MEASUREMENT OF TRAINING INTENSITY AND WORK DURING SUBMAXIMAL ISOKINETIC PROGRESSIVE RESISTANCE TRAINING PROTOCOLS

PRITESH BARCHHA

A thesis submitted in partial fulfilment of the requirements of the University of East London for the degree of Master of Philosophy

July 2015

Abstract

Physical exercise programmes are routinely prescribed in clinical practice to treat impairments, improve activity and participation in daily life because of their known physiological, health and psychological benefits (RCP, 2009). Progressive resistance exercise is a type of exercise prescribed specifically to improve skeletal muscle strength (Latham et al., 2004). The effectiveness of progressive resistance exercise varies considerably between studies and populations. This thesis focuses on how training parameters influence the delivery of progressive resistance exercise. In order to appropriately evaluate the influence of training parameters, this thesis argues the need to record training performance and the total work completed by participants as prescribed by training protocols.

In the first study, participants were taken through a series of protocols differentiated by the intensity and volume of training. Training intensity was defined as a proportion of the mean peak torque achieved during maximal voluntary contractions and was set at 80% and 40% respectively of the MVC mean peak torque. Training volume was defined as the total external work achieved over the training period. Measures of training performance were developed to accurately report the intensity, repetitions and work completed during the training period. A second study evaluated training performance of the training protocols over repeated sessions. These protocols were then applied to 3 stroke survivors.

Study 1 found sedentary participants could achieve a differentiated training intensity. Participants completing the high and low intensity protocols trained at 80% and 40% respectively of the MVC mean peak torque. The total work achieved in the high intensity low repetition protocol was lower than the total work achieved in the low intensity high repetition protocol. With repeated practice, study 2 found participants were able to improve in their ability to perform manoeuvres as shown by a reduction in the variation of the mean training intensity achieving total work as specified by the protocol to a lower margin of error. When these protocols were applied to 3 stroke survivors, they were able to achieve the specified training intensity but they were not able to achieve the total work as expected for the protocol. This is likely to be due to an inability in achieving a consistent force throughout the contraction.

These results demonstrate evaluation of training characteristics and support the need to record and report training performance characteristics during progressive resistance

exercise, including the total work achieved, in order to elucidate the influence of training parameters on progressive resistance exercise. The lack of accurate training performance may partly explain the inconsistencies between studies on optimal training parameters for progressive resistance exercise.

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Acknowledgements

Dr. Mary Cramp, Dr. Jane Culpan, Professor Helen Dawes and Professor Oona Scott for their enduring support to see through completion of my studies.

Holly Duglan and Edward Lazell for being understanding and supportive managers.

Dr. Roger Carpenter for helping me to prepare for the viva.

Sirisha Kodakandla, Aanya-Raj and my family for their love and kindness.

1.0 Introduction

The medical benefits to exercise were reviewed in the early 1990s by the Royal College of Physicians which highlighted the physiological benefits of physical activity (RCP, 2009). Exercise programmes form part of medical intervention to manage illness and maintain health and well-being (RCP, 2012). Exercise programmes can come in a variety of forms including recreational sport, endurance training, circuit stations, stretching, and resistance training. Each of these are prescribed depending on the outcome that is desired. Progressive resistance exercise is a type of exercise which is specifically designed to improve skeletal muscle strength through the performance of movements against a progressively increasing resistance (Latham et al., 2004; ACSM, 2009). In addition to forming part of recommendations for daily physical activity in healthy adults (DoH, 2011), progressive resistance exercise has been shown to be beneficial in a number of rehabilitation contexts. It has been recommended for patients with multiple sclerosis to manage fatigue (NICE, 2014), restoring physical function following musculoskeletal trauma such as hip fractures (NICE, 2011), and improving execution of activities of daily living for older people and stroke survivors (Liu & Latham, 2009; RCP, 2012).

This thesis focuses on measuring training performance in training protocols differentiated in intensity and total work. It is well established that muscle strength can improve following progressive resistance exercise. However, outcomes vary considerably between studies (ACSM, 2009). The training stimulus of muscle adaptation is not fully understood (Crewther et al., 2006) and the observed variation may be due to many factors of which the training parameters utilised in the delivery of progressive resistance exercise is of particular interest. Research has focused on the influence of training parameters such as the training intensity (relative resistance) (Seynnes et al., 2004) and number of repetitions on the effectiveness of progressive resistance exercise (Carpinelli & Otto, 1998). In healthy young and elderly populations, there is conflicting evidence on the optimal training intensity and number of repetitions for progressive resistance exercise. More recently, it was reported that the total work (measured in joules), which is the integral force exerted by muscles during the training period, to be an encompassing measurement for the amount of training completed (Wernbom et al., 2007). However, this has not been consistently reported in previous studies drawing question to whether participants in previous studies completed training as prescribed by the training protocols.

To fully understand the influence of training parameters on the effectiveness of progressive resistance exercise, this thesis argues the need to examine training performance particularly the amount of training that is completed. Without recording training performance and total work, it is not known whether all participants completed the regime specified by the training protocol.

Therefore, as part of this thesis, two studies were conducted to evaluate the use of isokinetic dynamometers to train groups of individuals at a differentiated training intensity and number of repetitions whilst recording the total work completed during the intervention. The protocols required participants to produce force that was equivalent to the target force using real-time visual feedback. Accurate performance therefore was dependent on the ability to not fall short of or exceed the target force during the muscle contractions. Measures of training performance were developed to accurately report the intensity, repetitions and work during the training period.

The first study was conducted to determine whether participants could perform the training protocols at the target training intensity and also evaluate whether participants could achieve total work as specified by the protocol. The second study was conducted to determine whether training performance improved with repeated practice such that all participants were able to achieve the training intensity specified and total work expected for the protocol. Following this, the protocols were applied to three stroke survivors as case studies basis to determine the training performance in a clinical population.

With increasing financial constraints on the National Health Service there has been a growing need for providing cost effective interventions that are evidence based (DoH, 1997). Cost-effective and evidenced based practice involves the utilization of research to determine interventions that have shown to be effective in producing the desired effect on outcomes and bear the lowest cost to service delivery (Rosenberg, 1995). For rehabilitation purposes, the application of interventions in a way which optimises potential outcome has shown growing interest in recent years (Cook et al., 2010). To deliver effective exercise interventions in healthcare, there needs to be an improved understanding of the influence of training parameters on outcomes following progressive resistance exercise in order to identify optimal regimes.

2.0 Literature Review

2.1 Introduction

This literature review is divided into four main sections. Firstly, the structure and function of skeletal muscle is outlined, with reference to current understandings of how muscles contract to produce force exerted at a joint as well as how strength can be assessed and is influenced by the length of muscle and the velocity of movement. A large part of this thesis reviews current understanding in progressive resistance exercise. The concepts and training parameters that underpin progressive resistance exercise are defined. The evidence on the effectiveness of progressive resistance exercise, particularly the influence of the training parameters is reviewed, separately for three populations – a) healthy young sedentary, b) healthy elderly and c) stroke survivors. This identifies the need to record and report training performance parameters during the implementation of progressive resistance exercise.

