexion

Figure 12: Supine hip stretch



3.5 Outcome Measures

3.5.1 Instrumentation

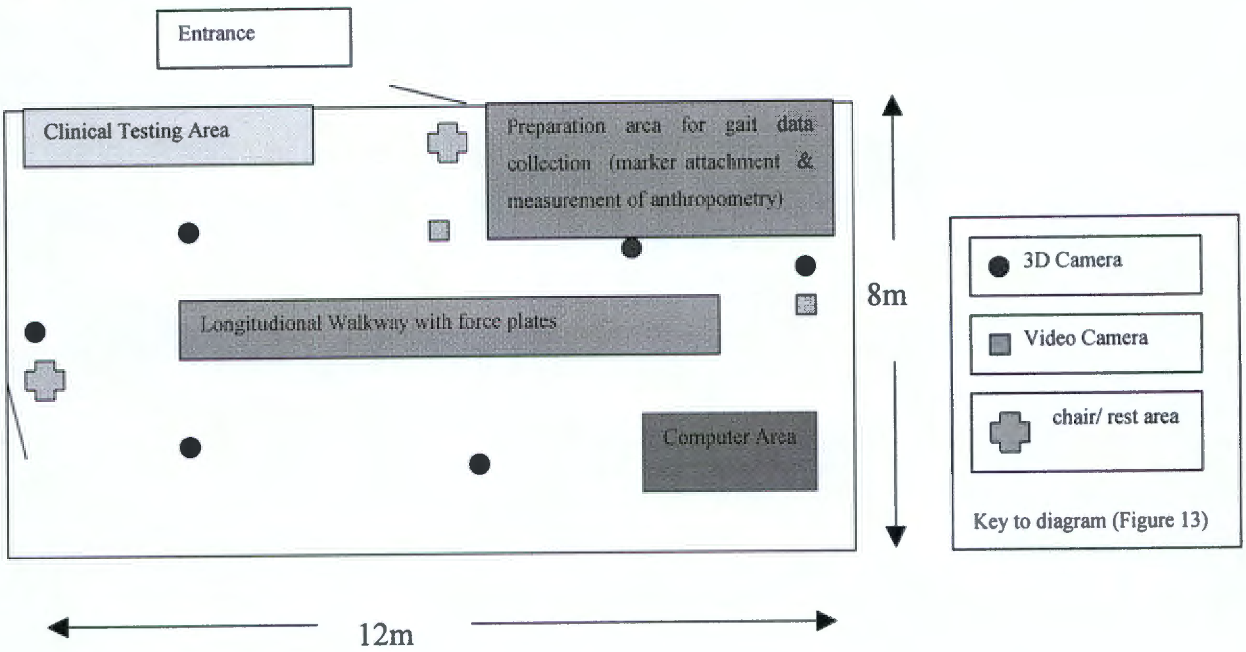
The following instrumentation was required for the testing procedure utilised in this study.

1. In order to obtain a measure of hip extension force, a hand-held dynamometer (Nicholas manual muscle tester) manufactured by Lafayette Instruments, PO Box 5729, Sagamore, Parkway North, Lafayette, Indiana, 47903, U.S.A., was used
2. The range of anterior hip structures was assessed using a Baseline goniometer (Fabrication Enterprises, 50 South Buckout Street, Irvington, NY10533, USA)
3. Functional mobility was assessed using the Motor Assessment Scale for Stroke (walking section) (Carr *et al.,* 1985) (see Appendix 6a). In order to execute this test, a stop-watch manufactured by A.E. Combs LTD, London, E181PS was used as well as a beanbag, tape measure and steps The bean bag was of weight 400 grams, 15cm in length and 10 cm in width (assembled by researcher). The tape measure was a rigid unit and the steps were a fixed unit situated at the testing site.
4. In order to obtain a measure of community ambulation, the Nottingham Extended ADL Score (mobility section) (Nouri and Lincoln, 1987) (see Appendix 6b) was used. No equipment was required to administer this test.
5. The gait laboratory data was collected using the Qualisys 3D Gait Analysis System (Qualisys Inc, 41C New London Tpke, Glastonbury, Connecticut, 06033, USA).
6. A post-intervention questionnaire was used to gather qualitative information regarding the intervention (see Appendix 8).

3.5.2 Development of the testing procedure

Testing was carried out on four separate occasions in the Gait laboratory at Queen Mary's Hospital-Roehampton. On each occasion the setting was identical. The layout of the laboratory is illustrated in Figure 13.

Figure 13: Diagrammatic layout of gait laboratory



3.5.2.1 Pilot study

A pilot study of the testing procedure in the laboratory was completed with a single healthy subject to ensure appropriateness of the research methodology, familiarise the researcher with testing techniques and procedure and establish tester reliability. Rest areas within the laboratory were identified. The testing position for the range of anterior hip structures and hip dynamometry was confirmed as being a stable side-lying position in which the research subjects would not be able to recruit alternative compensatory muscles to complete the activity. The clinical gait analysis process (including a full analysis on one healthy subject) was reviewed and factors specific to stroke patients such as the use of walking aids, and orthoses were identified. When subjects wore shoes for the gait analysis, an alternative marker placement was used. If a subject used a walking aid, this was maintained for all testing sessions.

3.5.2.2 Familiarisation of research subjects

Familiarisation of the research subjects was essential in order to ensure that the results would not be adversely influenced by the testing procedure and environment, which was not a normal environment for these subjects. All subjects were visited in their homes by the researcher in order to explain the test protocol prior to the start of phase

A. At the same time, the researcher was as able to gather baseline data, in the subject's normal environment, of functional, clinical measures and past history including medication profile (see Appendix 7).

There was also an initial testing session for all subjects in the gait laboratory, carried out 1 week prior to the start of phase A. This was done in order to allow the subjects to become familiar with the process and testing procedure in the gait laboratory and allow the researcher to become familiar with the application and securing of reflective markers in the particular case of each subject.

3.5.3 Testing procedure

At each testing session, the subject entered the laboratory through the same entrance. Testing was standardised throughout the study by ensuring that subjects were tested at the same time of the day at each session and used the same assistive devices. In order to minimise fatigue, a wheelchair was used to transport the subjects from the waiting area to the testing area at each session.

Each subject was asked to wear either shorts or a swimsuit so that clothing would not obscure the reflective markers, used for clinical gait analysis. Once the subject was sufficiently undressed, the clinical physiotherapy measures were gathered. Range of anterior hip structures was assessed, thereafter hip extensor muscle strength as measured by dynamometry was measured and finally functional scores as measured by the walking section of the Motor Assessment Scale (MAS), the 10m timed walk and Nottingham Extended Activity of Daily Living Scale (community participation) were gathered. The same tester completed all assessments throughout the study so as to facilitate test-retest reliability. Tester reliability had been considered during the initial pilot study period.

The next stage of testing involved gathering of the clinical gait data. Anthropometric data was collected. Reflective markers were then attached to standardised surface landmarks on each subject so that the standing and walking data could by collected via the 3D camera system. The testing procedures for the clinical physiotherapy measures and clinical gait analysis are described in full in the following section. Each testing session took approximately one hour to complete.

Figure 14: Equipment used for gathering clinical and functional measures

Clockwise from front left are handheld dynamometer, beanbag, universal goniometer stopwatch, and tape measure.

3.5.3.1 Clinical Physiotherapy Measures

At each testing session, clinical physiotherapy measures of range of anterior hip structures and hip extensor dynamometry were collected.

Range of anterior hip structures

The range of the anterior hip structures was assessed as the available range of passive hip extension (Kendall *et al.*, 1993) in side lying with full knee extension and a neutral spine position as measured with a universal goniometer. 10 degrees of passive hip extension was accepted as the average available range (Kendall *et al.*, 1993). The testing position used was as is described for the assessment of hip extensor muscle strength (see Figure 15). Reliability for goniometric measurements at the hip has been established (Holm *et al.*, 2000), however the variability between raters means that measurement error may account for 4 degrees on 95 % of measurements (Bartlett *et al.*, 1985). Although the same rater completed all measurements throughout the study, the data was collected in 5 degree increments so as to accommodate for possible measurement error. Three measures were collected at each session (see data collection sheet in Appendix 9).

Figure 15: Side lying testing position for assessment of hip structures

Hip extensor muscle strength

The hip extensor muscle strength was tested as the maximal isometric hip extension force produced in a side-lying position (Livesley, 1992) with full knee extension and neutral hip extension. A neutral hip extension position was defined as the position of 0 degrees as measured with a universal goniometer. Hand-held dynamometry (myometry) was used to provide a quantitative measure of muscle strength and the test used is known as the "make" test (Phillips *et al.,* 2000). This test requires the subject to produce a maximum isometric force at the point of force application of the dynamometer. All measurements throughout the study were performed by one female examiner who was experienced with hand held dynamometry (Phillips *et al.,* 2000) and with the subject and examiner in the identical position at each testing session (Livesley, 1992). The validity of the dynamometer is not yet fully established (Miller *et al.,* 1998), but dynamometry has been found to have reasonable inter and intra-rater reliability provided that it is used with strict criteria, standardised testing positions and procedures (Bohannon and Andrews, 1987; Livesley, 1992; Kilmer *et al.,* 1997; Richardson *et al.,* 1998).

The subject was positioned in side lying (gravity eliminated position) on a standard low plinth with both Anterior Superior Iliac Spines (ASIS) perpendicular to the plinth and the mid-point of acromion in line with the ASIS. The neutral starting position of zero degrees hip extension was confirmed with a universal goniometer (Keating and Matyas, 1996). This position was maintained with the use of pillows for packing and external stabilisation was given to prevent any pelvic rotation during the execution of the test. A sliding board was placed, supported by pillows between the subject's legs to prevent any hip adduction during testing (Livesley, 1992).

The examiner was positioned in standing alongside the plinth so as to be able to apply a perpendicular force via the myometer which was placed 3cm above the upper border of the popliteal fossa of the subject of the limb being tested. At each testing session, the examiner tested both the less affected and more affected side of the subjects. As a routine, the less affected side was tested first followed by the more affected side. In order to perform the test, the examiner held the myometer stable and positioned perpendicular to the limb on the upper border of the popliteal fossa of the subject while the subject exerted their maximum isometric force against the myometer for a period of 3-5 seconds (Phillips *et al.*, 2000). The examiner performed three repetitions of each trial with a 30-second rest between each trial (Lennon and Ashburn, 1993). Additional trials were performed if at least 2 of the repetitions were not within 10 % of each other (Phillips *et al.*, 2000). The limb being tested was not moved in between trials. The value in kilograms recorded by the myometer was multiplied by 9.81 to convert to Newtons (Phillips *et al.*, 2000). The value in Newtons was multiplied by the length of the moment arm (distance from hip joint to point of application of the myometer) in order to calculate a value for the moment at the hip joint in Newton meters (Nm). According to the manufacturer, the myometer that was used for this study has a measurement range of 0.0 – 199.9 kg, an accuracy of +/- 0.5 percent of full scale and sensitivity to 0.1 kg.

Figure 16: The Nicholas Manual Muscle Tester (front view)

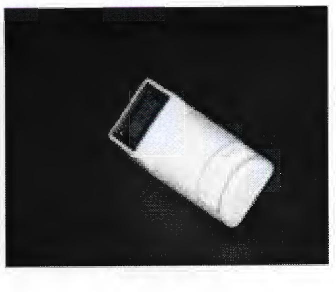
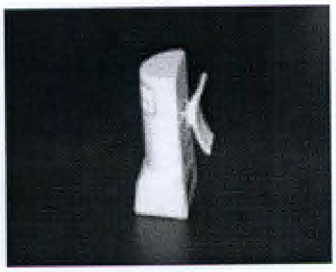


Figure 17: The Nicholas Manual Muscle Tester (side view)



3.5.3.2 Functional Measures

Functional ability was measured using the walking section of the Motor Assessment Scale for Stroke (MAS) It has been found to be a valid and reliable measurement tool (Carr *et al.,* 1985 and Poole and Whitney, 1988). The MAS score was gathered as the subjects were asked to complete a 10-metre traverse that had been marked out on the floor of the laboratory with masking tape. If they were able to walk 5metres in 15 seconds (grade 4 on MAS scale), they were then asked to walk 10 metres, turn around, pick up a beanbag from the floor and walk back to the starting point. In order to be successful at this level, the task needed to be completed in 25 seconds. If the subjects required at aid to complete the traverse, they scored a grade 3 on the MAS scale).

The Nottingham Extended ADL Test (mobility section) was used as a measure of community participation (Nouri and Lincoln, 1987). This scale is a general measure of independent function and includes activities such as outdoor function and the use of public transport. This scale is designed for interview administration. It has been found to be a valid and sensitive measure of performance (Gompertz *et al.,* 1994).

The 10 metre walk test was used as a measure of walking speed over a short distance (Wade, 1992). Timing of walking started as the subject's trunk crossed the start line of the 10 metre distance that was marked out on the floor of the laboratory. The 10 metre walk test has been found to have face validity and reliability when performed by a single observer (Rossier and Wade, 2001).

3.5.3.3 Clinical Gait Analysis

Gait Data

Kinematic data was directly measured by the 3 dimensional motion analysis system and kinetic data by use of a 3.3m long dual force-platform walkway (Hynd *et al.*, 2000). In addition to motion data being collected, static data was collected in the standing position. Standard force plates are usually only capable of collecting force data from one step in a single traverse. The dual platform force walkway was used as it allowed multiple force data to be collected during one traverse (Hynd *et al.*, 2000). Sufficient data could be collected during one traverse if necessary and this minimised the potential problem of fatigue with less able individuals who were completing the walking trials.

Anthropometry

The following anthropometric measures were taken before each gait testing session (Kadaba *et al.*, 1990):

- Height (measured with a wall mounted vertical height measure)
- Weight (measured via the force plate and including shoes and aids)
- Knee width (using callipers at level of knee joint midline)
- Ankle width (using callipers at the level of ankle lateral malleolus)
- Foot width (using callipers at the level of the first metatarsal head)

The following data was collected via the motion analysis system:

- Hip joint excursion and maximum hip extension (sagittal plane)

A reduction in hip extension is problematic as functional hip tightness may cause a reduced stride length which in turn is a limiting factor in walking performance (Kerrigan, 2001). Hip joint excursion in the sagittal plane was collected so as to obtain a measure of the functional hip range of motion during walking. It has been suggested that as muscle strength is increased, so the available range of motion over which the muscle would be active would also increase. This gait parameter was required so as to evaluate active hip range of motion as a result of the strengthening intervention. Lack of sufficient hip extensor muscle activity at the initial heel strike to mid-stance phase (Moseley *et al.*, 1993) may result in stance phase on a flexed hip with an inability to maintain single leg support in stance. Maximum hip extension angle in stance phase was collected so as to evaluate the impact of the intervention on single limb support with reference to the hip extension angle.

- Peak vertical ground reaction force

Peak ground reaction force has been shown to increase following a task related circuit training intervention aimed at improving locomotor function in chronic stroke (Dean *et al.,* 2000a). This measure was obtained via the kinetic data and calculated as the greatest force exerted at any one phase of stance phase for each individual.

- Gait speed

Gait speed was calculated by the system software and defined as the self selected average velocity for each traverse. The strength of the lower limb has been shown to be related to gait velocity in stroke patients (Bohannon, 1986). This gait parameter was required so as to evaluate gait performance as a result of the strengthening intervention.

- Step length

Reduced extension at the hip has been found to result in reduced step lengths (Murray, 1976). Step length was measured in order to identify if this would change as a result of the intervention. Step length was calculated by the system software and defined as the horizontal distance in the plane of progression during one step.

- Weight distribution in standing

Asymmetry favouring the hemiplegic side has been shown with a significant relationship between walking ability and lateral movement (Tyson, 1999). Weight distribution in standing was measured in order to identify if this would change as a result of the intervention. Weight distribution in standing was defined as the ratio of affected to less affected weightbearing in standing. This was calculated from the standing data collected via the two parallel force platforms.

Data was collected while the subjects stood on the force platform and then walked along the ten metre long walkway with a built in 3.3 metre longitudinal dual platform force walkway. Subjects were asked to walk at their self-selected normal speed and completed a maximum of ten traverses across the walkway. Subjects walked with shoes at their own discretion and any aids required. The subjects who wore shoes and used any aid were asked to wear the identical shoes and use the same aids for all testing sessions. The alternative marker positions as described were used for subjects who wore shoes for the testing. Video data was collected for each subject during each traverse.

Markers

The modified Helen Hayes marker set (Kadaba *et al.,* 1990) was used for the data collection. Reflective markers were attached to standardised surface landmarks that were different according to whether or not shoes were worn (see Figure 18). Digital photography was used to keep a record of the exact marker positions immediately prior to the walking test beginning. The photography was necessary so as to maintain a record of marker placement for each gait study to ensure accurate and standardised placement *i.e* tester reliability which would not affect the results obtained (Kadaba *et al.,* 1990).