2.2 Muscle structure and function

2.2.1 Structure of muscle and neuromuscular control

Skeletal muscle is specialised tissue that serves the function of producing force (MacIntosh et al., 2006). Skeletal muscle attaches to the bones of skeletons via tendons, mainly passing over joints, to control posture and movement. Muscles vary in structure depending on functional characteristics. Muscle fibres, which are the contractile unit of muscle tissue, contain myofibrils which have the ability to reduce in length. Myofibrils consist of a string of sarcomeres connected longitudinally by Z lines and these form the basic contractile unit of muscle. Myofibrils can shorten in length causing a subsequent pull on the tendons attached to bone to produce force (Macintosh et al., 2006).

The actin and myosin filaments overlap each other within sarcomeres by forming cross-bridges (Huxley and Hanson, 1954). In relaxed muscle, the cross-bridge sites are covered by tropomyosin. They are uncovered by the release of Ca^{2+} ions from the sarcoplasmic reticulum (SR) when impulses are transmitted by the T-Tubules. These impulses are usually generated in the M1 motor cortex and transmitted via descending motor pathways to motor neurones in the ventral grey matter in the spinal cord. There are usually more than a hundred motor neurones supplying each muscle and therefore maximal muscle activation depends on the ability to send impulses using all motor neurones associated with a particular muscle.

2.2.2 Motor Unit

A motor unit is composed of an alpha (α) motor neuron and the muscle fibres that are activated by it (MacIntosh et al., 2006). The motor unit has been described as the smallest functional unit of a muscle (Sherrington, 1925). Motor units were distinguished into two major types, type I and type II by Burke (1971). Further research classified type II into three different types (type IIa, type IIb and type IIx), described below (Pette & Staron, 2000; Graziotti et al., 2001). The presence of type IIb fibres is believed to be in mammals only and not in human skeletal muscle (Smerdu et al., 1994).

- **Type I**– These motor units have a slower twitch, the smallest twitch tension, are more fatigue resistant and contain oxidative enzymes compared to other types.
- **Type IIa**– These motor units have a faster twitch, are fatigue resistant and can produce larger contractions in shorter times compared to type I. They metabolise both aerobically and anaerobically, can produce larger contractions in shorter times and are more prone to fatigue compared to type I.
- **Type IIb** – These motor units have lower levels of myoglobin and mitochondria. They metabolise anaerobically and produce faster twitches but are prone to fatigue.
- **Type IIx-** These motor units are similar to the other type II but contain a specific myosin heavy chain isoform. They can produce an intermittent speed of twitch compared to muscles that contain primarily type I or type IIa.

Skeletal muscle fibres adapt to changes in activity pattern. In cat muscle, Buller et al. (1960) showed characteristics of slow muscle can change to characteristics of fast muscle when innervated with a nerve from a fast contracting muscle. Further work has shown that the physiological and morphological characteristics of skeletal muscle were determined by their innervations (Close, 1969; Dubowitz, 1967; Gordon et al., 1988). Although it was believed that the nerve influenced the muscle chemically, Salmons & Vrbova (1969) showed transformation of characteristics of the tibialis anterior and extensor digitorum longus muscles in a rabbit was achieved by altering its pattern of activity.

To achieve muscle adaptability while muscle is in vivo, altered patterns of physical activity are required. A number of physiological changes have been reported when muscles undergo a period of decreased activity (such as immobilisation) (Hortobagyi et al., 2000; Ohira et al., 2006) and increased activity (Trappe et al., 2006; Widrick et al., 2002). Trappe et al. (2006) investigated muscle changes in young healthy adults participating in marathon training. They found an increase in strength in type IIa and an increase in twitch speed in type I muscle fibres. Although it is important to consider changes in muscle fibre types, the purpose of this work is to investigate the effectiveness of progressive resistance exercise on muscle strength and other functional outcomes.

2.1.3 Assessment of muscle strength

Muscle strength is a measure of the amount of the force produced during voluntary contractions (Macintosh et al., 2006). The amount of force exerted can vary depending on how the assessment is conducted and three of the key factors include the type of muscle contraction, length of the muscle during contraction and the velocity of movement.

Muscle strength can be measured during isometric contractions where force is produced against a static external resistance with relatively no change in muscle length (Knuttgen and Komi, 2003). This can give an indication of the muscle's force capacity at a specific length. It can be measured concentrically or eccentrically where there is a progressive reduction or increase respectively in the length of the muscle during the muscle contraction (Amiridis et al., 1996). Cress et al. (1992) evaluated the force generated by the quadriceps muscle during concentric and eccentric actions at varying velocities (between 30-210°.sec^{-1}). Concentric contractions demonstrated progressive decline in maximum force at increasing velocities. Klopfer and Greig (1988) suggested this was potentially due to a reduction in motor unit recruitment whilst Jones et al. (2006) suggested this was due to less cross-bridges being formed at higher velocities. In addition to this, the cross-bridges which are made translate less force as the actin is moving along the myosin in the same direction that it contracts (Jones et al., 2006). Cress et al. (1992) found that eccentric contractions however show no reduction in force at increasing velocities with half of the participants even demonstrating a slight increase. The authors suggested this was due to elastic components in the muscle resisting the increase in muscle length which in turn contributes to the force generated. Jones et al. (2006) also suggested this was due to the increased transfer of force from the myosin head on the corresponding actin filament as it is moving in an opposing direction to the movement of the myosin head. The force produced during isometric contractions is higher than the force producing during concentric but not eccentric contractions. The lack of change in muscle length means there is no loss of cross-bridge formation but equally there is little contribution of the muscle's elastic components to generate force.

The force exerted depends on the length of the muscle as governed by the length-tension relationship (ter Keurs et al., 1978). As force is generated by the formation of cross-bridges between the actin and myosin, the amount of force that can be generated increases with the number of potential cross-bridges that can be formed. The force generated increases as muscles shorten from a lengthened position due to the increase in the number of cross-bridges that can be formed. A decline in force generation is then observed at the shortest muscle lengths, thought to be due to an interaction between adjacent sarcomeres (Jones et al., 2004). Muscle assessment must therefore take into consideration the muscle length at which the measurement of muscle strength was recorded.

Muscle strength is also influenced by the velocity of movement, thought to be due to the biomechanical interactions between actin and myosin (Jones et al., 2004). For concentric contractions, the amount of force generated by muscles reduces with increasing velocity of movement relative to the amount of force generated during isometric contractions. For eccentric contractions, higher velocities generate greater forces until a failure is reached where no force is produced. This occurs when the velocity results in the failure of the actin-myosin cross-bridges to form (Jones et al., 2004).

These above factors therefore influence how muscle strength can be measured. The measurement of muscle strength must be taken into consideration in assessment to appropriately evaluate muscle strength. When evaluating muscle adaptation, the method of measurement will determine what conclusions can be drawn. The following section covers how muscle strength can be increased through exercise.

2.3 Progressive Resistance Exercise

The concept of strength training was introduced by Delorme (1945) who found muscle strength improved by limb movements against physical weights. Strength training or more specifically, progressive resistance exercise is a type of exercise designed to improve muscle strength (Latham et al., 2004; ACSM, 2009). The principle of progressive resistance exercise is to produce dynamic movement through the available range against a resistive load and to repeat these movements over a period of time to achieve an increase in the maximal level of force muscle can produce. The prescription of progressive resistance exercise is guided by the following training parameters:

- **Training Intensity**: The resistive load that is applied is proportional to the maximal resistive load against which the participant can perform the movement. The proportional value that is utilised is defined as the *training intensity*. A key principle of progressive resistance exercise is that as participants become stronger, the resistance used during training is increased so that participants train at the same relative proportion of their maximal load i.e. the same training intensity (ACSM, 2009).
- **Repetitions:** The number of repetitions performed continuously in one set without rest.
- **Sets:** The number of sets of repetitions performed in one session.
- **Training frequency:** The frequency of training is defined as the number of sessions per week (Wernbom et al., 2007).
- **Duration:** The total number of sessions completed over the training period.
- **Total work:** The total external energy produced over the training period. Measured in joules, it is the summation of the total force, distance travelled per repetition and total repetitions completed over the training period.

The training parameters outlined may independently and in relation to each other have an effect on the training stimuli and in turn influence the effectiveness of progressive resistance exercise. The following section examines these parameters in more detail outlining their relevance to exercise prescription.

2.3.1 Training Intensity

In isoinertial training, the amount of load used as resistance against movement is determined from the 1 repetition maximum (1RM), which is the maximal resistance load a participant is capable of moving in one repetition (ACSM, 2000). The load used is a relative percentage of the 1RM load. The percentage of 1RM prescribed is defined as the training intensity. Training intensity can also be defined using the number of repetitions. For example the 6RM defines the maximal resistance load a participant is capable of lifting in six repetitions but no more (ACSM, 2009). In such cases, the intensity is the repetition number used and the load is not apportioned during training.

Norrbrand et al. (2008) theorised that the amount of resistance that is applied is key to achieving the training stimulus for muscle adaptation. They proposed that in order for the level of protein synthesis to exceed the level of protein degradation, participants must produce unaccustomed levels of muscle contraction during the training period.

The intensity of training has a direct influence on the acute physiological response as it determines the relative resistance against movement and thus the level of muscle force produced during the contraction. Higher intensities are associated with greater muscle activation (Komi & Vitasalo et al., 1976).

Higher intensities are generally considered to be above 60% 1RM whilst low intensities are considered to be below 50% 1RM (Schoenfeld, 2013; Raymond et al., 2013). There has been a lot of focus on the amount of relative resistance applied per repetition during progressive resistance exercise. It is well established that applying resistance to movement is more effective than control interventions (such as passive movements) for improving strength (ACSM, 1998) but the optimal training intensity is unclear. The fundamental principle for progressive resistance exercise was to 'overload' the muscle. Without overloading the muscle, it has been hypothesised that not all muscle fibres will be recruited reducing the potential for muscle fibre adaptation and muscle hypertrophy (Delorme, 1945 from Michael, 1998; Kraemer & Fleck, 2007).

There are obvious differences between training at high and low intensity in the amount of mechanical stimuli provided but it is more difficult to determine differences in the metabolic and hormonal stimuli. Robergs et al. (1991) compared glycogen metabolism during and after six sets of training between groups of participants training at high and low intensity (70% 1RM and 35% 1RM). They found at the end of training, although the level of glycogen degradation was similar between protocols (47.0 ± 6.6 mmol/kg wet wt training at 70% 1RM and 46.6 ± 6.0 mmol/kg wet wt training at 35% 1RM), the level of glycogenolysis was double in participants completing the 70% 1RM protocol. Such differences may influence the response to training.

Kraemer et al. (1990) found that participants completing high intensity training (80% 1RM) showed a 100-fold increase in plasma concentrations of growth hormone. However, the same exercise protocol with a 3-minute rest period between sets instead of 1-minute did not demonstrate any change (Kraemer et al., 1990). Takarada et al. (2000) utilised a low intensity protocol (20% 1RM) with a shorter rest period (30 seconds) and evaluated the change in plasma concentrations of growth hormone with and without occlusion. Although there was a 250-fold increase in growth hormone with occlusion, there was no marked difference without occlusion. This indicates high intensity training but not low intensity training effectively increases plasma concentrations of growth hormone in studies utilising progressive resistance exercise without occlusion.

2.3.2 Repetition number

Seynnes et al. (2004) defined the training volume as the number of repetitions completed per set. However, this does not take into account the number of sets completed which contributes to the total number of repetitions completed in each session. Wernbom et al. (2007) defines volume as the total amount of work (in Joules) for a given time period. They noted that as the training intensity utilised during the training period influenced the amount of force produced by the muscles, comparing programmes by the number of repetitions alone was not representative of the volume of training.

For the purposes of this thesis, the training volume will be defined as the total work completed. The training volume can be increased by either increasing the number of repetitions per set, the number of sets completed per session, the total number of sessions completed or by increasing the intensity of training (Lorenz et al., 2010).

2.3.3 Total Work

Whilst training intensity can be an indirect measure of the amount of relative force generated, it does not encompass the total energy exerted by muscles during the training period. The number of repetitions completed, the range of movement and the velocity of movement may also affect the amount of contractile force produced by muscles during the training period.

Isoinertial training, in which resistance is applied using an external weight (Frost et al, 2010), involves dynamic movement against a fixed external mass. The actual force produced by muscles is not constant through the range due to the acceleration and deceleration phases of dynamic movements (Lander et al., 1985). Cronin et al. (2003) reported the acceleration phase lasting between 64% and 83% for loads of 30% 1RM and 80%1RM respectively. Given that muscle activity subsides (seen by reductions in agonist activity) during deceleration phases (Elliott et al., 1989) and given the isoinertial properties of physical mass, the actual force produced by muscles may be affected by the biomechanics of dynamic resisted movements. The amount of force produced is also influenced by the joint range over which the resistance is moved (Cheng and Rice, 2013). As participants begin to fatigue, they may lose the ability to produce contractions through the full available joint range (Cheng and Rice, 2013), which in turn would result in less work completed.

This raises the importance of measuring total work during training. The external work produced is a summation of the total force exerted over the range of the movement.

It can be viewed as an encompassing measurement for training intensity and the number of repetitions, sets and sessions completed as it is dependent on the amount of force applied over the range and number of repetitions completed. It can also be measured as a relative value by multiplying the intensity of training by the number of repetitions completed per session. High intensity training at 80% MVC would theoretically achieve double the work per repetition compared to training at 40% MVC, assuming the acceleration and deceleration phases are equal. Studies favouring high intensity training over low intensity training (Seynnes et al., 2004) have not appreciated that the difference in outcomes could be a result of the higher intensity group completing more total work (Wernbom et al., 2010). Therefore, evaluating the influence of intensity when the total work is matched and when the total repetitions is matched is necessary to elucidate the factors which are responsible for the response to training.

The total work completed during training has been considered by a number of authors when evaluating the results following intensity differentiated progressive resistance exercise (Holm et al., 2008; Mitchell et al., 2012; Ogasawara et al., 2013). However, aside from the protocol parameters utilised, reference to the actual work completed has not been reported. This could have been due to the difficulties in the measurement of total work using conventional resistance equipment. Finni et al. (1998) used an optic fibre, which was inserted into the muscle tendon, to directly measure the force exerted by muscle. However, this is an invasive technique that may affect muscle mechanics making it difficult to draw conclusions. Computational models have also been considered (Erdemir et al., 2007) but these essentially only provide an estimate of muscle force. Due to the difficulties in its measurement, total work has scarcely been reported in literature evaluating the effectiveness of progressive resistance exercise. Without this, it is difficult to elucidate the influence and interplay between training parameters on the effectiveness of progressive resistance exercise. The aim of this thesis is therefore to develop protocols which can measure total work.