Markers were attached to the following surface landmarks bilaterally:

1. Space between the second and third metatarsal heads (no shoes)/ fifth metatarsal head (shoes)
2. Lateral malleolus (no shoes)/ 3 cm above lateral malleolus (shoes)
3. Mid-shank (tibia)
4. Femoral Epicondyle
5. Mid shank (femur)
6. Anterior Superior Iliac Spines
7. Sacrum
8. Mid point of acromion process

Figure 18: Marker positions

Conventional marker positions (anterior view)

Alternate marker positions (posterior view)

3.5.4 Post-intervention questionnaire

A questionnaire was developed to gather information regarding the subject's individual experiences and perceived response to the intervention (see Appendix 8). As the questionnaire was designed to gather subjective information about the subject's personal experience of the intervention, questionnaire using Likert style responses was chosen (De Vaus, 1991; Polgar and Thomas, 2000). The questionnaire was validated by a range of individuals with experience in questionnaire design, who were asked to consider the ease of use and relevance of the questionnaire. The questionnaire was administered to the subjects by an independent assessor, who had no previous exposure to the questionnaire, following the final stages of testing.

3.6 Data Analysis

The data was collected (see Appendix 9), coded and analysed using the statistical software package SPSS for Windows Version 10. Due to the nature of the data, both descriptive and inferential statistics were used. Statistical advice was obtained from Professor Martin Bland, medical statistician at St. George's Hospital Medical School, London (Bland, 2000).

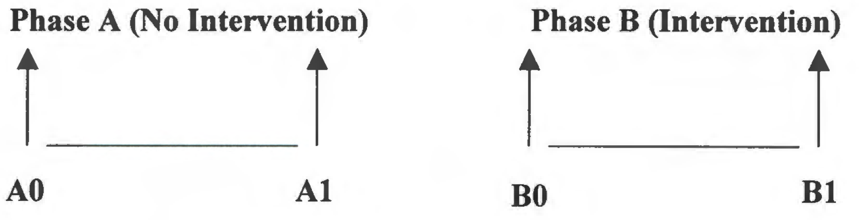
3.6.1 Descriptive analysis

Descriptive statistics in the form of means and medians as well as standard deviations are presented in the forms of graphs and charts. Kinetic data from the gait analysis are presented graphically. The results of the post intervention questionnaire are described.

3.6.2 Inferential statistical analysis

For the statistical analysis, parametric statistical tests on the mean of the 3 repeated observations for each variable (n=6) were used. The paired t-test was used to assess for statistically significant differences in the before and after measurements for Phase A and Phase B (Bland, 2000; Hicks, 1988). In this 3 step design study, involving one group of subjects taking part in two conditions, it was necessary to demonstrate that any difference that was found in the before-after measurements at each phase of the study could be attributed to the intervention, and were not as a result of time or practice. In order to establish whether any improvement found was a result of the intervention, the effect of learning and time was assumed to be the same at each stage of the study. As seen in Figure 19 below, a paired t-test can be done on the changes during each phase, and it is also possible to test if the change between phases was sufficient to be considered an intervention effect (Bland, 2000). In each case, a change was considered statistically significant if it differed from zero.

Figure 19: Formulae used to identify changes as a result of the intervention



Change during phase A $= (P_{A0} - P_{A1})$

Change during phase B $= (P_{B0} - P_{B1})$

Change between phases $= (P_{A0} - P_{A1}) - (P_{B0} - P_{B1})$

$= P_{A0} - 2P_{B0} + P_{B1}$ since $P_{A1} = P_{B0}$

P indicates the value of the parameter of interest at a particular time (A0, A1, B0, B1)

Pearson's correlation co-efficient was used to assess whether a relationship existed between any of the variables. A value closer to 1 indicates a strong correlation in a positive or negative direction depending on the sign of the value. A two-tailed t-test was used to assess for the significance of a correlation (Argyrous, 2000). Parametric tests were considered to be appropriate due to the interval nature of the data and the assumption of normal distribution (Bland, 2000). The level of significance (alpha) was established to be 0.05, which is considered to be evidence of a difference and the confidence interval was 95 % (Bland, 2000).

Chapter 4: Results

Six subjects were recruited for this exploratory study. All six subjects completed the testing and intervention stages of this study. Three male and three female subjects took part in the study. Four of the subjects were Caucasian and two were of Asian origin. Other characteristics of the study sample are shown Table 1. All of the subjects who participated in the study had a left sided hemiplegia. One subject used an ankle foot orthosis for all walking activity, three subjects used sticks for the testing as they required the use of a stick for everyday walking activity, and four subjects chose to wear shoes during testing.Four of the subjects scored level 3 on the walking section of the Motor Assessment Scale (MAS), while the remaining two subjects scored level 4.

4.1 Characteristics of Study Subjects

Table 1: Characteristics of study subjects

Characteristics	Mean	Standard Deviation	Range
Age (years)	64.8	6.2	15
Height (cm)	170.2	6.7	21
Weight (N)	699.4	93.5	259
Length of time since stroke (in months)	23.3	7.1	17

4.2 Changes as a Result of the Intervention

4.2.1 Clinical physiotherapy measures

There was a significant improvement in the clinical measure of affected hip extensor strength (p=0.05) after the exercise intervention phase of the study (*cf.* Tables 2 and 3). The paired t-test on the excess change following the intervention (*cf.* Figure 19 and Table 4) showed that the effect could not be attributed to the intervention alone (p = 0.2). There was no significant change in the range of anterior structures or timed ten-metre walk at any stage of the intervention. The mean range of motion for the less affected hip at time A0 was 9.2 degrees (SD=2.0) and the mean range at times B0 and B1 was 10 degrees (SD=0). The mean values for the clinical measures at times A0, B0 and B1 are shown in Figure 20. The actual values are presented in Table 2 and the statistical data are presented in Table 3. There was no change in the functional score for each individual subject as measured by the Motor Assessment Scale (MAS) or community participation for each individual subject as measured by the Extended Activities of Daily Living Scale (EADL). The mean score on the Motor Assessment Scale at each measurement time during the study was 3.3 (SD=0.5). The mean score on the Extended Activities of Daily Living Scale at each measurement phase of the study was 4.5 (SD=1.7).

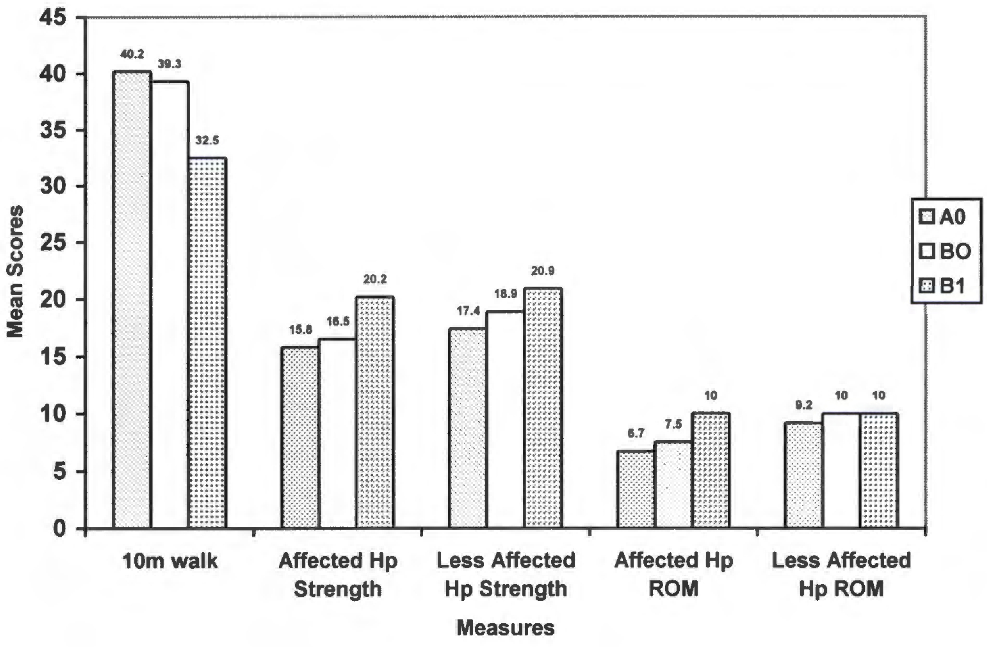
Table 2: Mean, standard deviation and range of clinical physiotherapy measures at each time during the study

Clinical Measures	Time A0	Time A1=Time B0	Time B1
10m Timed Walk (s)	Mean 40.2s (speed = 0.25m/s) SD 19.9 Range 17-63	Mean 39.3s (speed = 0.25 m/s) SD 25.3 Range 13-75	Mean 32.5s (speed = 0.31m/s) SD 17.0 Range 13 – 55
Hip Moment (Nm) on affected side	Mean 15.8 SD 6.7 Range 9.1-24.5	Mean 16.5 SD 8.0 Range 4.9-24.8	Mean 20.2 SD 6.2 Range 11.4-26.3
Hip Moment (Nm) on less affected side	Mean 17.4 SD 6.2 Range 12.4-28	Mean 18.9 SD 4.6 Range 8.9 – 24.1	Mean 20.9 SD 6.3 Range 11.3-29.6
Hip Extensor Strength Difference (Nm) between sides	Mean 5.5 SD 4.7 Range 1.3-13.8	Mean 4.9 SD 2.4 Range 1.9-8.1	Mean 3.3 SD 1.8 Range 1.8-6.7
Hip ROM (degrees) on affected side	Mean 6.7 SD 4.1 Range 0-10	Mean 7.5 SD 4.2 Range 0 –10	Mean 10.0 SD 0.0 Range 0

Table 3: Statistical comparison of changes in the clinical physiotherapy measures during the two phases of the study (*cf.* Figure 19)

Clinical Physiotherapy Measures	Mean Diff.	Std. Error Mean	95% Confidence interval		t	df	Signif. (2-tailed)
			Lower	Upper			
10 m timed walk (s) (Phase A)	0.8	4.1	-9.7	11.4	0.20	5	0.85
10 m timed walk (s) (Phase B)	6.8	4.2	-4.1	17.7	1.61	5	0.17
Hip moment (Nm) on affected side (Phase A)	-0.8	1.3	-4.1	2.5	-0.61	5	0.57
Hip moment (Nm) on affected side (Phase B)	-3.7	1.5	-7.6	0.2	-2.44	5	0.05
Hip moment (Nm) on less affected side (Phase A)	-1.5	1.8	-6.3	3.2	-0.83	5	0.45
Hip moment (Nm) on less affected side (Phase B)	-2.1	1.7	-6.5	2.4	-1.20	5	0.28
Hip extensor strength difference between sides (Phase A)	0.7	2.0	-4.5	5.8	0.34	5	0.75
Hip extensor strength difference between sides (Phase B)	1.6	0.9	-0.7	3.8	1.81	5	0.13
Hip ROM (degrees) on affected side (Phase A)	-0.8	0.8	-3.0	1.3	-1.00	5	0.36
Hip ROM (degrees) on affected side (Phase B)	-2.5	1.7	-6.9	1.9	-1.46	5	0.20

Figure 20: Mean change in physiotherapy measures from A0 to B1



Excess change of significant variables	Mean Diff.	Std. Error Mean	95 % Confidence Interval		t	df	Sign. (2-tailed)
			Lower	Upper			
Hip Moment (Nm) on affected side	-2.9	2.0	-8.1	2.3	-1.45	5	0.21

Table 4: Statistical comparison of changes in the hip moment between the two phases of the study (*cf.* Figure 19)

4.2.2 Gait Measures

There were no significant changes in any of the measures of gait performance as a result of the intervention. The actual values are presented in Table 5 and the statistical data are presented in Table 6.

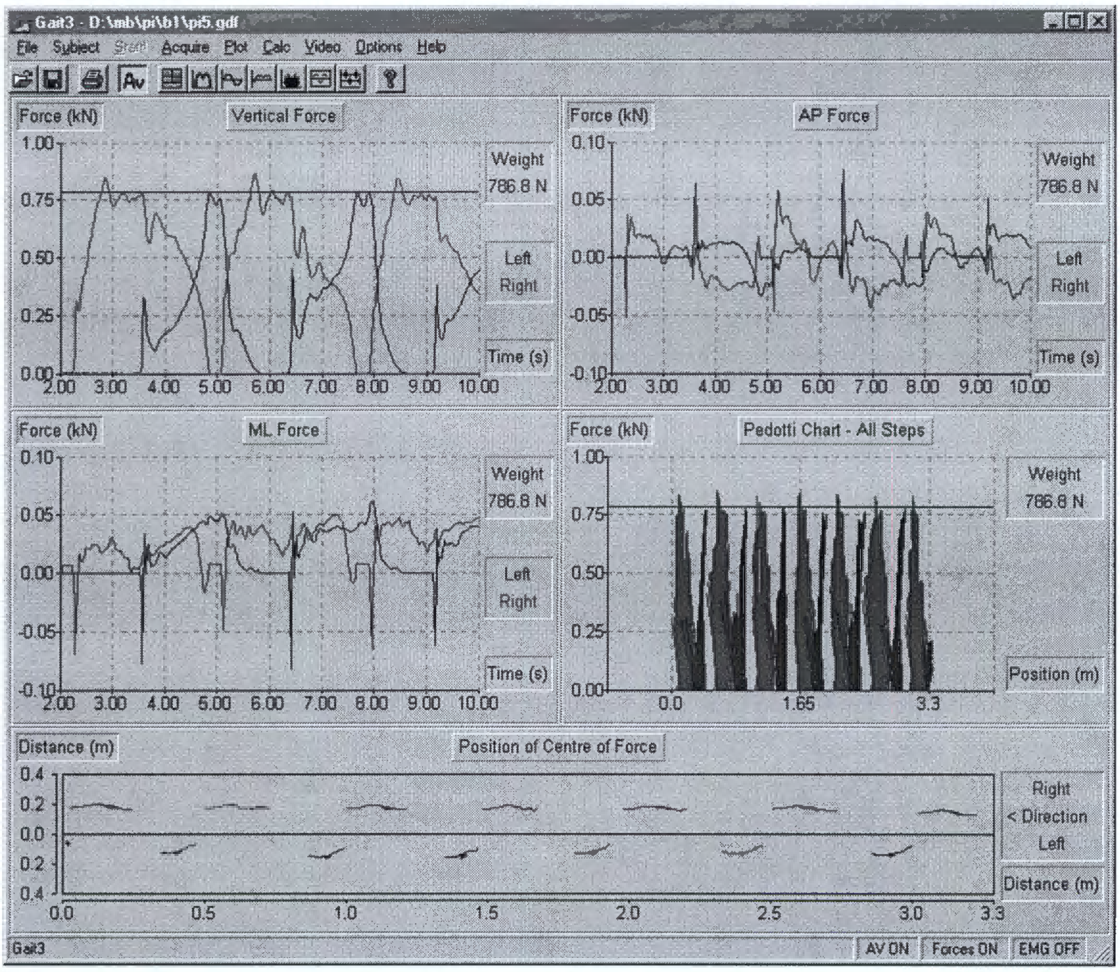
Table 5: Mean, standard deviation and range of gait measures at each stage of the study

Gait Measures	Time A0	Time A1 = Time B0	Time B1
Speed in cm/s	Mean 35.7 SD 25.9 Range 11.6-73.0	Mean 33.6 SD 30.6 Range 2.9-75.6	Mean 38.1 SD 25.7 Range 16.0 -71.7
Joint excursion (degrees) on affected side	Mean 20.8 SD 7.8 Range 7.0-33.6	Mean 23.1 SD 8.4 Range 13.1-37.3	Mean 22.9 SD 8.6 Range 9.7 - 35.5
Joint excursion (degrees) on less affected side	Mean 36.3 SD 8.0 Range 9.4-32.6	Mean 36.0 SD 10.9 Range 21.1-51. 7	Mean 36.0 SD 8.5 Range 23.9-46.8
Maximum hip extension (degrees) on affected side)	Mean 5.8 SD 9.9 Range –8.3-17.7	Mean 4.2 SD 11.1 Range –10.7-18.0	Mean 6.1 SD 10.0 Range –7.7-16.0
Vertical peak ground reaction force on affected side (N)	Mean 632 SD 80 Range 567-780	Mean 612 SD 89 Range 495-768	Mean 601 SD 80 Range 512-752
Step length (mm) on affected side	Mean 485 SD 161.9 Range 232-695	Mean 356.2 SD 111.4 Range 232-490	Mean 413 SD 79.7 Range 136-610
Weight bearing (N) on affected side	Mean 292 SD 83 Range 162- 400	Mean 280 SD 94 Range 162-370	Mean 284 SD 95 Range 139-397