2.4 Influence of Intensity and Volume on Effectiveness of Progressive Resistance Exercise

One of the first studies to evaluate the effect of training parameters was conducted by Berger (1962). Berger (1962) compared outcomes in six training groups differentiated by the intensity of training (2RM – 12RM) and found training at 4RM, 6RM and 8RM more effective compared to training at 2RM, 10RM or 12RM. Studies following this reviewed the effect of total repetitions (typically differentiating the number of sets completed) on the effectiveness of progressive resistance exercise (Carpinelli & Otto, 1998; Feigenbaum and Pollock, 1999). Carpinelli & Otto (1998) reviewed 16 studies which compared training groups completing 1 training set per session against training groups completing 3 sets. Only two studies found a significant difference between training groups favouring the higher set protocol whilst the others found no significant difference between training groups. However, Rhea (et al., 2002) cites that many of the earlier studies reviewed recruited a small number of participants. In order to compare interventions, particularly those which are similar, the sample size required to reach power is much greater (Wittes, 2002).

In 2002, the American College of Sports Medicine (ACSM) published guidelines on the optimum training parameters for progressive resistance exercise. For healthy adults they recommended a minimum of 1 set of 8-12 RM for 2-3 days per week. Further to this, for novice individuals they recommended training at 8-12 RM whilst intermediate and advanced individuals should train at 1-12 RM in a periodised fashion. These guidelines were updated in 2009 (ACSM, 2009) with additional detail for achieving specific goals: muscle hypertrophy, power and endurance. However, the guidelines published by the ACSM have been criticised (Carpinelli et al., 2004; Carpinelli, 2009). Carpinelli (2009) argues that a number of prescription guidelines were inaccurate due to inappropriate use of evidence. For example, the claim that training at an intensity of 80% 1RM is required for neural adaptation in experienced lifters was based on a single study (Hakkinen et al.,1985) that recruited a low number of participants (n = 11) and varied intensity of training throughout the programme. The issues raised by Carpinelli (2009) identified the need for detailed evaluation of evidence to assess the influence of intensity and volume on the effectiveness of progressive resistance exercise. However, they do indicate that optimal parameters for progressive resistance exercise may be population dependent.

This is also supported by Rhea et al. (2003) who conducted a meta-analysis of 140 studies on the optimal training parameters. They reported effect sizes separately for untrained and trained individuals and recommended training at 60% 1RM, 4 sets a session (per muscle group).Three days per week was found to be optimal for untrained individuals whilst utilising a higher intensity (80% 1RM), at a lower frequency (2 days per week) showed the greatest effect sizes in trained individuals. This indicates training at a lower intensity for more repetitions (and therefore potentially an equal amount of total work) is optimal for untrained individuals. However, without incorporating the total number of repetitions and total work into the analysis, it's difficult to ascertain the contribution of individual parameters on the effectiveness of progressive resistance exercise.

This meta-analysis was followed up by Peterson et al. (2004) from the same team who published meta-analysis of 177 studies on the optimal training parameters for untrained, recreationally active and athletic populations. In untrained populations, they found training at 60% 1RM for 4 sets per muscle group 3 days per week elicited the greatest strength gains. However, again the total number of repetitions per set and thus the total number of repetitions completed over the training protocol was not considered as part of the analysis. Thus it is uncertain whether a higher number of repetitions coupled with a lower intensity was more effective than training a high intensity for a lower number of repetitions. If it is, this is possibly due to an equivalent volume being completed.

Wernbom et al. (2007) conducted a meta-analysis on the influence of training parameters (specifically intensity, repetitions, frequency and mode of training) on muscle hypertrophy (muscle cross sectional area). To compare studies of different duration, they calculated the mean increase in cross sectional area per day (%). Most of the studies (44 in total using isoinertial resistance to dynamically train the quadriceps muscle) evaluated trained participants at high intensity (>60% 1RM). Although it was concluded that moderate to high intensity training elicited the greatest changes in muscle cross-sectional area, only three studies were included that utilised a training intensity of less than 50% 1RM. Also, one of these studies achieved an increase in cross-sectional area of 0.75% per day (estimated from graphical data); equivalent to the changes observed in studies utilising high intensity training which makes the evidence equivocal. Low intensity may therefore be as effective as high intensity training for eliciting changes in muscle hypertrophy. The article addresses the importance of looking at other assessment outcomes to evaluate muscle adaptation, not solely muscle strength. It also draws attention to the lack of experimental studies utilising low intensity for training.

There were only two reviews that included only studies which utilised multiple training groups differentiated by the intensity and repetitions (Steib et al., 2010; Raymond et al., 2013). They reviewed the effects of progressive resistance exercise in the older adult population. In order to evaluate progressive resistance exercise, the following sections review the primary evidence by population type. Deschenes and Kraemer (2002) reported classifying training status is important as the potential for muscle adaptation may decline as participants' progress during training programmes. The growing body of literature on progressive resistance exercise for trained/athletic individuals and athletes has focused on training for specific effects in performance in sport (Peterson et al., 2004). This literature review will focus on the effectiveness of progressive resistance exercise for sedentary individuals to inform the basis of progressive resistance exercise for rehabilitation.

2.4.1 Influence of Training Intensity and Repetitions on the Effectiveness of Progressive Resistance Exercise in healthy sedentary individuals

Table 2.1 shows studies that have utilised progressive resistance exercise and compared outcomes between multiple training groups differentiated by intensity/repetitions in 'sedentary' individuals. The age of participants, their training status, type of exercises utilised and training parameters set were all noted to indicate the variances in methodology between studies. Due to this variance, it is difficult to determine the effectiveness of progressive resistance exercise through comparison of studies. On the other hand, studies which have matched training groups may better inform optimal training parameters as characteristics between training groups would be homogenous. The following section provides an indication of the effectiveness of progressive resistance exercise in this population.

Table 2.1. Sampled population, training status, training methodology and parameters of studies evaluating PRE in healthy sedentary

Author	Age	Training status	Design	Limbs trained	Exercises	Assess Method	Intensity	No. Session	Sets. session^{-1}	Reps.set^{-1}	Muscle strength/CSA (%Δ)
Campos et al. 2002	22.5 ± 5.8	No participation in regular exercise programme for at least 6 months	RCT	Lower limb	Leg press, squat, knee extension	1RM	3-5RM 9-11RM 20-28RM	20	4 3 2	Until repetition failure	13-20% 13-20% 5-17%
Neils et al. 2005	23.2 ± 2.9	3 months prior training experience	RCT	Both	Bench press, bicep curl, tricep ext, leg ext, leg curl, squat	1RM	50% 1RM 80% 1RM	24	1	6-8	9.1% 8.6%
Lerger et al. 2006	36 ± 4.9	No more than 12 months participation in resistance training	RCT	Lower limb	Leg press, squat, knee extension	1RM	3-5 RM 20-28RM	20	4 2	Until repetition failure	10% 10%
Candow et al. 2007	43 ± 2.7	No prior participation in resistance training	RCT	Lower limb	Bench press, squat, pull down, knee ext/flex, seated row	1RM	60-90% 1RM 69-90% 1RM	18 18	2 3	10 10	29% 28%
Holm et al. 2008	25 ± 1	No participation in sports for more than once a week	Quasi-experimental	Lower limb	Isolated knee extension	1RM	15.5% 70%	36	5 5	36 8	19% 36%
Mitchell et al. 2012	21 ± 1	No formal weightlifting experience or regular weightlifting activity for past year	Quasi-experimental	Lower limb	Isolated knee extension	Peak torque	30% 80% 80%	30	3 3 1	Until repetition failure	27% 36% 29%
Schuenke et al. 2012	21.1 ± 2.7	No participation in exercise at least 6 months prior to the start	RCT	Lower limb	Leg press, squats knee extensions	1RM	40-60% 80-85%	17		20-30 6-10	38.8%
Ogasawara et al. 2013	25 ± 3		Quasi-experimental	Upper limb	Bench press	1RM	30% 75%	18	4 3	Repetition failure 10-12	6.5% 13.9%