Table 6: Statistical comparison of changes in the gait parameters during the two phases of the study (*cf.* Figure 19)

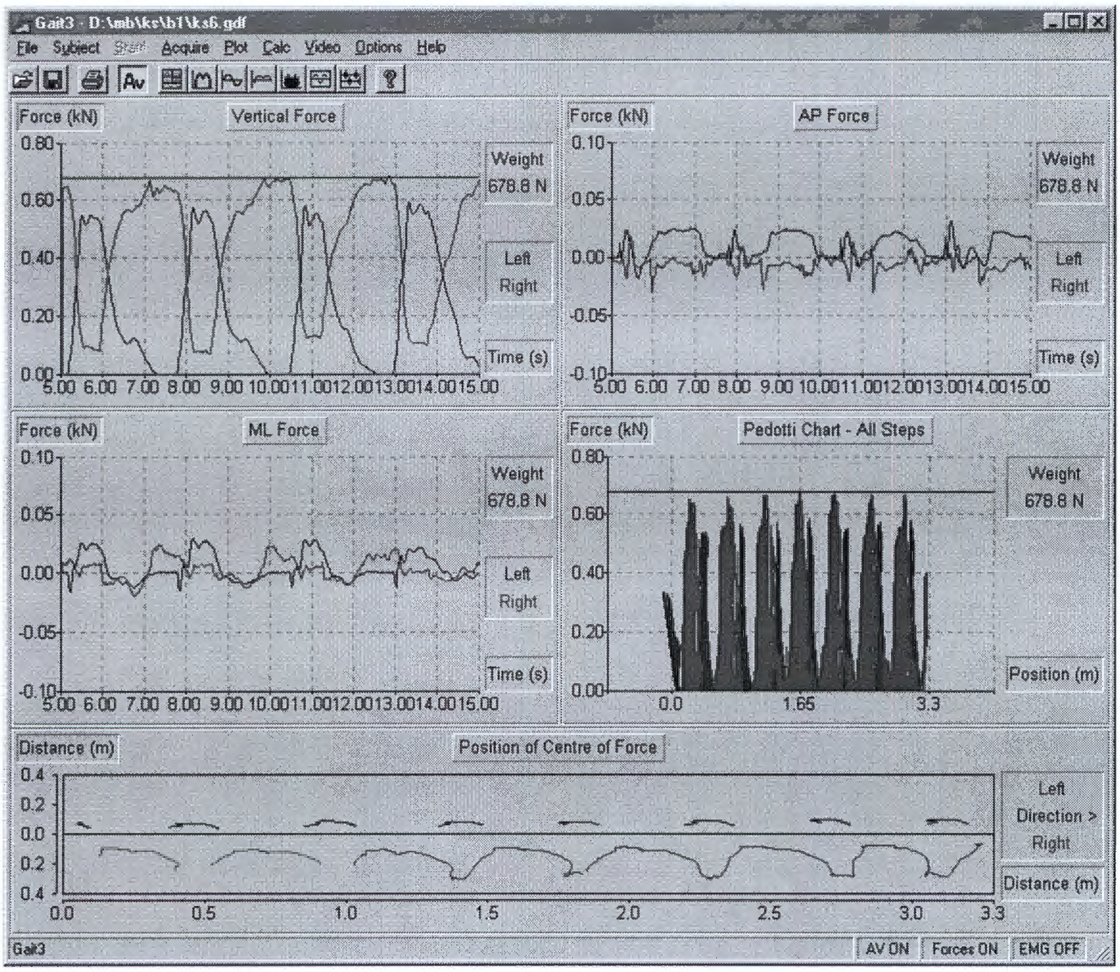
Gait Measures	Mean Diff.	Std Error Mean	95 % Confidence Interval		t	df	Sign. (2-tailed)
			Lower	Upper			
Gait speed (cm/s) (Phase A)	2.0	5.0	-10.8	14.9	0.40	5	0.70
Gait speed (cm/s) (Phase B)	-4.5	4.2	-15.2	6.3	-1.07	5	0.34
Joint excursion (degrees) on affected side (Phase A)	-2.3	1.7	-6.6	2.0	-1.39	5	0.22
Joint excursion (degrees) on affected side (Phase B)	0.3	1.4	-3.4	3.9	0.19	5	0.86
Maximum hip extension (degrees) on affected side (Phase A)	1.7	2.5	-4.6	8.0	0.68	5	0.53
Maximum hip extension (degrees) on affected side (Phase B)	-1.9	1.9	-6.8	3.0	-0.98	5	0.36
Vertical peak ground reaction force (N) on affected side (Phase A)	20.0	23.4	-40.1	80.1	0.86	5	0.43
Vertical peak ground reaction force (N) on affected side (Phase B)	11.2	9.0	-11.8	34.2	1.25	5	0.27
Step length (mm) on affected side (Phase A)	99.6	90.0	-131.6	330.9	1.10	5	0.32
Step length (mm) on affected side (Phase B)	-27.4	47.4	-149.2	94.4	-0.58	5	0.58
Weight bearing (N) on affected side (Phase A)	11.7	21.6	-43.8	67.1	0.54	5	0.61
Weight bearing (N) on affected side (Phase B)	-3.8	12.5	-36.0	28.5	-0.29	5	0.77

Figure 21: The force plate data for one subject walking with no assistive device



The ground reaction forces reflect the net vertical and shear forces acting on the platform surface (Winter, 1991). The vertical force plot shows the vertical ground reaction forces experienced by the left and right lower limbs. These patterns are different from the normal and do not display the characteristic double hump related to weight acceptance and push off during the stance phase (Winter, 1991). The horizontal ground reaction force in the anterior-posterior direction, should be posterior at heel strike and anterior during propulsion (Tibero and Gray, 1994). The mediolateral force is an indication of the internal rotation at heelstrike (lateral force) and external rotation (medial force) during propulsion (Tibero and Gray, 1994). The Pedotti (butterfly) chart is an indication of the resultant force plotted against position in the gait cycle. The position of the centre of force shows the number of steps over the whole traverse although the forces are only shown for 3 strides.

Figure 22: The force plate data for one subject walking with an assistive device



The contact of the stick is indicated by the continuous right step in the position of centre of force plot and that the vertical force plot that does not reach zero on the right side at any time during the displayed strides.

4.3 Correlations

4.3.1 Correlation between hip extensor strength on the affected side and gait measures

A significant correlation (n=6) was identified for affected side hip extensor moment (Nm) and step length on the affected side (r = 0.8, p = 0.04) as well as joint excursion (r = 0.8, p = 0.05) after the intervention phase of the study. Significance values for the correlations before and after intervention are presented in Table 7. Although these correlations are tentative and not conclusive, they may be an indication for further investigations.

Table 7: Correlations of hip extensor moment on the affected side with gait parameters

(* indicates significant difference)

Gait parameters	Affected Hip extensor moment (Nm) before intervention (B0)		Affected Hip extensor moment (Nm) after intervention (B1)	
Gait speed	r = 0.38	p = 0.46	r = 0.58	p = 0.22
Step length	r = 0.43	p = 0.39	r = 0.82	p = 0.04 *
Joint excursion	r = 0.68	p = 0.13	r = 0.80	p = 0.05 *

Correlations were also found between the less affected side hip strength and gait performance measures after intervention. The less affected side hip extensor moment (Nm) and step length on the less affected side were correlated (r = 0.95, p = 0.04) after the intervention phase of the study. A correlation between the less affected hip extensor moment (Nm) and joint excursion (r = 0.92 , p = 0.009) was also found after the intervention phase (see Table 8).

Table 8: Correlations of hip extensor moment on the less affected side with gait parameters

(* indicates significant difference)

Gait parameters	Less Affected Hip extensor moment (Nm) before intervention (B0)		Less Affected Hip extensor moment (Nm) after intervention (B1)	
Gait speed	r = -0.09	p = 0.86	r = 0.26	p = 0.62
Step length (less affected)	r = -0.03	p = 0.95	r = 0.95	p = 0.04 *
Joint excursion (less affected)	r = 0.55	p = 0.26	r = 0.92	p = 0.009 *

4.4 Post Intervention Questionnaire

There was a good response to the use of a home based strengthening programme as shown by the post-intervention questionnaire. All the participants reported compliance with the exercise programme. This was verified by reviewing each of the individual training diaries that were completed during the intervention period. One subject was unable to produce a completed set of training records. Four of the six subjects specified improved confidence in daily activities and walking. All of the subjects reported having a good understanding of the safety issues related to exercising and the warning signs of when to stop exercising.

Four of the six subjects reported completing the single set exercise programme on a daily basis with one rest day each week as they found this protocol to be less exhausting for them. Two subjects, who were functionally independent and mobile within the community preferred to do the programme three times weekly with two repetitions of each exercise set during the thrice weekly sessions as they found this protocol less time-consuming.

Four subjects reported difficulty with the prone lying exercises with two of the subjects being unable to complete any of prone lying exercises on a regular basis. The reason for the difficulty with prone lying was due to one subject having a hiatus hernia and another finding that prone lying caused problems with an indwelling urinary catheter. The other two subjects who reported difficulty with the prone lying exercises stated that the difficulty was related to their restricted mobility and having difficulty getting themselves into the prone lying position. The less mobile individuals also reported some difficulty with completion of the step up exercises and the theraband hip extension exercise, but with assistance from their partners to achieve the starting position, were able to complete the exercises as requested. It was possible to provide alternative activities for those who were unable to complete the prone exercises and those subjects who were unable to do the prone hip extension exercises were requested to do hip extension exercises in supine with knee and hip flexion. There were no reported difficulties with the stretching exercises.

Five of the six subjects plan to continue with exercise on a regular basis, while one of the six was not as confident that he would continue exercising as he had never enjoyed exercise. He did however report that he would increase his general level of activity with walking indoors and outdoors.

Increased confidence and mobility with less use of walking aids was the most reported change. One subject reported that negotiating steps were easier than before, while another reported more ease with getting out of bed and up from a chair.
Three subjects reported improved indoor mobility with less dependence on walking aids for assistance indoors. One subject reported that prior to the exercise intervention she was not able to walk short distances outdoors with a stick and that she had been wheelchair dependent for outdoor mobility and unable to go outdoors in her garden. She reported that she was now able to go out and hang up her washing. Another subject reported feeling safer when walking in the road.

The results obtained are an indication that hip extensor muscle strength has an influence on gait performance. The perceived benefits of a home-based strengthening programme were positive. These results are discussed in the following section.

Chapter 5: Discussion of Results

The aim of this study was to evaluate whether the implementation of a "hip extension focused" home exercise programme would influence gait performance as measured by gait speed, peak ground reaction forces, step length, joint excursion and walking function in the individual following stroke.

A "hip extension focused" exercise programme was defined as a programme that involved the training of the hip extensor muscles in a functional pattern. This meant that the exercise programme involved all hip muscles required to produce a stable extended hip in the stance phase of gait. The results of this study show that participation in a home-based "hip extension focused" exercise programme with individuals following a stroke is feasible and has positive benefits for the participants.

Statistically significant changes were found in the study group ($n = 6$) for the identified parameters of hip extensor strength after the intervention ($p = 0.05$), although this change could not necessarily be attributed to intervention effects. It is possible that the effects may have in fact been due to the passage of time or a specific practice effect. Studies with larger numbers are required in order to establish a definite intervention effect. Hip extension strength was significantly correlated with step length ($r = 0.82$; $p = 0.04$) and joint excursion ($r = 0.8$; $p = 0.05$) after the intervention. These correlations, although tentative and not conclusive, may be an indication that hip extensors play an important role in providing stability for the lower limb during gait.

Self-reported compliance of the study participants with the exercise regime during the intervention phase of the study was good. No subjects withdrew from the study. The researcher suggests that good compliance with the exercise programme in this study emphasises the previously identified perceived need for home exercise intervention in care received by individuals following stroke (Rimmer *et al.*, 2000)

5.1 Change in Clinical Measures

After the home exercise intervention, the clinical physiotherapy measures of angular range of anterior structures, timed 10 metre walk and functional scores were not significantly different. There was significant improvement in the clinical physiotherapy measure of affected hip extensor strength ($p=0.05$) after the exercise intervention phase of the study but this improvement could not be attributed to the intervention ($p = 0.2$) (see Table 4 in Chapter 4). There was no change in the score on the walking section of the Motor Assessment Scale (MAS) or the measure of community participation as shown by the Nottingham Extended Activities Daily Living Scale (EADL). The actual values are presented in Table 2 in Chapter 4 and the significance values are presented in Table 3 in Chapter 4.

5.1.1 Angular range of anterior structures

It should be noted that there did appear to be a slight trend towards an increase in the range of structures as can be seen from Figure 20 in chapter 4, but no indication of a significant increase in range of angular structures. This is not surprising considering the confounding factors related to the use of a goniometer in individuals with an upper motor neurone lesion.

Goniometric measurements are influenced by the patient's specific problem and the reliability of goniometric measurements within neurological practice is yet to be clearly established (Gajdosik and Bohannon, 1987). The universal goniometer was chosen as a measure of the range of anterior structures with the knowledge that results needed to be interpreted with caution. Goniometric measurements should be seen as measurements of range and not factors that may affect range (Gajdosik and Bohannon, 1987). The measurements may have been influenced by medication levels of individual subjects (see Appendix 7 for a complete list of medication profiles for each subject). One subject was placed on a course of Baclofen for a four-week period due to her experiencing leg cramps. This subject did not report any side effects related to the use of Baclofen, and the course was discontinued prior to the intervention phase of the study, however it is unknown what the effect of this medication was on the measured angular range of motion during this study.

The nature of each individual's upper motor neurone lesion may also have had an influence of the range of anterior structures on the testing days (Carr *et al.,* 1995). Limited range of motion may be due to either spasticity or structural muscle shortening in spastic limbs (Ashton *et al.,* 1978). Harris *et al.* (1985) found that the goniometric measurements in spastic cerebral palsy patients displayed a wide variation in measurements and suggested that a difference in 10 to 15 degrees would not signify a meaningful change in range of motion. Prone hip extension, as a method of measuring hip flexion contracture, has been considered to be the most accurate technique to measure hip extension in people with spasticity (Bartlett *et al.,* 1985), although the measurement of range of passive hip extension with a goniometer has been found to have low reliability, due to the difficulty of detecting hip extension substitutions (Ashton *et al.,* 1978). In this study, it was not feasible to position the subjects in prone to assess hip extension range due to difficulties with the affected upper limb positioning whilst in the prone position and therefore the test position was modified in the side-lying position.

5.1.2 Hip extensor strength

The improvement in Hip extensor strength ($p = 0.05$) cannot be attributed as a intervention effect as the excess improvement was not significantly different following the intervention ($p = 0.2$). Although it is possible to identify the trend towards an increase in hip extensor strength, the small sample size and high variability limits any conclusive statement. The researcher suggests that the lack of significance of excess improvement that would allow the change to be attributed to the intervention and not time or practice may be as a result of the high variability and the small sample. The sample size and variability of the sample affects the standard error of the mean. The higher the variability and the smaller the sample size, the larger the standard error of the mean (Munro et al., 1993). In this case, the standard error of the mean was 2.02. Other influencing factors may have been the specific measurement tool, the testing position as well as the actual prescribed intervention.

The handheld dynamometer is used as a clinical tool to measure muscle strength in stroke patients (Shamay and Shepherd, 2000). It is a reliable tool, although the validity of measurements and clinical inferences are not certain (Miller *et al.,* 1998). The issues related to subject and test design should be considered when interpreting strength results obtained with a dynamometer (Keating and Matyas, 1996). The testing position eliminated the effects of gravity and was as such a non-functional position. The functional standing position was not used as it may have allowed the subjects to use compensatory actions which meant that the hip extensor muscles may not have been adequately isolated if that testing position had been used. Those individuals with hypersensitivity to sensory stimulation had difficulty achieving and maintaining a side lying position when testing the less affected side, and at this point an assistant was required to provide external support. This may have influenced the results obtained for the less affected side, in addition to which the reliability of measurements on the non-paretic side may be reduced due to the wider range of movement patterns available to the subject (Riddle *et al.,* 1989).

In this study, hip extensor strength was defined as the hip extensor moment in Newton metres (Nm) produced when tested according to the described methods using hand-held dynamometry. The hip joint extensor moment was calculated by multiplying the dynamometer force and the lever arm (Keating and Matyas, 1996). The lever arm was defined as the distance between the point of application of the dynamometer (3 cm above the popliteal fold and the greater trochanter of the hip joint. The hip moment, rather than the actual force measured in Newtons (N), was used so as to facilitate comparison incorporating individual subject differences in limb size and anthropometry. Group comparisons with normalised measurements rather than individual measurements are considered to be more reliable as these values provide a better estimation of the muscle strength (Keating and Matyas, 1996). A normal value of 8.45kg (SD 1.5) for isotonic hip extensor force, obtained using the same testing position as used in this study, has been published by Livesley (1992). It should be noted that this value was presented in kilograms, indicative of no normalisation for individual differences. This value was also obtained using a small sample (n = 9) of younger individuals (mean age 38 (SD 8.7)) compared to those who participated in this study. The values for hip extensor strength obtained in this study incorporated consideration of individuals' body size and for this reason may be considered to be more representative of the group that was studied than those values that have been provided for normal subjects.