Ext – extension; Flex – flexion; CSA – Cross-sectional area

Campos et al. (2002) evaluated the effect of low intensity (20-28 RM) and high intensity (3-5 RM) training on muscle cross-sectional area in untrained males. The repetition maximum of 20-28 RM indicates the load used was determined as the load at which participants fatigued between 20-28 repetitions. The high intensity group showed significant improvements in muscle cross-sectional area for all muscle fibre types whilst changes in the low intensity group did not reach significance. Using the same training protocols, Leger et al. (2006) also evaluated the effect of low intensity and high intensity on muscle cross-sectional area in untrained (less than 1 year participation in resistance training) participants. In contrast, both groups showed a 10% increase in muscle cross-sectional area and differences between groups were not significant. Leger et al. (2006) noted that participants were older than those reported in Campos et al. (2002) and may be of a different training status.

Neils et al. (2005) evaluated outcomes between one group performing super slow contractions (90-120 seconds per set) and another performing fast contractions (20-45 seconds per set). Although the main purposes of the study was to assess whether velocity has an influence on outcomes, differences in the intensity of training (50% 1RM for slow contraction training group and 80% 1RM for fast contraction training group) may have had an additional effect on the effectiveness of progressive resistance exercise. They found both groups demonstrated similar changes in muscle 1RM for the bench press (8.6% and 9.1% for low and high intensity groups). As both groups completed the same number of repetitions (one set of 6-8 repetitions per exercise), the theoretical total work completed would have been almost double in the high intensity group. On the other hand, as the low intensity group performed contractions slower, the time that the muscle was under tension would have been greater than the low intensity group thus increasing total work. Without total work being reported, it is difficult to know whether the similarities in outcome were as a result of the two groups completing the same amount of work.

Candow et al. (2007) compared outcomes following six weeks of progressive resistance exercise between groups of untrained individuals (no prior participation in resistance training). The first group trained for two sets per session three days per week and the second group three sets per session three days per week. Both groups trained at an intensity of 60-90% 1RM and in order to train participants to fatigue, they were instructed to select an intensity such that they began to fatigue at the end of the training set. Despite one group completing more sets per session and therefore a higher amount of work over the training period, there was no difference in outcomes between groups. This could be due to the lower repetition group training at a higher intensity as they would generally require a higher intensity to reach fatigue over a smaller number of repetitions. However, without reporting the intensity of training or the total work completed, differences between groups with respect to outcomes against the training performed are unclear.

Holm et al. (2008) employed a within subject design to evaluate the influence of intensity on muscle cross-sectional area when participants were trained at 70% 1RM on one limb and 15.5% 1RM on the opposite limb in sedentary males. Participants completed 8 repetitions per set for the high intensity protocol and 36 repetitions per set for the low intensity protocol. Muscle strength (1RM) increased significantly in both groups but was significantly higher ($p < 0.001$) in the high intensity group (36% ±5% in high intensity vs. 19% ±2% in low intensity).

It could be argued that a within-subject design may better extrapolate the influence of training parameters on the effectiveness of progressive resistance exercise due to the inter-individual variability in the training response. However, there is evidence to suggest that neuromuscular adaptations in trained muscle (Carroll et al., 2001) can translate to the contra-lateral limb observed as an increase in voluntary force and neural activation (Farthing, 2009). Therefore employing a within subject design may incorporate cross-education between limbs (Howatson et al., 2013) making it difficult to evaluate the influence of intensity.

Similarly, Mitchell et al. (2012) also employed a within subject design. Eighteen recreationally active (but with no experience of resistance training) males participated in a unilateral leg training programme for 10 weeks (3 times per week). Each leg was assigned to one of three training conditions: a) one high intensity set (80% 1RM) until repetition failure b) three high intensity sets (80% 1RM) until fatigue and c) three low intensity sets (30% 1RM) until fatigue. Following training, muscle cross-sectional area and isometric strength improved significantly in all groups but were not different ($p = 0.92$). Despite there being no differences between groups for the change in isometric strength, isotonic strength was significantly higher in the high intensity 1-set and 3-set groups ($p = 0.04$). As the training was isotonic, changes in dynamic muscle strength for the high intensity group may have been over-estimated as it was similar to the muscle assessment. Therefore, the isometric outcomes may provide an indication of the effects of training muscle without the effects of previous practice.

Schuenke et al. (2012) evaluated changes in muscle cross-sectional area and fibre type in two groups of untrained females. The first completed 20-30 repetitions at 40-60% 1RM and the second completed 6-10 repetitions at 80-85%. After six weeks the high intensity group demonstrated significant increase in cross sectional area for all three fibre types whilst the low intensity group did not demonstrate significant changes. These results are contradictory to Mitchell et al. (2012) who found similar changes between low intensity and high intensity training where the low intensity group completes more repetitions.

Ogasawara et al. (2013) also compared training between high (75% 1RM) and low (30% 1RM) intensity in a within-subject design but for the upper limbs. All participants completed the high intensity protocol first and then the low intensity protocol 12 months later. The high intensity group completed 3 sets of 10 repetitions whilst the low intensity group completed 4 sets until volitional fatigue. The high intensity group (13.9%) demonstrated almost double the percentage change ($p < 0.05$) than the low intensity group (6.5%). Although a period of 12 months was elapsed between starting the next training protocol, participants' strength had not returned to baseline values. This may have independently affected the response to training. Ogaswara et al. (2013) noted that it was possible that some participants may have changed their daily activities following participation in the first protocol. Hence, participants may have presented as a more active population following participation in the first protocol.

In sedentary participants, the differences between high and low intensity training where the low intensity group completes more repetitions and theoretically an equal amount of work remain unclear. Some studies have found no difference between groups training at a different intensities (Leger et al., 2006; Neils et al., 2005; Mitchell et al., 2012;) whilst others favoured high intensity training (Campos et al., 2002; Holm et al., 2008; Schuenke et al., 2012; Ogasawara et al., 2013).

There are distinct differences between studies in the populations used due to their definition of inactive or sedentary individuals. Firstly, despite being titled 'Untrained Individuals', Neils et al. (2005) selection of participants required them to have reported at least 3 months of previous resistance training experience. They noted that early changes following training in sedentary individuals were solely attributable to neuromuscular adaptation. Rather, they wanted to investigate comparisons following early adaptation. However, it can be argued that neuromuscular changes are a component to the changes in strength following progressive resistance exercise and must be reported as part of outcomes.

With the exception of Neils et al. (2005), other studies used sedentary individuals by selecting criteria that limits participants according to the following criteria:

- Leger et al. (2005) selected participants who had not participated in a resistance-training programme for more than 12 months. However, it was noted that subjects were physically active.
- Mitchell et al. (2012) selected participants who had no formal weightlifting experience or regular weightlifting activity for the past year.
- Holm et al. (2008) selected participants on the basis that they had not participated in any sports more than once a week.
- Schuenke et al. (2012) reported participants had not participated in exercise at least six months prior to the start.
- Ogasawara et al. (2013), Campos et al. (2002) reported that participants were previously untrained but did not have a specific selection criterion.

The definition of sedentary/untrained populations is inconsistent between studies. Leger et al. (2005) and Mitchell et al. (2012) defined sedentary through the exclusion of participants with a long history of participation in resistance training. However, given that a response to resistance training is observed after just a few sessions (Patten et al. 2001), they may not have successfully recruited participants of the same training status with these criteria. Although Holm et al. (2008) selected participants on the basis that they had not participated in sports for more than once a week, participants' daily activities were not considered as part of the selection criteria. Thus they may have recruited participants who were active, as part of their daily life, as opposed to participating in sport, which in turn may have contributed to recruitment of participants that were not homogenous in terms of training status. As previously noted, given that optimal training parameters vary between untrained and trained populations (Rhea et al., 2003), consideration must be given to ensuring population selection criteria ensure recruitment of a homogenous population.

Three of the studies used a within-subject design to assess the influence of intensity on outcomes (Holm et al., 2008; Mitchell et al., 2012; Ogasawara et al., 2013). To minimise the effects of limb dominance, half of the participants in Holm et al. (2008) completed the low intensity protocol on the dominant limb whilst the other half completed the high intensity protocol on the dominant limb. Despite this, the order of training was not taken into consideration as an additional factor. Although an equal number of participants in Holm et al. (2008) completed the high and low intensity protocol in the dominant limb; the order in which the training was performed (dominant limb or non-dominant limb first) was not reported. The order of training may have had an additional effect on the training response.

Mitchell et al. (2012) ensured that each limb assigned to one of the three conditions in a counterbalanced fashion. Although this may have minimised the effects of limb dominance on the response to training, the order in which the limbs were trained may not have been accounted for. In Ogasawara et al. (2014), all participants completed both protocols with a 12 months break between protocols. However, given that the high intensity protocol was completed first and that participants' strength had not returned to baseline, the effect of prior experience in resistance training remained when the participants completed the low intensity protocol 12 months later.

In some studies, participants were instructed to perform to repetition failure/fatigue or participants were instructed to train at an intensity range. As the intensity or total repetitions were not recorded nor the total work completed during the training period, it is difficult to extrapolate the influence of training parameters on the effectiveness of progressive resistance exercise. In addition, differences in training status and study design between studies also make it difficult to interpret outcomes. There is a separate body of literature focusing on healthy elderly participants. The optimal outcomes for this population may differ in this population and therefore these studies were also reviewed.

2.4.2 Influence of Training Intensity and Repetitions on the Effectiveness of Progressive Resistance Exercise in healthy elderly

Given that the dose-response relationship may be population dependent, the influence of training intensity and number of repetitions has been examined separately for populations of different training status, age and medical condition. Steib et al. (2010) conducted a meta-analysis on studies utilising progressive resistance exercise in healthy elderly participants. They evaluated the effect size of 22 studies that utilised multiple training groups that were differentiated by training intensity and found high intensity training was slightly favoured over low intensity (total effect size = 0.88, 95% CI = 0.21, 1.55). However, the effect of repetitions completed or the training volume was not taken into consideration.

In a later review, Raymond et al. (2013) conducted a similar meta-analysis but on a wider variety of variables including flexibility, falls and quality of life. They also found high intensity was favoured over lower intensity for muscle strength (total effect size = 0.83, 95% C.I. = -0.02, 1.68) but not other measures. However, this study also reported relative volume by multiplying the intensity by the total repetitions. Despite concluding high intensity training being more effective than low intensity training, they found studies where the low intensity group completed equivalent-training volumes found similar improvements in leg strength compared to the high intensity group. This supports that the total volume rather than the intensity to be the contributing factor in eliciting muscle strength improvements. Experimental studies utilising multiple training groups were evaluated below in order to elucidate the effect of training intensity, repetitions and volume.

Hortobagyi et al. (2001) trained two groups of participants (high intensity – 80% 1RM; low intensity – 40% 1RM) 3 times a week for 10 weeks. The high intensity group completed 4-6 repetitions whilst the low intensity group completed 8-12 repetitions. No significant difference was found between the high (37%) and low (30%) intensity group for change in strength. Vincent et al. (2002) compared two training groups (n=18 in total) completing 24 weeks of training, 3 sessions per week. One group trained at 50% 1RM for 1 set of 13 repetitions and the other at 80% 1RM for 1 set of 8 repetitions. Again, there was no difference in the change in leg extension strength between the high intensity (15%, $p < 0.05$) and low intensity (11%, $p < 0.05$) group.

Seynnes et al. (2004) evaluated the influence of intensity in two groups of frail elders, the first training at high intensity (80% 1RM, n=8) and the other at low intensity (40% 1RM, n=6). Although both groups improved knee extension muscle strength significantly (57% ± 4.8% and 37% ± 5.9%, $p<0.001$), the high intensity group showed greater change ($p<0.001$). As both groups completed the same training volume, defined here as the total number of repetitions per set, differences between groups may have resulted from the higher intensity group completing more work.

Beneka et al. (2005) trained participants for 16 weeks, 3 times per week, utilising multiple knee extension exercises. The low intensity group (50% 1RM) completed almost double the repetitions per set (12-14) than the high intensity group (90% 1RM) which completed 4-6 repetitions per set. Contrary to Hortobagyi et al. (2001), they found the changes in the high intensity group (11.2% in males and 15.2% in females) were significantly greater than the changes in the low intensity group (3.7% in males and 3% in females). However, the percentage change in the high intensity group was half of what was observed by Hortobagyi et al. (2001). Fatorous et al. (2005) trained participants for a much longer period (24 weeks) utilising multiple exercises for the upper and lower limb muscle groups. They found much larger changes in muscle strength (1RM of the leg press) compared to the previous studies (63% for the high intensity group and 43% for the low intensity group) but contrary to Hortobagyi the changes in the high intensity group were significantly greater ($p < 0.05$). In a later study Fatorous et al. (2006) also reported the changes in flexibility of the participants in the training programme.

There could be several reasons for why high intensity was significantly more effective than low intensity training in three studies but not in the others. The first is the differences in population sampling between studies as Beneka et al. (2005) and Fatorous et al. (2005) selected participants who were below the VO_2 threshold of 25 ml/kg/min. These participants demonstrated limited aerobic capacity which could be due to limitations in cardiac output, pulmonary effusion and blood flow (Bassett & Howley, 2000). These participants may therefore have impaired exercise performance as a result of a lower lactate threshold (Wilmore & Costill, 1999). The response to exercise may differ as a result, which indicates that high intensity is favoured in participants with a limited aerobic capacity.

Secondly, it is unknown whether the differences in outcomes were a result of the high intensity group completing more work during the training period. This is supported by Raymond et al. (2013) who found low intensity training resulted in similar changes compared to high intensity training when the low intensity group completed equivalent volumes. Both Hortobagyi et al. (2001) and Vincent et al. (2002) used equivalent training volumes between high and low intensity groups, according to Raymond et al. (2013).