An effective training programme should be based on the principles of overload and specificity (Sale, 1988; Sale and MacDougall, 1981). Shamay and Shepherd (2000) suggest that weaker muscles will respond more quickly to any strength stimulus, regardless of the type of exercise prescribed although past a certain strength threshold, improvements in motor performance are more likely with task specific training. With respect to the prescribed intervention in this study, it is possible that the muscle overload was not sufficient to encourage strength change or that the exercise program was not executed correctly due to the lack of supervision from a qualified instructor. The possibility of the incorrect execution of specific exercise techniques during completion of unsupervised home exercise programs by stroke patients has been suggested by Wall and Turnbull (1987) as an explanation for insignificant results following exercise intervention. They stated that supervision of stroke patients during completion of an exercise program was necessary to ensure the correct execution of muscle and movement patterns. In this study, the lack of significant strength change that can be attributed to the intervention following the prescribed strength training may be an indication for the need to include more task specific strengthening activities in a more supervised environment that ensures correct execution of the specific programme.

5.1.3 Functional score

There was no change in functional score as measured by the walking section Motor Assessment Scale for Stroke (MAS), which is an assessment of gait speed, balance and level of assistance required. Bohannon (1996) has stated that caution should be taken in making judgements about function based on strength measurements. Buchner *et al.* (1996) demonstrated a non-linear relationship between leg strength and gait speed in older adults. They found no association between strength and gait speed in stronger individuals and a non-linear association in weaker individuals. They did however acknowledge that in the extremes of the strength ranges, this association was not applicable. They were also unable to identify a point at which strength would limit performance and attributed this to co-morbidities that could influence performance. Ferruci *et al.* (1997) also identified a clear strength threshold for performance particularly when strength was the only limiting factor. Muscular strength was found to be a significant predictor of performance, independent of age and anthropometry. The relationship was non-linear, and the threshold for hip flexor strength as a predictor for walking speed was below 15 kg (Ferruci *et al.,* 1997). Above this threshold, strength was not a predictor of gait speed in older adults. These authors did not identify a lower limit when strength would limit performance and excluded individuals who were unable to perform the muscle action against gravity. Shamay and Shepherd (2000) have suggested that improvements occurring beyond the threshold level identified by Buchner *et al.* (1996) and Ferruci *et al.* (1997) may be as a result of training "directly related to the action" being tested.

It is possible that the training intervention in this study was not sufficiently task-related to result in functional change as measured by MAS. The lack of change in function as measured by the MAS may also have been due to the fact that in this study, strength was not the only limiting factor. There were additional confounding variables such as balance and co-ordination problems, which were not specifically addressed by the intervention. In addition, a variety of co-morbidities such as hypertension and depression could have affected the functional performance and the strength training of individual subjects and hence the group results.

The Motor Assessment Scale (MAS) is a measure of the required level of assistance and walking speed (Lennon, 2001) and may therefore not be sensitive to changes at the impairment level. The MAS was chosen as an outcome measure of clinical function in this study as it has been shown to be a valid and reliable tool (Carr *et al.,* 1985). It also has been found to have both face and concurrent validity (Poole and Whitney, 1988). The MAS has been used as a clinical marker of function after stroke (Weiss *et al.,* 2000) and in previous exercise training and gait re-education studies (Weiss *et al.,* 2000; Lennon, 2001; Baskett *et al.,* 1999; Shamay and Shepherd, 2000). The MAS seems to be more applicable in the measurement of change following an acute stroke. In this study, it may not have demonstrated all the possible changes that could have occurred, particularly at the higher level of the scale. The gait subsection of the MAS requires that for any individual to move from a grade 3 on the scale to a grade 4, they may not use a walking aid. This could result in a ceiling effect, particularly with chronic stroke patients who may have adapted to the use of a walking aid. The use of only one section of the MAS scale may also have limited the value of the scale as an outcome measure, although it is considered to be valid to use the individual sections of the scale separately (Carr and Shepherd, 1998). Task and context specific training may also influence the outcomes that are measured and the sensitivity of the measure to change (Dean and Mackey, 1992). It follows that as the exercise programme did not emphasise walking speed, and was not context specific to the outcome measure, the MAS should be considered as not being an appropriate measure to have used as a measure of function in this study.

5.1.4 10m timed walk

There was no significant change in the time taken to walk 10 metres ($p = 0.17$). Although the timing of walking is considered to be a valid and reliable measure of outcome (Wade, 1992), problems have been identified as performance can be affected by external and internal factors such as stress and illness. This has been noted in a recent study where it was reported that the subject's performance at repeated walking tests was influenced by their feeling unwell (Rossier and Wade, 2001).

Unwanted side effects of prescribed medication, namely dizziness, fatigue, drowsiness, apathy, bradycardia and hypotension, may have affected testing, particularly of walking under the specified testing conditions of this study. The elderly individual is known to be more susceptible to medication effects, side effects of medications and episodes of dizziness and unsteadiness may reflect the noxious effects of a single medication (Chapron, 1995). Two of the participants had a change of medication during the pre-intervention phase. One subject received a course of Diazepam for a severe episode of facial neuralgia. The side effect of this was that the subject experienced severe drowsiness. Another participant had problems with dizziness, linked with anti-hypertensive medication. This was worse in the morning than in the afternoon and although testing was arranged for the afternoon, the dizziness had not resolved completely prior to some of the testing sessions. Measured performance may have been less than each subject's actual capacity due to the unwanted and uncontrolled side effects of medication, particularly as most of the participants ($n=5$) were on antihypertensive medication which has the known effect of inducing orthostatic hypotension (Chapron, 1995). Postural hypotension can lead to balance disorders and lightheadedness that may in turn influence performance.

It may have been more relevant in this study to use a test of walking speed that assessed comfortable speed over a longer distance rather than maximum speed over a shorter distance (Teixera-Salmela *et al.,* 1999; Wade and Rossier, 2001). This would have allowed for more comparison with the gait laboratory data. Furthermore, Dean *et al.* (2000a) has stated that the effects of acceleration and deceleration should be avoided by allowing measurement to be taken over the middle part of a 14 metre long walkway. In this study, no consideration of the effects of acceleration or deceleration was incorporated into the testing procedure due to the space constraints in the laboratory. The timed walk measures obtained may therefore have included possible acceleration and deceleration effects, which may in turn have affected the results obtained.

5.1.5 Community participation

Community participation as measured by the Nottingham Extended Activity of Daily Living Scale (EADL) was also unchanged after the exercise intervention. The individual subjects had reported changes in community mobility according to the post-intervention questionnaire, although these were not detected with the use of the EADL scale. It is possible that the method of scoring on the EADL is not very sensitive. Wade (1992) suggested that scoring on a scale of 0 – 3 was more useful than scoring according to dependence or independence. This would mean that changes with respect to the level of assistance required or ease of completing the activity could be detected. As the scale is currently used, no change in level of required assistance is measured. In this study, additional information was gathered by questioning of the individual subjects and their relatives (see Appendix 8 for a version of the questionnaire that was used in this study). The disadvantage of using such post-intervention questioning is that a retrospective self-report can be open to bias (Rodriquez *et al.,* 1996). However it would seem that the overall opinion of the participants was that involvement in the exercise programme resulted in a positive experience.

People with stroke have been found to be active in managing their impairments and developing strategies such as exercising and relearning once in their own environment (Pound *et al.,* 1999). Baskett *et al.* (1999) found that a home-based hands off intervention was at least as effective as conventional inpatient rehabilitation and attributed this to the control the individual has over his or her own environment and goal setting process. Baskett *et al.* (1999) noted a reduction in depression over the intervention period and that caregivers were very positive about the impact of the self managed programme. Jones and Mandy (2000) suggested that physiotherapists may not be allowing patients to have sufficient control over their recovery and that empowerment of individuals may result in improved outcome. Useful information with respect to the implementation of a home exercise programme with stroke patients was gathered with the post-intervention questionnaire. Guidelines for the safe, effective implementation of home exercise programmes with stroke patients need to be developed and these exploratory study results can be used as a framework for further research in this area. There was a reported increased level of general activity and a good understanding of the safety precautions associated with exercise following a stroke. There was also a reported increase in general confidence with respect to mobility. The positive experience of involvement in a self directed exercise programme may have led to a higher level of autonomy and self empowerment (Jones and Mandy, 2000). All subjects involved in this study reported greater confidence and increased levels of activity. The carer satisfaction was also reported to be good. This positive opinion of the participants, following the intervention, adds to the value of the home exercise programme as a method of intervention.

5.2 Change in Gait Measures

There was no significant change in self-selected gait speed ($p = 0.9$) and joint excursion ($p = 0.86$) following the intervention. The presence of co-mordidities such as hypertension and obesity and the use of anti-spasmodic medication by three of the subjects during the study period meant that external factors related to these issues may have influenced joint excursion, strength performance and gait speed (see Appendix 7 for the medication profiles of each participant). Ferruci *et al.* (1997) have stated that medical conditions, health-related behaviours, emotional well-being and socio-economic factors may potentially influence lower extremity performance. The actual values for the gait measures after the intervention are presented in Table 5 in chapter 4 and the significance values are presented in Table 6 in chapter 4.

5.2.1 Gait speed

The artificial environment in the gait laboratory may explain the lack of improvement in self-selected gait speed after of the intervention. There was a slight increase in gait speed over the study period and this can most likely be attributed to a practice effect rather than to any intervention effect. During collection of the average gait speed data via the motion analysis system, the subjects were required to complete an average of 6 traverses in the laboratory. There was a short distance allowed prior to, and following, the collection of data via the motion analysis system that may have controlled for acceleration and deceleration effects. Most noticeably, endurance factors became an issue for the more functionally dependent subjects when gathering data over the set number of traverses. It should be considered that while it is preferable to obtain a measure of average gait speed that does not overestimate gait ability, there are limitations to the information that can be provided from the collection of gait velocity information in a gait laboratory. These limitations include the artificial environment of the laboratory and the encumbrance of walking with the attached reflective markers. It may be also argued that endurance should have been addressed in the intervention as this was required in the testing and assessed by the outcome measures used.

5.2.2 Joint excursion and maximum hip extension in stance phase

Age matched reference values have been published for the hip during gait (see Table 12 in Appendix 1c). Total joint excursion is 39 (SD 3.5) degrees (Winter, 1991). A reduction in hip extension is considered to be a limitation as functional hip tightness may cause a reduced stride length which in turn may affect walking performance (Kerrigan, 2001). Joint excursion at the hip in hemiplegic individuals was studied by Dean *et al.* (2000a). They identified a "marked reduction" in joint excursion associated with reduced hip extension in the stance phase of gait in hemiplegic subjects. This reduction persisted following their strength training intervention despite an apparent increase in hip extension range during the stance phase of gait. Dean *et al.* (2000a) also reported an increase in power generation at the hip in two of the experimental group subjects, which were not present in the control subjects. No power calculations were completed in their study (n = 4) and therefore it was difficult for these researchers to demonstrate whether hip extension in stance phase did improve as a result of the strength training intervention. Similarly, in this study there was no apparent increase in maximum hip extension in stance phase. These results may be due to the ineffectiveness of the intervention or may be attributed to influencing factors such as the repeated reliability of application of reflective markers and the data collection methods or the effects of medication on joint excursion.

Spasticity can influence joint excursion but this may be less severe if soft tissue length is maintained (Carr *et al.,* 1995). Ada *et al.* (2000) studied the effect of muscle length on strength and dexterity after stroke. These researchers found the shape of the torque-angle curve to be altered, with significant weakness at the shortest range of muscle length ($p < 0.05$) and concluded that the provision of strength training at different muscle lengths could have functional benefits for an individual who has had a stroke. Carr *et al.* (1995) suggested that soft tissue length should be maintained by both passive and active means. The nature of the upper motor neurone lesion means that it is difficult to identify absolute causes of restricted range of motion, and as has been previously noted, medications and environmental factors may also influence spasticity and therefore the measured range of motion. The reduced joint excursion measured in the study subjects before the intervention may be an indication that stretching as well as strengthening at different muscle lengths is indicated as part of a home exercise programme with chronic stroke patients. The non-significant change in total excursion after the intervention could be attributed to insufficient stretching incorporated in this programme. It may also have been that the active range over which the hip extensors had sufficient muscular control did not include any increased range of motion that had been achieved as a result of the intervention that was prescribed or insufficient use of task related activities.

5.2.3 Weight-bearing and peak vertical ground reaction forces

Changes over the study period were not significant for affected side weight bearing ($p = 0.77$). This lack of significant change after the exercise intervention may be a result of the small number of individuals who participated in the intervention or result from the method of weight bearing symmetry data collection. Bohannon (1987) found a negative correlation with weight-bearing symmetry and cadence in hemiplegic subjects. This measure was based on an average ratio of five measures of weightbearing as measured by electronic scales. In this study, insufficient measures of weight bearing symmetry meant that an average of the ratios of weightbearing could not be calculated.

Peak vertical ground reaction force was also not significantly changed after the intervention ($p = 0.27$). Dean *et al.* (2000a) found an increase in peak ground reaction force as measured during sit to stand following their intervention. When measuring peak ground reaction force during sit to stand, the centre of pressure data could be accurately analysed. The measurement of peak ground reaction forces obtained during walking data collection in this study may have been influenced by any alteration in the foot contact pattern of the individual subjects. Furthermore, it would have been useful to measure the vertical ground reaction force at a specified point in the gait cycle so as to standardise measures. In weaker individuals, the muscle activity that is produced is a reflection of the best possible activity that they are capable of (Carr and Shepherd, 1995). Balance difficulties may have influenced the walking pattern and hence the foot-contact that was produced during the walking trials. The use of a walking aid may also have encouraged stereotypical movement patterns during the gait cycle, which would have prevented an increase in the ground reaction force on the affected side regardless of the increase in hip extensor strength.

The results of this study are similar to those of Wall and Turnbull (1987), Hesse *et al.* (1994) and Lennon (2000). Wall and Turnbull (1987) used a weight bearing home exercise programme designed to increase the weight bearing ability of the affected leg. They found no improvement in any group with respect to gait symmetry and duration of single limb support. These findings were attributed to the widely differing gait patterns of the study subjects, an ineffective exercise programme with poor consistency, compliance and an inability to ensure correct execution of the individual exercises. They suggested higher frequency intervention of shorter duration that is in line with the requirements for developing a new skill (Gentile, 2000). Frequent practice is associated with the development and improvement of skilful activity (Shamay and Shepherd, 2000), however it is essential to ensure correct execution of the individual exercises. The home-based programme, as was used in this study, should be considered a useful adjunct to facilitating frequent practice and development of new skills, provided that adequate supervision and assistance is available. In this study, participants were encouraged to practise their exercise programme on a daily basis and a review of the training diaries that were completed provided the information that the practice did in fact occur (see Appendix 5). It is unknown how effective the practice was that did take place although reported compliance with the intervention was good as demonstrated by the training diary. It was not possible to ensure correct execution of the individual exercises, although the researcher reviewed each individual subject's execution of the programme every two weeks throughout the intervention phase.

Hesse *et al.* (1994) studied mildly affected acute stroke patients before and after therapy. All subjects were able to walk 20 metres unassisted and testing was completed with no aids or orthoses. They found no improvement in the symmetry of ground reaction forces measured at heel strike and toe-off although they did find an improvement in stance duration and weight acceptance on both sides. The lack of change in symmetry was attributed to the possibility that the study subjects had reached a certain level of functional ability as a result of adaptive mechanisms and no further change in gait parameters such as ground reaction forces should be expected. Stance duration and weight acceptance were found to be independent of the improvement in gait velocity which may further reinforce the conclusion that the gait laboratory methods as used in this study may not have been suitable to detect clinical changes in this particular study group. Hesse *et al.*, (1994) state that gait kinetics serve as in independent measure of therapeutic effects on an intervention and the results of this study should be considered in line with their statement.

Lennon (2001) used clinical gait analysis to measure outcome after treatment in two patients. No change was identified in gait symmetry variables. These findings were similar to those found by Hesse *et al.* (1994). A possible explanation for their findings was the type of intervention and that the intervention needed to be task- related. Another suggestion was that the gait laboratory methods were not suited to identify any specific change related to the type of intervention and that gait kinetics should be considered as an independent measure of outcome (Lennon, 2000) rather than the only measure of outcome.