In addition to this, there is scope for evaluating the influence of intensity in the short term (less than 6 weeks) where improvements in strength are due to changes in neuromuscular activation rather than hypertrophy. Over a short period, with protocols that are matched for work, by having the low intensity group completing more repetitions, low intensity training could be as effective as high intensity training.

The optimal parameters for progressive resistance exercise may also differ in neurological populations such as stroke, where the underlying condition may affect the response to training. This is reviewed in the next section.

2.4.3 Progressive Resistance Exercise in Stroke

Populations with specific impairments may also demonstrate different responses to progressive resistance exercise depending on the parameters utilised. Stroke causes damage to neurons in the brain either by haemorrhage or ischemia. Damage to neurons from the motor cortex responsible for producing movement causes loss of function (Darling et al., 2011). The disability resulting from stroke varies between survivors depending on the location and size of the damage (Darling et al., 2011) and may be influenced by the amount of recovery following stroke. Loss of motor function is a predominant impairment in stroke (Wade, 1992).

The main aims of stroke rehabilitation in Physiotherapy are to reduce the effects stroke has had on functional ability. Interventions aimed to reduce impairments may contribute to recovery of function. In addition, impairments themselves may have an effect on confidence in functional activities (Ouellette et al., 2004). Evaluating the effectiveness of progressive resistance exercise on muscle strength is important in stroke due to the muscle impairments stroke survivors present with as well as the association between muscle impairment and activity. The primary aim of progressive resistance exercise is to increase strength and the following section reviews studies using progressive resistance exercise in isolation, with muscle strength as a primary outcome measure in order to elucidate the sole effects of progressive resistance exercise.

Five systematic reviews have examined the effectiveness of progressive resistance exercise in stroke survivors (Saunders et al., 2004; Morris et al., 2004; Ada et al., 2006; Lexell & Flansbjer, 2008; Saunders et al., 2013). Saunders et al. (2004) conducted a review of the effects of physical fitness training on stroke survivors. The focus of their review was the effectiveness of cardio respiratory training; studies included those that incorporated cardio respiratory training and progressive resistance exercise together and therefore the effectiveness of progressive resistance exercise as a single intervention was not differentiated. In a later update of the review (Saunders et al., 2013) the effects of resistance training as a single intervention were inconclusive due to the lack of sufficient trials that met their criteria. Morris et al. (2004) evaluated studies that utilised progressive resistance exercise in isolation. Of the 350 articles, eight articles met the inclusion criteria five measured changes in muscle strength and showed large effect sizes (d = 1.2-4.5). However, these studies varied considerably in the populations' time since stroke, sample size and muscles trained.

Due to the decrease in muscle cross sectional area (Ryan et al., 2002) and muscle activation (Hara et al., 2000) in chronic stroke (> 6 months), the response to training may differ between acute and chronic stroke survivors. Later reviews presented the evidence for the effectiveness separately for acute and chronic stroke survivors as well as the level of strength (above or below grade 3 in oxford scale) (Ada et al., 2006). Ada et al. (2006) reported the effect sizes of studies with acute (less than 6 months following stroke) and chronic participants as well as very weak (lack of full range of movement against gravity) and weak participants separately. They found differences in the effect size between these four categories. However, splitting the studies in this way resulted in there being a small number of studies in each category. Lexell and Flansbjer (2008) conducted a systematic review of the effectiveness of progressive resistance exercise in stroke but these were limited to studies that utilised progressive resistance exercise at an intensity of 70% or more. Previous reviews have shown that progressive resistance exercise can be effective at improving muscle strength and activity in stroke survivors. However, the potential effects of training parameters on outcomes have seldom been cited. Further evaluation of experimental studies was conducted to determine whether there are indications of a differential response.

Examining the experimental studies utilising progressive resistance exercise in stroke survivors, considerable variability is observed in the training regimes utilised. This may account for the differences in the outcomes following progressive resistance exercise. This is demonstrated in the table below. Table 2.2 shows the sampled population, training status as well as the methodology of studies evaluating progressive resistance exercise in isolation for chronic stroke survivors. Of the studies evaluating progressive resistance exercise in stroke participants: 3 studies trained participants on the isokinetic dynamometer at varying speeds (Engardt et al., 1995; Sharp & Brouwer, 1997) or at a single speed to a number of muscles (Kim et al., 2001); 2 studies trained participants using gym equipment (Teixeira-Samela et al., 1999; Cramp et al., 2006); and 2 studies used pneumatic resistance to train participants (Ouellette et al., 2004; Flansbjer et al., 2008). Ouellette et al. (2004) and Flansbjer et al. (2008) who both used pneumatic resistance to train participants, had similar inclusion criteria, recruited participants of similar baseline strength, trained participants for a similar duration and utilised similar training intensities found very different changes in the magnitude of change. Stroke participants in Flansbjer et al. (2008) achieved much higher changes in knee extension strength despite a lower theoretical work being completed (arbitrary work of 256) compared to Ouellette et al. (2004). However, without reporting of the total work completed by participants, it's difficult to ascertain whether stroke survivors in Ouellette's study completed more work.

Due to the differences in the sampled population, training methods used and baseline strength and duration of training, it is difficult to determine the influence of intensity and volume from meta-analysis. In addition, no studies have reported the total work completed over the training period. Overall, the available evidence shows that strength training has a positive effect in improving muscle strength after stroke, but it has been suggested that an optimal training intensity and volume have yet to be determined (Ada et al, 2006). There are a multitude of differences in the training parameters including the: intensity, velocity, volume, frequency. In addition to this, the type of exercises employed, the equipment used to deliver resistance and the baseline characteristics of participants vary between studies. Therefore it is not possible to draw definitive conclusions on the influence of intensity and volume on the effectiveness of progressive resistance exercise. Comparing training groups that are differentiated by the intensity and volume of training but matched for the total work completed over the training period may elucidate the influence of these parameters on the effectiveness of progressive resistance exercise.

Table 2.2. Sampled population, training status, training methodology and parameters of studies evaluating PRE in Stroke

Author	Stage of Stroke	Training status	Limbs trained	Type of Training	Exercises	Assess Method	Baseline KE torque (N·m)	Intensity	No. Session	Sets. $session^{-1}$	Reps. set^{-1}	Muscle strength (%Δ)	Gait velocity (%Δ)
Engardt (1995)	Chronic	Ambulatory with or without assistive devices	Paretic LL only	Concentric isokinetic	KE/KF	Isokinetic 60°/s	62.4	MVC	12	3 to 15	10	19.6*	12.3
	Chronic			Eccentric isokinetic	KE/KF	Isokinetic 60°/s	61.8	MVC	12	3 to 15	10	26.8*	3.7
Sharp (1997)	Chronic	Independent ambulators (min 12 m)	Paretic LL only	Concentric isokinetic	KE/KF	Isokinetic	15	MVC	18	3	6 to 8	16.7*	5.3
Teixeira-Samela (1999)	Chronic	Independently ambulatory for 15 minutes & 45 minute tolerance for physical activity	Both LL	Conven-tional	Isometric, concentric, eccentric	Isokinetic 60°/s	192.09	80% 1RM	30	3	10	42.3*	26.9
Kim (2001)	Chronic, >50 years old	Independently ambulatory for 40 meters, 45 minute tolerance for physical activity	Paretic LL only	Concentric isokinetic	KE/KF, Hip Ext/Flex, Ankle DF/PF	1RM	-	MVC	18	3	10	50	8.9
Cramp (2006)	Chronic (6-12 months)	Community dwellers, independently ambulatory	Both LL	Conven-tional	KE, HIP Abd/Ext, Squats	1RM	88	50% 1RM	24	3	10	32*	16 (estimated)
Ouellette (2004)	Chronic, >50 years old	Residual weakness, community dwelling, independently ambulatory, >1 limitation in PF10 of medical outcomes survey	Both LL	Pneumatic	Leg press, KE, Ankle PF	1RM	41.5	70% 1RM	36	3	10	33.5*	-1.5
Flansbjer (2008)	Chronic, 40-70 years	>15% reduction in muscle strength in paretic limb, independent ambulators for 200m, able to independently move joint	Both LL	Pneumatic	KE/KF	1RM	41	80% 1RM	20	2	8	53.9*	10