The use of walking aids at each subject's discretion may have influenced the symmetry and peak ground reaction force values obtained in this study. Chen *et al.* (2001) have found that indeterminacy can occur when analysing cane-assisted gait while using force plates to measure reaction forces if a force plate is unable to resolve all forces simultaneously. These researchers found that hemiplegic individuals who walk with a cane have shorter step lengths, slower velocities and longer stride times than those who do not use a cane to walk. Consideration of the fact that three of the subjects who participated in the current study used a cane or stick to walk means that the data, with respect to symmetry and peak vertical force on the less affected side, should be interpreted with caution. Another possible suggestion for the lack of change of the peak force values on the affected side is that the kinetic data may have been more susceptible to variability, particularly with the small subject numbers. Kinetic data has been found to be more variable than kinematic data (Winter, 1984).

5.3 Correlations between hip extensor strength and gait parameters

Muscle strength in the lower limb has a relationship with gait performance, although it should be acknowledged that this is a tentative association, rather than a causal relationship (Shamay and Shepherd, 2000). The identified correlations between hip extensor strength, affected side step length ($r = 0.82$; $p = 0.04$) and joint excursion ($r = 0.8$; $p = 0.05$) after the exercise intervention suggest an improvement in muscle recruitment on the affected side. The correlations for hip extensor strength, step length and joint excursion were not present before the intervention, which may indicate that the intervention resulted in the subjects acquiring an improved ability to effectively recruit their hip extensors in a more functional pattern.

The correlation of hip extensor strength with joint excursion was present before the intervention ($r = 0.68$; $p = 0.13$), but not significant. The correlation was present and significant after intervention ($r = 0.8$; $p = 0.05$). This is an indication that muscle strength is associated with muscle length (Ada *et al.*, 2000). Dean *et al.* (2000a) noted that reduced hip extension range in the stance phase of gait was associated with an overall reduced hip joint excursion. An improvement in muscle strength could relate to increased muscle control over the joint excursion with a correlation with the affected side step length.

In this study, no correlations between hip extensor strength and gait speed were found. This result is contradictory to that of Bohannon (1986), who found correlations for hip extensor strength and gait speed ($r = 0.6$) in hemiplegic individuals. The methodology used in his study may have influenced the results. The testing position was gravity assisted and correlations were made between the maximum hip extensor force rather than the mean of repeated measures. Gait speed measures were obtained from a timed 10-metre walk test of maximum speed. There was also no indication given of the functional level of the participants in Bohannon's study. In this study, the subjects demonstrated a range of functional levels, although they were mostly dependent for assistance with activities of daily living and were physically deconditioned. This may be an explanation for contrasting results found in this study relating to the previously identified correlation between hip extensor strength and gait speed (Bohannon, 1986).

Correlations may not exist if there is a non-functional recruitment pattern present, which may have been the case in this study. EMG studies are needed to confirm this suggestion, although it can further be justified when reviewing neuroplastic theory in that the opening up of new pathways may be facilitated by active participation (Stephenson, 1993) and that training might "stimulate and refine the pattern of re-organisation of neurones" (Dobkin, 1998b). This is further supported by the fact that Miller and Light (1997) attribute strength training effects in the older population to neural factors. Sharp and Brouwer (1997) related some of the changes demonstrated by their subjects following strength training to improved motor unit recruitment and motor learning as a result of practice.

5.4 The Intervention

The prescribed intervention may have influenced the results obtained during this study. The intervention was designed to be a strengthening programme. As such this did not include the training of walking. The outcome measures were, however, focused on walking and were not always measuring that which the intervention was designed to improve. This may account for the lack of change measured with respect to the measured parameters.

The study subjects were required to participate in the strength training protocol for a six-week period. There is lack of consensus in the literature as to what the most appropriate time span of execution of an exercise programme in stroke patients is. Strength training research has involved studies lasting a range of durations from 4 to 20 weeks (Damiano *et al.,* 1995a; Damiano *et al.,* 1995b; Sharp and Brouwer, 1997; Teixeira-Salmela *et al.,* 1999; Dean *et al.,* 2000a; Duncan *et al.,* 1998 and Weiss *et al.,* 2000). In strength training, the early increases in voluntary strength are attributed to neural adaptation and motor learning (Sale, 1988; Miller and Light, 1997). As it seems that neural adaptation and motor learning produces a response to strength training, the strength training programme in this study was designed to last over a six week period, which has been found to be sufficient to allow for neural adaptation to strength training (Sale, 1988). Weiss *et al.* (2000) found that most strength changes were achieved by the eighth week of the intervention following a strength training protocol used with older community dwelling stroke patients. It may have been better to run the intervention over an eight-week period so as to allow further adaptation and consolidation of new movement patterns. This may then also have allowed for the incorporation of task related activities and additional practice experience that may have further improved outcome. The neuromuscular system has the flexibility to accomplish the same kinematic patterns with different motor patterns (Winter, 1985), although task related training may be required to improve the efficiency of the motor patterns that are used.

The intervention required that the subjects completed all the strengthening activities bilaterally, due to the possible presence of ipsilateral impairments. Stroke can cause functional problems in the lower limb ipsilateral to the lesion with abnormal muscle activation and altered muscle firing order (Kim and Pohl, 2000). The individual exercises were prescribed as they have been shown to strengthen the extensors of the lower limb (Nugent *et al.,* 1994; Dean *et al.,* 2000a; Duncan *et al.,* 1998). The muscles that were addressed included all the functionally active muscles assisting in the achievement of a stable extended hip. Progression was based on the functional repetition maximum, where exercises were made more difficult by increasing the functional weightbearingload when the subject could complete 2 sets of ten of the exercise at the lower functional load. The progression protocol used by in this study was described by Duncan *et al.* (1998) who used this functional repetition maximum progression in their study involving a similar home based exercise programme.

Concentric, closed chain exercise as used in this study has been shown to be more useful in achieving improvement in functional abilities, although if a muscle is very weak any stimulus to generate a force is beneficial (Shamay and Shepherd, 2000). Dean *et al.* (2000a) used sit-to-stand from various chair heights to strengthen the affected leg extensor muscles. They also incorporated stepping onto a block, tandem standing and resisted leg extension in standing to induce strength changes in their hemiplegic subjects. Nugent *et al.* (1994) used step-ups onto a wooden block to achieve hip extension strength training in their study relating to weight-bearing exercise and walking outcome. Duncan *et al.* (1998) used resistive theraband in a strengthening protocol and functional exercises in which body weight was used for resistance. Resistive theraband provides resistance in the outer range of muscle length with limited load on the muscle in the inner range. It appears that the use of functional weightbearing exercise against gravity would be the most appropriate form of resistance for the population being considered. An exercise programme that is aimed at increasing strength will be most effective if it incorporates specific, functional exercises that load the muscle sufficiently while encouraging transferability of skill (Shamay and Shepherd, 2000).

The implementation of precautions, related to the safe independent execution of an exercise programme in a deconditioned study group, was essential as part of this study. The co-morbitities that may accompany stroke such as hypertension, diabetes and obesity necessitate that individuals who are exercising have clear instructions and awareness of the warning signs of when to stop exercising (Rimmer *et al.,* 2000). The exercise programme did not include any cardiovascular training and therefore the exertion that was required could be considered to be no more than would occur in a regular home based physiotherapy session. In addition to this, all subjects were provided with guidelines with respect to warning signs during exercise.

5.5 Limitations of the Study

This initial exploratory study has provided evidence and information about the feasibility of strengthening as a home based intervention. It has also provided more information about the role of the hip extensors in gait performance. There were a number of factors that could have limited the results obtained.

Due to the small sample size and resulting statistics, the results may be valid for study group, but may not be applicable to the stroke population in general. Duncan *et al.* (1998) used small numbers in their pilot randomised controlled study of home based strength training, and indicated that larger studies were needed to ratify their results. Shamay and Shepherd (2000) discussed the fact that most of the recent studies addressing strength training in stroke patients have involved small numbers. Although they acknowledged that larger studies are required, they stated that the magnitude of change in many of these studies suggested that changes are unlikely to be due to measurement error. Correlation statistics were calculated in this study, although these may only at best indicate a tentative relationship and do not indicate a causal relationship. The correlation statistics therefore need to be interpreted with caution.

All the subjects who participated in the present study had a left hemiplegia. This resulted from the subject's willingness to participate rather than an exclusion of those with a right sided hemiplegia. A group consisting of individuals with the same affected side may be more comparable and the hemiparetic side has not been found to be predictive of any measure of gait performance (Bohannon, 1987). A further limitation with respect to standardisation was that no classification according to site of lesion with MRI was done. The type of stroke and size or location of the lesion may have affected each individual's ability to respond to exercise. From the results of this study, it would seem that medication levels and co-morbities such as hypertension and cardiac problems were the factors that influenced the individual subject's ability to participate in the exercise programme. Exercise stress testing was not included in baseline assessment, although safety measures were in place as subjects were taught the warning signs of when to stop exercising. The lack of safety measures with respect to exercise limited the study with respect to the possibility of progressive muscle overload and may in turn have reduced the effects of the strengthening program.

In this study, there was a wide range of individuals with different functional levels. The group consisted of individuals who scored three or four out of a maximum possible score of six on the motor assessment scale (MAS). A lack of a homogeneous group with respect to function may have influenced the results with variability of the data. Variability in the amount of change seen in each subject may have been due to differences in exercise intensity as well as the relative health of the individual subjects (Shamay and Shepherd, 2000). Heterogeneity within a sample is considered to be a limitation in neurological strength training research (Guilani, 1995).

There are limitations for each measurement tool that was used in this study. The goniometer is not validated for use in neurology and the measure achieved with its use is strictly a measure of range. It does not provide any indication for the cause of restriction (Gajdosik and Bohannon, 1987). The universal goniometer was not particularly suited as a measurement tool as it did not provide a functional measure of joint excursion and was only an indication of whether the subject had sufficient range of anterior structures available for gait. The force applied during goniometer measurement, environmental and external factors such as stress may also have influenced results (Gajdosik and Bohannon, 1987).

Functional scales need to measure that which the intervention is addressing (Lennon, 2000). Dean *et al.* (2000a) indicated that with variability of initial skill, provided that measurement tools are appropriate for all functional levels, measured improvements in performance are possible for all skill levels. The functional scale that was used did not measure impairments that were addressed by the exercise intervention and were not appropriate for all functional levels. Balance has been significantly correlated ($p = 0.4$) with gait speed (Bohannon, 1987) and the prescribed exercises may have had an influence on the balance of the study subjects. No measure of balance or lower limb muscle strength apart from hip extensor strength was incorporated in the testing sessions and this is a limitation of the study. The dynamometer testing position used to gather hip extensor force data may also have affected the results in addition to which no other strength measurements of lower limb muscles apart from hip extensor strength were obtained. It is possible that strength changes occurred in other lower limb muscles apart from the hip extensors and the influence that any other strength changes may have had on the measures of gait performance that were assessed is unknown.

The measure of community participation did not provide any indication of increased activity levels. It would seem that the Extended Activity of Daily Living Scale (EADL) is only sensitive to change that involves a change of intervention in two or more activities of daily living (Gompertz *et al.,* 1994).). In addition, the sensitivity and validity of the functional test, and the degree of community participation as a measure for this intervention, was not established prior to the intervention.

There are limitations with respect to data obtained via clinical gait analysis. The force plate that was used for data collection was a 3.3m long dual platform walkway (Hynd *et al.,* 2000). This longer walkway facilitated the collection of data from one complete stride, although some of the research subjects were unable to walk without lower limb crossover, which resulted in inaccurate force data. This crossover occurred when subjects were unable to contact each platform separately for each stance phase. The potential increase in walking base has not previously been noted in subjects with pathological gait walking across the dual platform system (Hynd *et al.,* 2000). The issue of indeterminacy (Chen *et al.,* 2001) with force resolution when subjects were walking with canes or sticks meant that data from the side that the stick was used was not available for peak ground reaction force and single stance time. The fact that assistive devices were allowed for the testing may have influenced data collection. In addition to this, marker placement may not have always been consistent, although measures were taken to ensure the maximum possible consistency. These measures included the use of digital photography and video recording before all walking trials. Another factor that may have influenced the results was the artificial environment of the laboratory.

Finally, the methodology adopted for this pilot study meant that the subject group acted as their own control group. The parameters measured before the intervention were used to evaluate the effects of the intervention. The lack of a randomised control group meant that there was limited possibility for making any statements about the results with respect to the general population.

Chapter 6: Recommendations and Conclusions

6.1 Recommendations for Further Research

The results of this study warrant further investigation. A randomised, controlled clinical trial with a larger sample size is indicated. The positive correlation that hip extensor strength has with the gait performance measures, reported activity increases and subject confidence that have been identified, support this recommendation.

For future research, a recommendation would be to improve the choice of outcome measures as well as include the use of an outcome of balance such as the Berg Balance Scale and a measure of motor impairment such as the Fugl Meyer Motor Score (Duncan *et al.,* 1998). The use of clinical gait analysis needs to accommodate for the slower speed of walking which occurs in stroke patients, the need for the use of walking aids and the endurance issues associated with repeated walking trials in those individuals who are more functionally impaired.

EMG studies may be indicated in order to determine the effects of strengthening activities on muscle activation. It would also be recommended to focus on the physiological benefits and effects of the intervention and consider methods to improve feedback regarding correct execution of exercise in the home environment.
There is a need to establish the clinical inference of dynamometry measures and further research is needed to develop age-matched norms for hip extensor strength. This may provide clinicians with an indication of what is a clinically significant hip extensor weakness. Further research is needed in clinical methods of measurement with respect to the hip musculature as well as specific methods of addressing hip extensor strength using resistive exercise within rehabilitation of the individual following stroke.

The long-term outcomes of strength training programmes in stroke patients need to be further investigated so as to determine the optimum length of intervention. Further research is needed into the use of home exercise programmes, particularly with respect to safety considerations and appropriate dosage of individual exercises. The effects of functional levels, cardiovascular fitness and co-morbities on the ability to participate in a strengthening programme also need to be established.

6.2 Conclusions

The aim of this study was to evaluate whether the implementation of a “hip extension focused” home exercise programme would influence gait performance as measured by velocity, peak ground reaction forces, step length, joint excursion and function in the individual following stroke. There was some indication of a relationship between hip extensor muscle strength and gait performance following stroke with significant correlations between hip extensor strength and step length ($r = 0.82$, $p = 0.04$) and joint excursion ($r = 0.8$, $p = 0.05$). There was also a trend towards an increase in hip extensor muscle strength following the intervention. These results suggest that the implementation of a home exercise programme is feasible and may influence certain gait parameters following stroke.

Although there was no follow-up testing to assess for any lasting benefits, a likely possibility for the noticed trends of improvement in clinical measures is improved activation of the hip extensor muscles with associated neuroplastic changes. The capacity for change exists for longer than would be expected as a result of spontaneous recovery following a stroke if the opportunity for practice exists (Shamay and Shepherd, 2000). It is therefore important that therapists provide that opportunity for guided activity and practice during the rehabilitation process.

The home-based programme, as was used in this study, should be considered a useful adjunct to facilitating frequent practice and development of new skills, provided that adequate supervision and assistance is available. The execution of home-based unsupervised exercise programs in physically deconditioned individuals seem to be beneficial according to a protocol which allows variable practice with regular supervision. With respect to exercise prescription, for those who are older and de-conditioned, sessions should begin at a lower intensity level (moderate rather than maximal intensity), consist of single set programmes and progress more slowly (Feigenbaum and Pollock, 1999). The subjects who participated in this study performed well with respect to safety under these exercise conditions. Although it is necessary to ensure an effective intervention, safety considerations are paramount. It therefore can be suggested that these guidelines should be considered when prescribing strength training for individuals following stroke.

A programme used with physically deconditioned individuals following a stroke, should employ functional task related activities that require bilateral execution of exercise and encourages overload of the specific muscles being trained (Shamay and Shepherd, 2000). The progression protocol based on a functional repetition maximum seems to be appropriate and daily practice with less repetition is most suitable for the individuals with greater functional impairment. A longer period of intervention in the home setting may be more beneficial (Weiss *et al.*, 2000) and from the finding of this study it can be suggested that a six week period may not be sufficient to achieve long lasting results. The most important factor in ensuring effective intervention would appear to be the correct execution of the individual exercises and the availability of accurate feedback as a form of motivation.

Although this study was limited by the small sample size, the high variability amongst the subjects and the choice of outcome measures, it can be suggested that hip extensor strength influences gait performance. It seems that clinical gait analysis and the use of kinetics as a measure of outcome should be considered as necessary, but separate to functional measures of outcome. Furthermore, there is a need to establish a valid and reliable method to measure hip extensor strength in the stroke population. Issues relating to reduced performance and the impact on functional measures in physically deconditioned individuals who may be limited by medication effects and physical illness also needs further investigation.

The correlations of hip extensor strength with step length and joint excursion as well as the trend towards an increase in hip extensor strength as a result of the intervention, may be an indication of the necessity of addressing hip extensor strength and range during the stroke rehabilitation process. It is important to consider the role that hip extensors have in providing stability for the lower limb during gait. If a hemiplegic person can achieve a more efficient hip extensor muscle contraction as result of an exercise programme, this may improve their ability to achieve a stable leg upon which to stand and support the trunk during gait and, as a result, improve gait performance and independent function. However no clear conclusion can be made regarding any significant change in muscle strength or function as a result of this intervention. For future studies in this area, it is necessary to consider the choice of outcome measures employed carefully as well as the size of the study sample in order to provide conclusive information regarding the benefits of a particular strengthening intervention.

The positive influence of improved autonomy and empowerment should be acknowledged and there were reported benefits of participation for those involved in this study. Teixeira-Salmela (1999; p.1215) stated that regardless of the cause, "the rehabilitative value of psychological gains in subjective perceptions should not be underestimated with disabled groups who are at risk of functional decline." There are positive benefits of a structured, unsupervised home exercise programme and if individuals who have had a stroke are given the support and guidance, they appear to be able to comply with an independent home exercise programme. In the rehabilitation of stroke patients, the use of a hip extension focussed home exercise program should be explored in order to facilitate enhanced gait performance.

Table 9: Muscles of the Hip: Actions and Innervations.

Adapted from: Magee (1997)

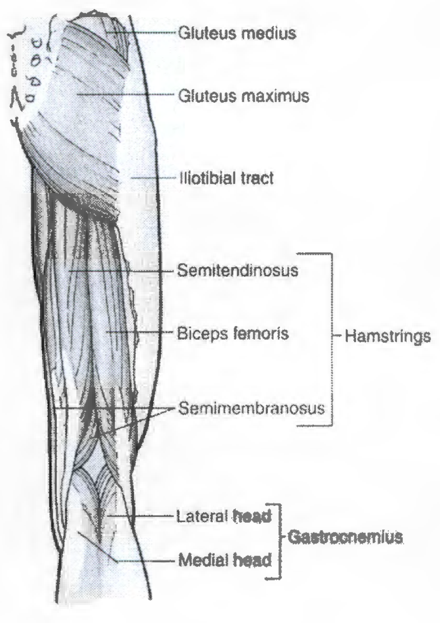
Action	Muscle Acting	Innervation
Extension of the Hip	Biceps Femoris	Sciatic
	Semimembranosus	Sciatic
	Semitendinosus	Sciatic
	Gluteus maximus	Inferior gluteal
	Gluteus medius (posterior part)	Superior gluteal
	Adductor magnus	Sciatic
Abduction of the hip	Gluteus medius	Superior gluteal
	Gluteus minimus	Superior gluteal
	Gluteus maximus	Inferior gluteal
	Tensor Fascia Latae	Superior gluteal
Flexion of the hip	Psoas	L1-3
	Iliacus	Femoral
	Rectus femoris	Femoral
	Adductor longus	Obturator

Appendix 1 (a): Functional anatomy of the hip

The hip provides the stability for the lower limb during functional activity and the actions of the hip muscle occur in the range of flexion-extension, abduction-adduction and internal-external rotation (Sodeberg, 1986).

Figure 23: Muscles of the gluteal region

Source: Moore and Agur (1995)



The hip extensors, namely the gluteus maximus and hamstring muscles work to extend the hip with the greatest activity during isometric muscle contractions and extension, external rotation and abduction (Sodeberg, 1986). The medial hamstrings assist with hip extension and internal rotation while the lateral hamstrings assist in hip extension and lateral rotation (Kendall, 1993). The muscle activity during hip extension is also supplemented by the action of the gemelli, obturator internus and adductor magnus. The hip abductors, namely gluteus medius and minimus control the position of the femur and pelvis during weight-bearing and the middle and posterior fibres of gluteus medius assist in hip extension (Kendall, 1993) acting as a hip extensor during gait (Winter, 1991). Muscles responsible for producing hip flexion are psoas major and iliacus (Kendall, 1993).

Appendix 1 (b): Movement control, plasticity, normal muscle strength and function

The corticospinal tract

The most direct route for information which is processed by the motor cortex to travel to the musculature to produce movement is via the corticospinal tract (Porter, 1999). The corticospinal tract acts as " a conduit for movement parameters controlled by each cortical area" from where it originates (Porter, 1999). This tract originates from multiple areas of the motor and parietal cortex with axons arising from the pyramidal cells in the motor cortex, supplementary motor cortex, pre-motor area and somatosensory cortex (Porter, 1999). It travels through the medulla, with 75-90% of fibres crossing at the spinal cord medullary junction (Davidoff, 1990). The uncrossed fibres form the anterior corticospinal tract while the crossed fibres form the lateral corticospinal tract (Davidoff, 1990). This means that the right motor cortex mostly controls the movement of the left side of the body and the left motor cortex mostly controls the right sided movement of the body (Bear *et al.,* 2001). The ipsilateral or uncrossed motor pathways seem to be linked with recovery of motor function following injury to the motor cortex (Ashe and Ugurbil, 1994). The tract terminates in the ventral horn of the spinal cord at the level of the motor neurones and interneurones that control the distal limb muscles (Bear *et al.,* 2001). Normal muscle activity and control depends upon both the central and peripheral neural connections. Consideration of the consequences of dysfunction within these connections is appropriate when dealing with an individual following stroke.

Cerebral blood supply

The blood supply to the brain is provided by the internal carotid and basilar arteries forming the Circle of Willis at the base of the brain. The motor cortex structures are sustained by the blood supply from the middle and anterior cerebral arteries which arise from the Circle of Willis to supply all surface areas and deep structures (Porter, 1999). If a blockage occurs in any of these cerebral arteries, loss of brain and resulting motor function, due to tissue ischaemia, can result.

Plasticity of the nervous system

The ability that the motor cortex has to re-organise and adapt in response to external stimuli or following injury is known as plasticity (Porter, 1999). This re-organisation and adaptation is aimed at optimising or restoring function (Stephenson, 1993) and rehabilitation following brain injury can foster reconnection of damaged neural circuits (Robertson and Murre, 1999). Functional imaging is used to evaluate the neural mechanisms used by the brain during performance of motor tasks and motor performance has been shown to improve with repeated synaptic modifications between the cortical, subcortical and spinal sensorimotor regions (Dobkin, 1998a). Repetitive activity of neurones of the corticospinal tract has been shown to be associated with the long term potentiation that results in improved efficiency of synaptic connections for storage and transmission of neural information, is fundamental for learning and occurs with repetitive practice of motor tasks. (Asanuma and Pavlides, 1997; Dobkin, 1998b). As motor learning occurs, the excessive muscle contractions that are associated with a new task become more specific as a result of the adaptive plasticity of the nervous system (Dobkin, 1998a). This means that as a new movement is learned it becomes more controlled due to the long-term potentiation that is induced by practice. It seems that functionally relevant, repetitive activity with appropriate feedback may enhance synaptic efficiency and "restore connections that reduce disability" (Dobkin, 1998b).

Muscle strength

During a muscle contraction, the mechanism of shortening involves the making and breaking of crossbridges within the sarcomere (contractile unit of muscle) in order to generate a force and allow muscle fibres to slide over one another (Goldspink and Williams, 1990). The force developed during a muscle contraction depends on the number of crossbridges engaging between the actin and myosin filaments of the sarcomere during that shortening process. Muscle strength depends on the number of motor units activated in addition to the fibre-type composition of the motor units and the rate of contraction (Kerr, 1998). Muscle strength also includes the ability to produce and control forces (Guiliani, 1995) and the force produced is dependent on both the length or position of the muscle and the velocity of the required muscle contraction.

The compliance of muscle tissue is reflected in the nature of the muscle contraction. Connective tissue restrictions can lead to decreased locomotory efficiency as a result of inefficient muscle contractions (Goldspink and Williams, 1990). Length-tension relationships in human muscle demonstrate that when a muscle is placed in either a very lengthened or shortened position it will generate less force when compared with contraction force in mid-range (Kerr, 1998). The muscle activity will be increased when the movement corresponds to the best mechanical advantage for that muscle (Sale, 1988).

Force-velocity relationships in human muscle indicate that as the velocity of the muscle shortening increases (concentric activity), the amount of force that can be produced by that muscle system decreases (Kerr, 1998). The velocity of contraction in an isometric contraction is considered to be zero and therefore the force produced is larger than that of an concentric contraction. As the velocity of lengthening increases (eccentric contraction), the force output increases (Kerr, 1998). Controlled eccentric contractions are required for functional activities such as gait and in line with specificity of training, the activity should match the desired goal, hence the need to consider the force-velocity relationship in exercise strength training protocols.

Awareness of the factors influencing muscle strength is necessary so as to be able to provide effective and efficient exercise programs that facilitate muscle strengthening effects. Exercise prescription principles need to consider the range within which the muscle is active as well as the velocity of the movement that is required to achieve the effective muscle contraction required for independent function.

Appendix 1 (c): Normal gait and clinical gait analysis

The gait cycle

A stride consists of a stance and a swing phase for each limb and is considered to be one gait cycle (see Figure 32). The stance phase begins at heel strike (0% of the gait cycle) and ends at toe off when the swing phase begins (60% of the gait cycle). Stance can be divided into initial contact (0%), loading response (0-10%), mid-stance (10-30%), terminal stance (30-50%) and pre-swing (50-60%), while swing is divided into initial (60-70%), mid (70-85%) and terminal swing (85-100%) (Cochran (1982) cited by Vaughan *et al.,* 1992). Double support occurs between initial contact on the one foot and toe- off on the other foot and single support corresponds with opposite limb swing phase. This characterises the co-ordination between the two lower limbs during the gait cycle (Craik and Dutterer, 1995). Mid-stance occurs when the swinging foot passes the stance foot and the body's centre of gravity is at its highest point (Vaughan *et al.,* 1992).

Figure 24: The temporal components of one gait cycle.

Source: Murray M (1967)

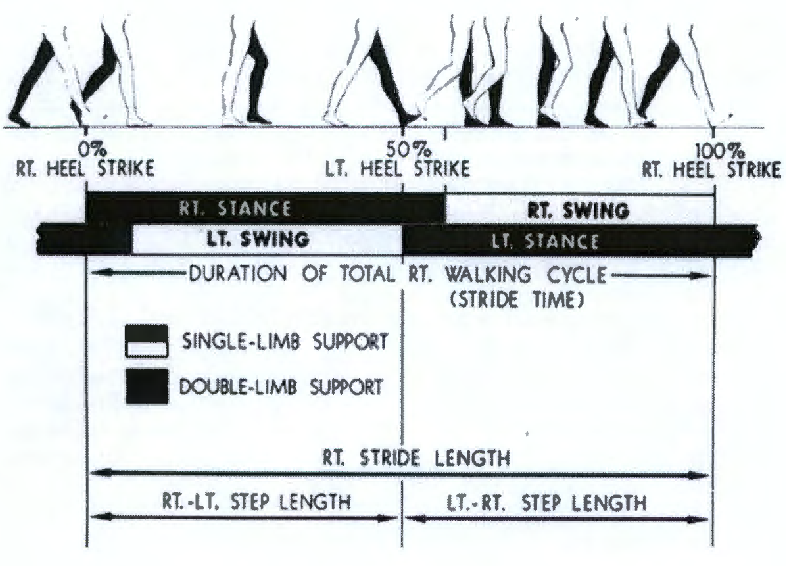


Figure 25: Definitions related to Human gait

Source: Winter DA (1991)

Cadence:	Number of steps per minute
Stride length:	Horizontal distance in the plane of progression covered heel strike to the following heel strike of the same foot
Step-length:	Horizontal distance in the plane of progression during one step
Stance/Swing ratio:	Ratio of the stance phase to the swing phase
Gait Velocity:	Horizontal speed of the body along the plane of progression
Kinetics:	Term used to describe the analysis of forces, includes power, joint reaction forces and ground reaction forces
Kinematics:	Term used to describe spatial movement of the body, not considering the forces that cause the movement
Co-efficient of variance:	Indication of the variability of the stride periods during gait data collection (CV).
Moment of force:	Product of a force acting at a distance about an axis of rotation and causing angular acceleration
Ground Reaction Force:	Net vertical and shear forces acting on the surface of the force platform

As walking involves synergistic and antagonistic muscle activity, the required kinematic movement can be achieved with a unique combination of muscle activity in any individual. This is described as indeterminancy at the motor level (Winter, 1991) and makes the assessment of human gait complicated. Clinical gait analysis is defined as the systematic assessment and documentation of human locomotion (Ounpuu, 1995). The components of clinical gait analysis include videotaping, collection of temporal and stride parameters as well as joint kinematic parameters, calculation of joint kinetic information (using kinematic and force plate data) and measurement of muscle activity during the gait cycle. Temporal and stride parameters include velocity, cadence, stride length, step length and percentage of swing to stance.

The type of muscle activity necessary during gait usually depends on the nature of the moments or torques acting around the joints of the standing limb as well as the direction of the desired motion (Norkin and Levangie, 1992). Electromyographic (EMG) data has been used to gather data to describe muscle activity during the gait cycle. In considering the muscle activity throughout the gait cycle, it can be seen that the basic function of the lower limb during single support stance is to extend sufficiently to achieve the required push off for swing (Winter, 1980). From heel strike to foot flat, gluteus maximus and hamstring muscles work isometrically and eccentrically to control hip flexion at the hip and the trunk forward acceleration. From foot flat to midstance, the muscle activity in gluteus maximus becomes concentric with the ground reaction force posterior to the limb and a resulting extension moment to facilitate weight acceptance. (Winter, 1991). See Figures 34 and 35 for EMG representation of muscle activity during gait.

Gluteus medius anterior fibres act to control the pelvis during weight acceptance and mid-stance, while the middle fibres act as a hip extensor to assist in controlling hip flexion in late swing and during weight acceptance (Winter, 1991). During the swing phase there are no ground reaction forces and the muscle activity required is to accelerate and decelerate the swinging limb, facilitate ground clearance and co-ordinate segmental alignment for heel strike (Norkin and Levangie, 1992). Gluteal activity in the early part of the swing phase serves to control the forward moving thigh (Winter, 1991).

Figure 26: EMG representation of muscle activity in gluteus medius and maximus muscle groups.

Source: Winter DA (1991)

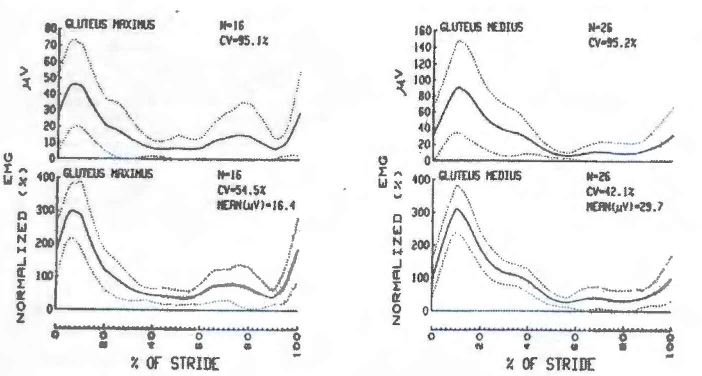
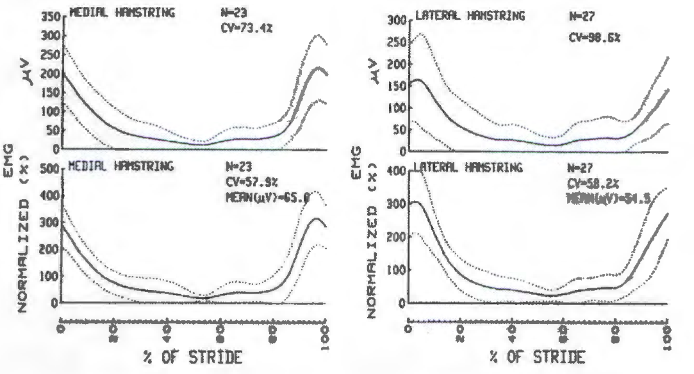


Figure 27: EMG representation of muscle activity in the hamstring muscle group.

Source: Winter DA (1991)



Joint kinematics is the term used to describe the spatial motion of the joint and is dependant on the marker set used to gather the data. Differences in marker set placement and hence joint angle definitions may limit the comparative value of this data (Ounpuu, 1985). Winter (1991) presented data for joint angles for 18 healthy elderly individuals walking at a natural cadence (See Table 12 and Figure 36). The mean age of this group was 68.9 +/- 4.0 years. The mean cadence was 111.8 +/- 8.7 steps per minute, the mean stride length was 1.38 m and the mean stance time was 65.7 % +/-1.52. Adaptations noted when compared with a younger population is a decreased step length, increased stance time and double support periods and reduced push-off. This relates to a more stable and safer gait pattern (Winter, 1991).

Figure 28: Joint angles during the gait cycle of an elderly individual walking at a natural cadence

Source: Winter, DA (1991)

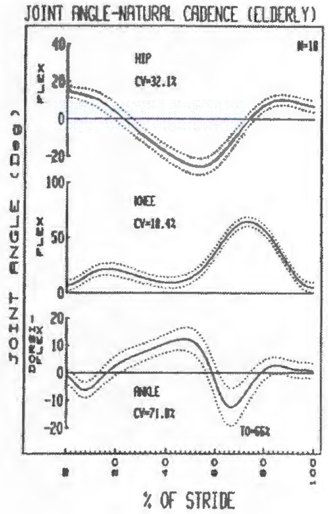


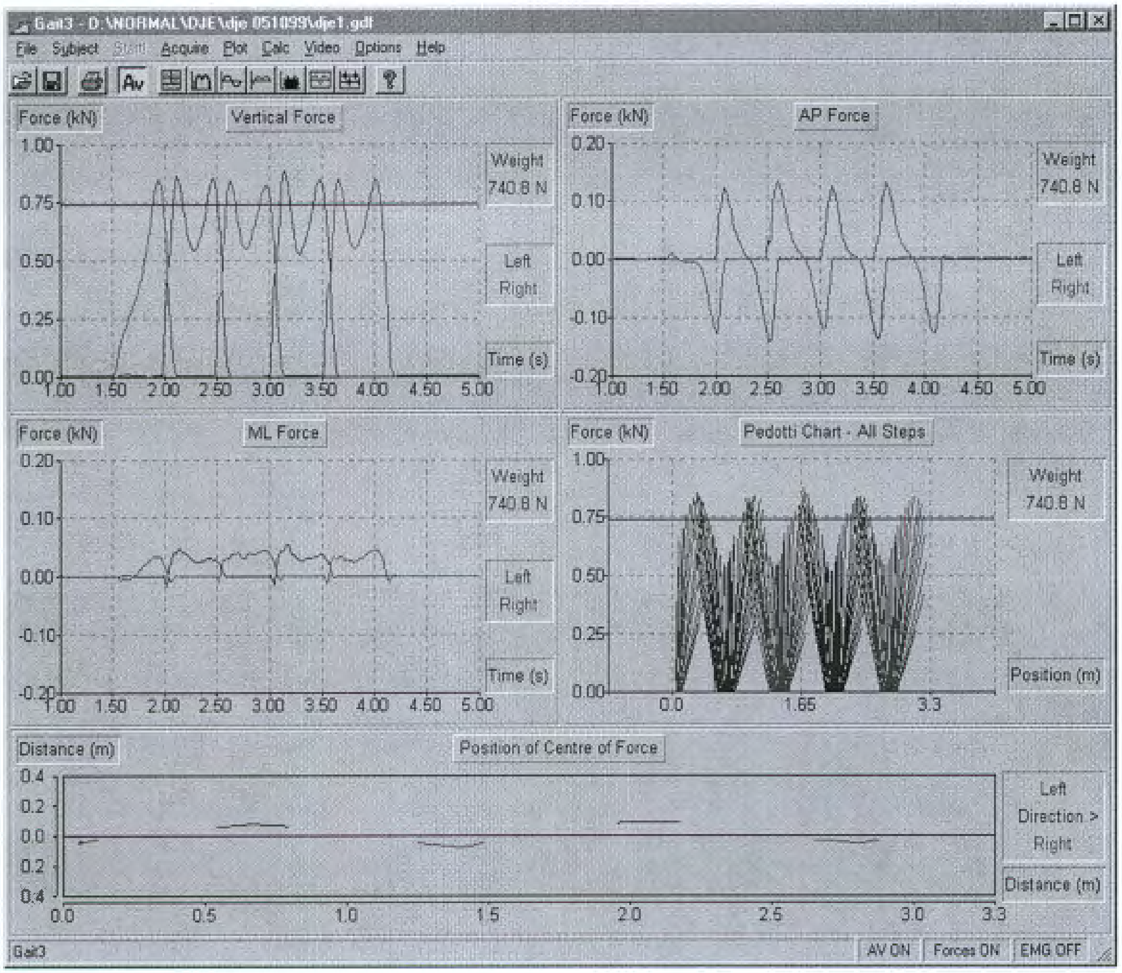
Table 10: Mean joint angles at the hip for elderly (mean age: 68.9) subjects walking at natural cadence

Adapted from Winter DA (1991).

% Stride	Mean Joint Angle	Std Deviation
0	14.63	3.06
6	12.89	3.45
10	11.40	3.97
16	7.13	4.46
20	3.20	4.51
26	-3.32	4.15
30	-7.77	3.95
36	-14.13	3.97
40	-17.98	4.15
46	-22.73	4.35
50	-24.86	4.36
56	-25.07	4.39
60	-21.94	4.47
66	-12.97	4.28
70	-5.94	3.79
76	3.20	3.24
80	7.38	3.04
86	10.23	2.77
90	9.99	2.72
96	7.96	2.96
100	6.76	2.91

Joint kinetics deals with the variables that are the cause of the specific gait pattern being observed (Winter, 1991) and are determined mathematically using the inverse dynamics approach or the resultant ground reaction force method (Ounouu, 1995). Kinetic calculations require kinematic and force plate data to be collected simultaneously. Kinetics at a joint involve the individual muscle forces, the moments acting across a joint and the mechanical power acting at the joint and the variability of the human neuromuscular system means that a range of joint kinetic combinations can be used to achieve the same kinematic pattern at a joint (Winter, 1991).

Figure 29: Force plate data for one normal subject walking with no assistive device



Appendix 2: A comparison of the Bobath and Motor Re-learning Programmes

The Motor ReLearning Programme and the Bobath Concept are two of the therapeutic approaches used in clinical neurophysiotherapy practice (Kwakkel *et al.,* 1999)

The Motor Relearning Programme encourages the use of training and exercise to encourage motor performance and includes consideration of the environment. Patient involvement and motivation is essential for the rehabilitation process and it is believed that the way in which the patient attempts to achieve a goal reflects the degree and distribution of muscle weakness and loss of soft tissue extensibility which impose mechanical constraints on movement (Carr and Shepherd, 1998).

The Bobath Concept aims to re-educate normal movement by the manipulation of proprioceptive afferent input (Lennon, 1996). The "problem" with the Bobath theory is that the "emphasis is on tone and reciprocal innervation as a requirement for normal movement" (Lennon, 1996) and strength training is not uniformly applied within the Bobath Concept, as resistance activities have been considered to increase spasticity (Bobath, 1990).

It is however evident that there is little up to date, published literature describing how the Bobath approach has developed since the last edition of Adult Hemiplegia (Bobath, 1990).

"Since this last publication, the concept has been taught via an oral tradition on post-graduate courses" (Lennon, 1996; Lennon and Ashburn, 2000), however a recent focus group study of the Bobath concept completed amongst experienced physiotherapists has explored how the concept has changed since 1990. This group has established that more attention is paid to the musculoskeletal system and that task specific practice with manual guidance is now considered to be a critical element of the concept (Lennon and Ashburn, 2000).

Appendix 3(a): Ethics application for study

SECTION 1 **Details of applicant (s)**

1	**Short title of project:**	The effects of a strengthening exercise programme on hemiplegic gait

Give one key word for each of the following:

Condition:	**Stroke**
Subject:	**Individuals with non-acute stroke**
Treatment:	**Muscle Strengthening**

2 Details of responsible investigator:

Surname:	**Busse**
Forename:	Monica
Title:	Ms
Present appointment of applicant:	School of Physiotherapy St George's Hospital Medical School Cranmer Terrace, Tooting SW17ORE
Qualifications:	BSc Physiotherapy BSc (Med) Hons Ergonomics
Address:	C/O School of Physiotherapy SGHMS 2nd floor Grosvenor Wing Cranmer Terrace, Tooting SW17ORE
Tel: 0208-7250377	Fax: 0208 7252248

E-mail: Mbusse@hcs.sghms.ac.uk

3 Please give details of other trials/studies in which the investigator/s

(a) Is currently involved

N/A

(b) Has been involved in the last six months N/A

(c) *Please use the form attached to Annexe C for details of* ***other investigators and/or centres*** *to be involved in this project*

4 **Proposed start date and duration of this project:**
February 2001 start date, for completion September 2001

5 **Who is sponsoring the study?**
There is no external funding for this project

6 **Location/s of project:**
Testing and exercise prescription to take place at the gait laboratory at Queen Mary's Hospital, Roehampton.

7 FUNDING

Please give full details where applicable of:

(a) **Payment to subjects** £ N/A
Refund of travel expenses

(b) **Payment to Trust/practice/research funds** £ N/A

(c) **Personal payment or personal benefit to researcher** £ N/A

Is payment:

(i) A block grant No

(ii) Based on the number of research subjects recruited No

(d) **Details of other benefits, e.g. equipment**

(e) **Will the costs incurred by the host institution be Covered by the payment?** No

SECTION 2 Details of project

8 **Aims and objectives of project:**

1. To establish the effects of a specific muscle strengthening programme in individuals following stroke
2. To investigate any possible functional change as a result of a specific exercise programme

9 **Scientific background of study** *(Approximately 250 words)*

Although many individuals regain walking ability after stroke, approximately half of all these people have continuing mobility problems and do not achieve full and independent walking function. In addition to this, they often experience a continual decline in functional status after discharge from rehabilitation (Wade *et al.,* 1992). Dean *et al.* (2000a) completed a randomised controlled pilot study, which established the efficacy of a task-related circuit class in improving walking function in chronic stroke. They found that exercise classes are one way to provide ongoing programmes to maintain, and/or improve function after discharge from rehabilitation.

Dean *et al.* (2000b) also reported a small multiple single case design study to investigate the effect of a locomotor training programme with a specific component designed to increase push-off in walking on the performance of locomotor related tasks and muscle strength in chronic stroke. They found that all subjects showed improvement in functional tests during the training phase and maintained the improvement in the second non-training phase. Moseley at.al., (1993) described the factors which contribute to walking problems in individuals following stroke. They identified hip muscle strength and control as a possible contributing factor to the problems that individuals with stroke experience when walking.

A review of the literature has shown evidence for task specific locomotor training to improve hemiplegic gait, although little research is available addressing specific muscle length and strength relationships around the hip joint and the impact of these relationships on hemiplegic gait. Therefore, the researcher asks the question whether the use of a specific hip muscle exercise programme will have an effect on the stance phase of gait for the individual following stroke.

References:
Dean C, Richards C and Malouin F (2000a) Task-related circuit training improves performance of locomotor tasks in chronic strokes: a randomized, controlled pilot trial. *Arch. Phys. Med. Rehabil* 81, 409-417
Dean C, Malouin F and Richards C (2000b) Locomotor training in chronic stroke: multiple single case design. Paper presentation at the Sixth International Physiotherapy Congress of the Australian Physiotherapy Association
Moseley A, Wales A, Herbert R, Schurr K and Moore S (1993) Observation and Analysis of Hemiplegic gait: stance phase. *Australian Journal of Physiotherapy* 39(4) 259-266
Wade D, Collen F, Robb G and Warlow C(1992) Physiotherapy Intervention late after stroke and mobility. *British Medical Journal* 304, 609-613

10	**Brief outline of project** *(Approximately 250 words)*

An A-B before and after study design will be used. Six individuals, at least six months after stroke will be recruited to participate in the study. The study duration will be 12 weeks with each phase lasting 6 weeks. During phase A, no training or advice will be given to the subject. Baseline measures of gait patterns will be obtained in week 1 of phase A (pre-intervention evaluation) with repeated measures at the end of phase A /beginning of phase B and the end of phase B. During phase B, the subject will participate in a strength training programme aimed at improving hip extensor muscle strength and hip flexor muscle length. The exercises which will be used will be standard and accepted in normal physiotherapy practice. They will be non-demanding and tailored to suit the patient's functional abilities. The subjects will be provided with home instructions to assist them in completing the exercises in the correct manner.

11	**Study design (e.g. RCT, cohort, case control, epidemiological analysis)**

Before- After Study (A-B Design)

12	**Size of the study:**	**Will the study involve:**	
(a)	**Human subjects**		Yes
(i)	**How many subjects are being recruited?**		6
(ii)	**How many controls will be recruited?**		0
(iii)	**What is the primary end point?**		Completion of the exercise programme
(iv)	**How was the size of the study determined?**		Study size determined by feasibility and related research
(v)	**What is the statistical power of the study?**		N/A
(b)	**Patient Records**		Yes
(i)	**How many records will be examined?**		6
(ii)	**How many controls records will be examined?**		0
(iii)	**What is the primary end point?**		
(iv)	**How was the size of the study determined?**		Study size determined by feasibility and related research

(v) **What is the statistical power of the study?** N/A

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13 Scientific critique:

Has the protocol been subject to scientific critique. If so, please give the following information:

(If the critique formed part of the process of obtaining funding, please give the name and address of the funding organisation):
Funding applications have been submitted to the Chartered Society of Physiotherapy Charitable Trust. Protocol has been reviewed by research supervisors, namely Prof. CL Vaughan and Sarah Tyson

If the critique took place as part of an internal process, please give brief details:

Critique has taken place as a requirement of the Master of Science in Biomedical Sciences degree for which the researcher is registered. This is a requirement of the University of Cape Town and takes place prior to acceptance of the proposal.

SECTION 3 Recruitment of subjects

---

14 How will the subjects in the study be:

(i) Selected? Six individuals with stroke, at least six months post stroke and have been discharged from the rehabilitation unit.

(ii) Recruited? The subjects will be recruited from discharged patient records within St George's NHS Trust.

(iii) What inclusion criteria will be used? The subject will have to meet the following inclusion criteria:

- First stroke resulting in hemiplegia
- Aged between 40 and 80 years
- At least six months post-stroke
- Discharged from all rehabilitation services and living in an area local to the study (5 mile radius)
- Able to participate in an exercise programme independently and attend measurement sessions in the gait laboratory at the beginning and end of each phase over the study duration.
- Able to walk 10 metres independently with or without an assistive device

(iv)	What exclusion criteria will be used?	The subject will be excluded if they have any medical condition that prevents participation in an exercise-training programme. The subject will also be excluded if they are unable to give informed consent or are unable to communicate sufficiently to be able to follow the instructions for completing the training programme.

How will the control subjects group be:

(v)	Selected?	**N/A**
(vi)	Recruited?	**N/A**
(vii)	What inclusion criteria will be used?	**N/A**
(viii)	What exclusion criteria will be used?	**N/A**

15 (a) **How many subjects are being studied locally?**

6

(b) **Are any of these subjects involved in existing research or have been involved in any research in the last six months ?** *No*

(c) **Will any of the subjects involved be in a dependent relationship with the investigator?** *No*

(d) **Will any of the subjects involved be medical students ?** *No*

SECTION 4 **Consent**

16 **Is written consent to be obtained?** *Yes*

17 **How long will the subject have to decide whether to take part in the study?**

Maximum 2 weeks

Subjects will be contacted in writing with a letter of invitation to participate and a study information sheet. The researcher will contact the subjects within 2 weeks of them being sent the letter to obtain written consent.

18 **Will the subject be given a written information sheet Or letter?** *(Please see Guidelines).* *Yes*

19 **Have any special arrangements been made for subjects for whom English is not a first language?** *Yes*

If yes, give details:

The researcher will follow the communication strategy used by the physiotherapy department at St George's NHS Trust and will cover any of the relevant costs.

(i) **Will any of the subjects or controls be from one of the following vulnerable groups?**

Children under 18

People with learning difficulties

_______ Unconscious or severely ill
_______ Other vulnerable groups

No

(ii) **What special arrangements have been made to deal with the issues of consent for the subjects above?** *(Please see Guidelines)*
Written, informed consent will be obtained for all participants in the study

SECTION 5 **Details of intervention**

24 **Please list those procedures in the study to which subjects will be exposed indicating those which will be part of normal care and those that will be additional (e.g. taking more samples than would otherwise be necessary). Please also indicate where treatment is withheld as a result of taking part in the project.**
The subjects will be expected to participate in an exercise programme. There will be no withholding of treatment as a result of the study.

SECTION 6 **Risks and ethical problems**

25 **Are there any potential hazards?** *Yes*
If yes, please give details, and give the likelihood and details of precautions taken to meet them, and arrangements to deal with adverse events.
Risks associated with exercise. Subjects to be informed of associated risks and precautions. Screening for general ability to participate in en exercise programme will take place prior to beginning of study. See exclusion criteria.
The exercises which are to be prescribed will be non-demanding and standard to normal physiotherapy practice. The subjects will be provided with videotaped instructions to ensure safe and correct execution of the programme and the researcher will have regular telephonic contact with the subjects.

26 **Is this study likely to cause discomfort or distress?** *No*

27 **Are there are particular ethical problems or considerations that you consider to be important or difficult with the proposed study?** *No*

28 **Will information be given to the patient's General Practitioner?** *Yes*

SECTION 7 **Indemnity and Confidentiality**

29 **Have arrangement been made to provide indemnification and/or compensation in the event of a claim by, or on behalf of, a subject for non-negligent harm?** *N/A*
(Please indicate N/A if not applicable)
The researcher is a full time employee of the Joint Faculty of Health Care Sciences and St George's Hospital Medical School. As such the faculty and medical school holds insurance which covers employees to carry out their normal professional duties. The researcher is registered physiotherapist and the planned research falls within the scope of normal professional work.

31 **LOCAL CONFIDENTIALITY ARRANGEMENTS**

32 **Will the study include the use of any of the following?**

Audio/video recording *Yes*

Observation of patients *Yes*

(i) How are confidentiality and anonymity to be ensured?

No individual will be identifiable from any published results. Individual consent will be obtained for video recordings.

(ii) What arrangements have been made to obtain consent for these procedures?

Written consent form is to be signed by all participating subjects. Consent for video photography will be requested.

33 **Will medical records be examined by research worker(s) outside the employment of the NHS?** *Yes*

Records to be examined by the researcher who is employed by the joint Faculty of Healthcare Sciences Kingston University and St George's Hospital Medical School

34 **What steps will be taken to safeguard confidentiality of personal records?**

All information collected during the course of the research will be kept strictly confidential. Any information which leaves the hospital/surgery will have names and addresses removed so that the subject cannot be recognised from it. Data will be stored in a secure, locked area.

The results of the research may be published in a research journal, however the subjects will not be identified in any report or publication.

Appendix 3(b): Information sheets, consent form and letter of invitation

Dear:

Re: **Research into the effects of muscle strengthening and stretching in individuals following stroke**

I am writing to inform you that a patient who is registered at your practice has agreed to partake in a study that I am running looking at the benefits of a strengthening and stretching programme on function in individuals following stroke.

The individual concerned is:

Name: ____

Address: ____

____

The study will involve participation in a structured, supervised exercise programme for a six- week period. Changes in function will be measured before and after intervention. If you would like any further information about this study, please contact me at:

School of Physiotherapy
St George's Hospital Medical School
2nd floor Grosvenor Wing
Cranmer Terrace
Tooting
SW17ORE
Tel: 0208-7250377

Thank you
Yours truly,

Monica Busse
School of Physiotherapy

PATIENT INFORMATION SHEET

1. Study Title

The effects of a strengthening exercise programme on hemiplegic gait

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your GP if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Consumers for Ethics in Research (CERES) publish a leaflet entitled 'Medical Research and You'. This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES, P0 Box 1365, London N16 OBW. Thank you for reading this information sheet

3. What is the purpose of the study?

The aim of the study is to establish if a specific strengthening programme will improve the walking pattern of an individual following a stroke following discharge from rehabilitation.

4. Why have I been chosen?

Your name was found from a list of patients who have been discharged from physiotherapy at St George's NHS Trust

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. This will not affect the standard of care you receive.

6. What will happen to me if I do take part?

You will be involved in the research for a period of four months during which time you will need to visit the gait laboratory at Queen Mary's Hospital, Roehampton four times. These visits will take up a morning of your time. Full travelling expenses will be offered. During the testing morning, a full assessment of how you walk and whether there is any muscle weakness that may affect your walking will be done. During the study period, you will be expected to complete an exercise programme, three times a week, for six weeks of that period.

The research method to be used is a before-after study design. This will involve two phases. The first phase will be a monitoring phase and will only involve testing. The second phase will involve your participation in a three times weekly exercise programme lasting approximately half and hour. The exercise programme will be specifically designed to strengthen the hip muscles.

7. What do I have to do?

There should be no lifestyle restrictions involved in this study, however you should not be involved in any additional physiotherapy intervention during the entire period of the study.

8. What are the possible disadvantages and risks of taking part?

The possible disadvantages and risks of being involved in this study are the same risks as being involved in any exercise programme, however with careful monitoring there should be no disadvantages to your participation.

9. What are the possible benefits of taking part?

It is hoped that the treatment will help you. However, this cannot be guaranteed. The information we get from this study may help us to treat future patients with stroke better.

10. What is new information becomes available?

Sometimes during the course of a research project, new information becomes available about the treatment that is being studied. If this happens, your researcher will tell you about it and discuss with you whether you want to continue in the study. If you decide to continue in the study you will be asked to sign an updated consent form. On receiving new information your researcher might consider it to be in your best interests to withdraw you from the study. He/she will explain the reasons and arrange for your care to continue.'

11. What happens when the research study stops?

When the study finishes, the participation in a regular exercise programme need not stop. The researcher will provide you with a list of resources and advice on how to get exercise support in your area

12. What happens if something goes wrong?

If taking part in this research project harms you, there are no special compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms may be available to you.

13. Will my taking part in this study be kept strictly confidential

All information collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the hospital/surgery will have your name and address removed so that you cannot be recognised from it. Your own GP will be notified of your participation in the trial

14. What will happen to the results of the research study?

The results of the research may be published in a research journal, however you will not be identified in any report or publication.

15. Who is organising and funding this research?

This research is being organised by the researcher who is based at the School of Physiotherapy at St George's Hospital Medical School, Tooting. This research is supported by the Chartered Society of Physiotherapy and the Faculty of Healthcare Sciences at Kingston University.

16. Who has reviewed this study?

This study has been reviewed by the Ethics committee based at St George's Hospital, Tooting.

Thank you for taking part in this study

17. Contact for further information

If you have any further questions regarding this study, you can contact the researcher, Monica Busse at:

School of Physiotherapy
St George's Hospital Medical School
Grosvenor Wing
Cranmer Terrace
Tooting
SW 17 ORE
Tel: 0208-7250377

You will be given a copy of the information sheet and a signed consent form to keep.

Patient Identification Number for this study:

CONSENT FORM

Title of Project: The effects of a strengthening exercise programme on hemiplegic gait

Name of Researcher: Monica Busse

School of Physiotherapy
St George's Hospital Medical School
Grosvenor Wing
Cranmer Terrace, Tooting, SW 17 ORE
Tel: 0208-7250377

1. I confirm that I have read and understand the information sheet dated ________ for the above study and have had the opportunity to ask questions. ☐

2. I UNDERSTAND THAT MY PARTICIPATION IS VOLUNTARY AND THAT I AM FREE TO WITHDRAW AT ANY TIME, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that sections of any of my medical notes may be looked at by responsible individuals from St George's Hospital NHS Trust 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 give consent for photographs or video tape recordings to be taken during the testing procedures and give consent for the material to be shown to appropriate professional staff and be used in educational publications. I understand that every effort will be made to conceal my identity, but full confidentiality is not guaranteed. ☐

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

Dear:

Re: **Research into the effects of muscle strengthening and stretching in individuals following stroke**

I am writing to invite you to participate in a study that I am running looking at the benefits of a strengthening and stretching programme on function in individuals following stroke. The study will involve participation in a supervised, structured exercise programme for a six- week period. Changes in function will be measured before and after intervention.

An information sheet is attached. Please read this carefully and if you would like any further information about this study or would like to join the study, please contact me at the following address:

School of Physiotherapy
St George's Hospital Medical School
2nd floor Grosvenor Wing
Cranmer Terrace
Tooting
SW17ORE
Tel: 0208-7250377

Thank you

Yours truly,

Monica Busse

School of Physiotherapy

Appendix 4: Exercise programme instructions

Instructions for completion of exercise programme and training diary

- **If you feel light-headed, dizzy, faint or unwell at any time during completion of the exercise programme, stop exercising IMMEDIATELY and please inform Monica. See your GP if necessary.**
- **You will be provided with a weekly training diary that needs to be completed each time that you do an exercise session over the next six weeks. All the exercises that are listed in the training diary are illustrated in your exercise handbook.**
- **You will be taught how to do the exercises correctly, how many exercises to do each week as well as how to progress them each week. All this information will be recorded in your exercise handbook.**
- **Please do not do any exercises if you have not specifically been taught how to do them.**
- **If you are unsure of how to do any of the exercises at any time, please telephone Monica on the contact number provided.**

Appendix 5: Training diary

Training Diary

Name:

Date of week beginning:

Exercise	**Number of repetitions in each set**	**Number of sets per session**	**Number of exercise sessions per week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Active hip extension in prone and supine										
Weight transfer (gait training)										
Step Ups										
Squats										
Chair Stands										
Wall slides										
Hip Extension in standing										
Supine passive hip extension with opposite leg neutral										
Stride standing										
Supine passive hip extension with opposite hip in flexion										

Please indicate in the columns provided (numbered 1-7 for each day of the week) when the prescribed exercises have been completed.

Appendix 6(a): The Motor Assessment Scale for Stroke

General Instructions:

1. The test should be carried out in a quiet, private room or a curtained off area
2. The test should be carries out when the patient is maximally alert and not under the influence of any hypnotic or sedative drugs
3. The individual being tested should be dressed in suitable street clothes with sleeves rolled up and without socks and shoes
4. Each item is recorded on a scale of 0 to 6
5. All items are to be performed independently unless otherwise stated. Standby help means that the therapist may steady the individual, but not actively assist
6. The individual should be scores on best performance. Repeat three times unless otherwise stated
7. The therapist may give general encouragement, but no specific feedback on whether the response is correct or incorrect
8. Instructions should be repeated and demonstrations given if necessary
9. Equipment required for testing the walking item is: stopwatch, tape to mark distance walking, beanbag and steps.

Scoring Criteria

Walking Item of MAS

1. **Stands on affected leg and steps forward with the other leg. Weight-bearing hip must be extended. Therapist may give standby help.**
2. **Walks with standby help from one person**
3. **Walks 3 metres alone, with any aid, but no standby help**
4. **Walks 5 metres with no aid in 15 seconds**
5. **Walks 10 metres, with no aid, turns around, picks up small sandbag from floor and walks back in 25 seconds**
6. **Walks up and down four steps with or without an aid, but without holding onto the rail three times in 35 seconds**

Appendix 6(b): Nottingham Extended Activities of Daily Living Index

	Not at all (0)	With help (0)	Alone with difficulty (1)	Alone easily (1)
Mobility DO YOU:				
• Walk around outside	______	______	______	______
• Climb stairs	______	______	______	______
• Get in and out of the car	______	______	______	______
• Walk over uneven ground	______	______	______	______
• Cross roads	______	______	______	______
• Travel on public transport	______	______	______	______

Appendix 7: Medication lists for individual subjects

Medications

KS	Tizanadine Hydrochloride 2 mg am and pm Bisoprolol Fumarate 5mg Lisonopril 20mg Simavastatin 10mg Aspirin 75mg Tolterodine Tartrate 1 mg BD Ibuprofen 200mg bd Lactulose 10 mls prn
IE	Astorvastin 10 mg Isosorbide mononitrate 10 mg Enalapril Maleate 5mg Frusemide 40 mg Amitryptiline 20 mg Moprol 20mg
PI	Frusemide 40mg Thyroxine 50 mg Simvastatin 10 mg Digoxin 250mcg Lisonopril 15 mg Omeprazole 10 mg Warfarin 5mg Diazepam 10 mg daily
CG	Baclofen (4 week programme started and completed in baseline measurement phase) Hormone Replacement Therapy
TA	Isosorbide mononitrate 20mg Tildiem Retard 120 mg Aspirin 75mg BD Glyceryl Trinitrate 400 micrograms PRN
JO	Istin Amlopdine 5mg

Drug	Indications	Drug Interactions	Adverse Drug Reactions
Tizanadine Hydrochloride	Spasticity	Diuretics, β-blockers, antihypertensives, digoxin, CNS depressants	Drowsiness, fatigue, dizziness, hypotension, bradycardia
Baclofen	Spasticity	CNS depressants	Fatigue, weakness, dizziness, tiredness
Bisoprolol Fumarate	Stable, chronic heart failure		
Lisonopril	Adjunct to diuretics in congestive heart failure	NSAIDs, antihypertensives, tricyclics	Hypotension, dizziness, fatigue, palpitations, headache
Simavastatin	Reduction of cholesterol	Digoxin	Headache, dizziness, muscle cramps, myalgia
Aspirin	Pain Anti-platelet action		Gastric ulceration
Tolterodine Tartrate	Unstable bladder with urgency	Anticholinergics	Headache, dry mouth, paraethesis
Astorvastin	Primary hypercholes-terolaemia	Digoxin, warfarin	Headache, myalgia, Insomnia
Isosorbide mononitrate	Prophylaxis of angina		Headache, flushes, dizziness
Enalapril Maleate	Renovascular hypertension	NSAIDs, antihypertensives, corticosteroids, alcohol	Hypotension, headache, fatigue, dizziness
Frusemide	Oedema	Carbamazepine	Malaise, dry mouth, rash
Amitryptiline	Depression	Diuretics, NSAIDs, Carbamazepine, diazepam, antihypertensives	Hypotension, palpitations, tachycardia
Moprol			
Thyroxine	Hypothyroidism	Anticoagulants, tricyclics	Arrythmias, headaches, muscle cramps, flushing
Digoxin	Chronic cardiac failure	Diuretics, corticosteroids	Weakness, apathy, headache
Omeprazole	Reflux Oesophagitis	Diazepam, digoxin	Headache, Dizziness, Myalgias
Warfarin	Thomboembolic conditions	NSAIDs, antibiotics	Alopecia, rash, diarrohea
Tildiem Retard	Angina	Antihypertensives, β-blockers	Bradycardia, ankle oedema
Glyceryl Trinitrate	Acute angina		Headaches, dizziness
Diazepam	Relief of muscle spasm, anxiety disorders	Tagamet	Drowsiness, fatigue, ataxia
Istin Amlopdine	Hypertension		Headache, Oedema, Fatigue

***Information obtained from MIMS Monthly Index of Medical Specialities (June 2001), Haymarket Publishing Services**

Appendix 8: Post Intervention Questionnaire

The aim of this questionnaire is to gather information about the *overall feeling* that you have with respect to the completion of the exercise programme that you have been doing for the last 6 weeks. From this questionnaire, it should be possible to identify any *advantages, disadvantages and suggestions* that you have which may help improve similar future interventions involving exercise programmes with people who have had a stroke.

Thank you for being involved in this study

Instructions for completion of questionnaire:

There are ten questions and each question has five possible responses, ranging from "strongly agree" to "strongly disagree" and one option if you do not know the answer or do not have a strong opinion about the question asked.

In cases where you select strongly agree or disagree, you may be asked to provide examples to support you answer.

Please indicate in the bracket above the answer that best reflects how you feel.

1. **I have completed the exercise programme as requested over the last six weeks.**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

2. **I have had particular difficulty with completing some of the exercises.**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

Please comment:

___

___

3. **Any difficulties that I had with completion of specific exercises were easily resolved by adapting the exercises.**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

Please comment:

___

___

4. **There have been noticeable benefits for me as a result of doing this exercise programme on a regular basis.**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

Please comment:

___

___

5. **I understand the safety considerations linked with doing an exercise programme on a regular**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

6. **I will continue to do the prescribed exercise programme on a regular basis**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

7. **I have noticed a general increase in my level of physical activity since I have participated in this exercise programme**

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

8. I am able to perform certain activities with more ease than before

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

Please comment:

____

____

9. My walking ability indoors has changed since I have been doing this exercise programme

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

Please comment:

____

____

10. My walking ability outdoors has changed since I have been doing this exercise programme

[ ]	[ ]	[ ]	[ ]	[ ]
Strongly Agree	**Agree**	**Don't know**	**Disagree**	**Strongly Disagree**

Please comment:

____

____

I have the following suggestions for any future interventions:

____

____

____

Appendix 9: Data collection sheet

Subject Number: ______________________

Affected side: ________________________

Date of Testing: ______________________

Phase of study: **A0** **A1** **A2** **B1** **B2** **C**

Medication:

Aids required:

Clinical and Functional Measures

Nottingham Extended Activities Score			
Ten metre Timed Walk (s)			
Motor assessment scale score (walking item)			
Right Hip joint passive extension (degrees)	**0**	**5**	**10**
Left Hip joint passive extension (degrees)	**0**	**5**	**10**
Right Hip extensor strength (kg)			
Left Hip extensor strength (kg)			

Height (m):	
Weight (N):	
Left Knee width (mm)	
Right Knee width (mm)	
Left Ankle width (mm)	
Right Ankle width (mm)	
Left Foot width (mm)	
Right Foot width (mm)	

Special Comments:

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