Concentric/Eccentric isokinetic – Concentric/Eccentric contractions at constant speed; Conventional –Resistance equipment such as free weights, fixed movement machines; Pneumatic – Fixed movement machine which provides resistance to movement using pneumatic air pressure. LL – lower limb; KE – Knee extension; KF – Knee flexion; Ext – Extension; Flex – Flexion; Abd – Abduction; DF – Dorsiflexion; PF – Platerflexion; 1RM – 1 Repetition Maximum. *$p<0.05$

2.5 Summary

It is well established that muscle strength improves following progressive resistance exercise. However, outcomes vary considerably between studies. The variation may be due to many factors of which the training parameters utilised in the delivery of progressive resistance exercise is of particular interest. The training stimulus of muscle adaptation is not fully understood and research has focused on the influence of training parameters such as the intensity (relative resistance) and volume (total work) on the effectiveness of progressive resistance exercise.

In healthy young sedentary participants, there is conflicting evidence on the influence of intensity and volume on the effectiveness of progressive resistance exercise. With the evidence of the influence of training status on outcomes, differences between studies and the general limitations in the definition of a sedentary population may have contributed to the conflicting results. Population sampling may also have been a reason for conflicting results in the studies on older adults. In both bodies of literature, total volume has not been reported and therefore it is unknown whether the differences in outcomes between groups training at a differentiated intensity are a result of the higher intensity group completing more work. It is also unclear whether participants trained at the intensity as specified by the protocol. In a stroke population, there have been no studies using multiple training groups differentiated by intensity and/or volume. Given the variability in training modalities, and parameters between studies, it is difficult to assess the influence of a single training parameter on the effectiveness of progressive resistance exercise.

To fully understand the influence of training parameters on the effectiveness of progressive resistance exercise, training performance needs to be considered. Without measuring training performance, it is not known whether all participants completed the regime specified by the training protocol. Therefore, as part of this thesis, training protocols were evaluated to determine whether training can be performed at a differentiated intensity and volume whilst being matched for the total work completed.

3.0 Development of Three Sub-maximal Isokinetic Training Protocols Differentiated By Training Intensity and Volume

3.1 Introduction

The literature review presented evidence that muscles are adaptable to demands placed on it. In summary, following progressive resistance exercise, skeletal muscles undergo neural and physiological adaptations that increase the maximal voluntary force generated by the muscle. The training parameters, namely the training intensity, repetitions and total work are important considerations for developing training protocols that can effectively strengthen skeletal muscle.

A number of meta-analyses have shown that the degree of change may be influenced by the training parameters utilized during progressive resistance exercise (Rhea et al., 2002; Peterson et al., 2004; ACSM, 2009; Wernbom et al., 2007). There is conflicting evidence on the optimal training parameters for progressive resistance exercise in healthy sedentary (Campos et al., 2002; Neils et al., 2005; Schuenke et al., 2012) and healthy older adults (Steib et al., 2010; Raymond et al., 2013). Training at a high intensity (80% of 1RM) has shown to be more effective than training at a low intensity (40% of 1RM) when both groups complete the same number of repetitions per set and sets per session (Seynnes et al., 2004). Wernbom et al. (2007) argued that a higher amount of work is completed per repetition when training at higher intensities compared to lower intensities. The higher work achieved may be responsible for the greater outcomes observed rather than training intensity. Theoretically, given that work is the integral of force and distance (Luna et al., 2012), training at an intensity of 80% should achieve double the total work compared to training at 40% over the same distance travelled. Therefore, in order to match the total work between high and low intensity training protocols, the lower intensity protocol must be completed for more repetitions. When the total work is theoretically matched between training groups, similar outcomes have been reported between high and low intensity training protocols (Hortobagyi et al., 2001; Vincent et al., 2002).In a sedentary population, the results are conflicting. Some studies have found no difference between groups training at different intensities (e.g. Leger et al., 2006; Neils et al., 2005; Mitchell et al., 2012) whilst others favoured high intensity training (e.g. Campos et al., 2002; Holm et al., 2008; Schuenke et al., 2012; Ogasawara et al., 2013). Lerger et al. (2006) found no significant difference in high intensity training (3-5RM) compared to low intensity training (20-28 RM) where the low intensity group completed more repetitions. Mitchell et al. (2012) compared high intensity (80% 1RM) training with low intensity training (30% 1RM). As the training was performed to repetition failure, it is expected that the low intensity group would have completed more repetitions per set compared to the high intensity training leading to equivalent training volumes between groups. However, they found high intensity training was favoured contradicting Lerger et al. (2006). Total work was not reported and it is difficult to ascertain whether the total work achieved in the low intensity group was equivalent to the total work achieved in the high intensity group, particularly as the repetitions were completed until repetition failure. In order to ascertain the influence of training intensity on the effectiveness of progressive resistance exercise, outcomes must be evaluated when the low intensity training is delivered equivalent to the total work completed in high intensity training as well as when both groups complete the same number of repetitions over the training period. These studies highlight the inconsistencies in outcomes between high and low intensity training when the total work is matched and there has been limited reporting of training performance.

In order to measure work, the forces exerted by muscles during the resisted contractions must be measured (Finni et al., 1998). In dynamic manoeuvres, the distance travelled is also a factor in the total amount of force that is produced by muscles (Hislop & Perrine, 1967). Muscles would complete more work if the dynamic contractions were completed over a larger range of movement. Therefore, the range of movement for each manoeuvre completed must also be standardised. The majority of previous studies have used isoinertial training to administer progressive resistance exercise. As isoinertial training uses an external weight to deliver the resistance against movement, the relative forces produced by muscles during contraction and therefore the intensity of training is difficult to record. Participants may also produce higher forces at the beginning of the range to generate momentum in order to successfully complete the repetition although previous authors have attempted to control for this by limiting the time of each repetition (Beneka et al., 2005). Fatigue may also affect performance. This could be represented as a change in the velocity or the range of movement, which directly affects the amount of work performed by the muscles (Cronin et al., 2003). In addition to this, other factors such as stress levels (Wegner et al., 2014), and caffeine intake prior to participation (Astorino et al., 2011) may also affect training performance. Isokinetic dynamometers have been used in training programmes and provide more information about training performance. They can indirectly measure the force exerted against resisted movements (Kannus, 1994). The range of movement can also be standardised to ensure that the muscle is trained throughout the range of movement. Isokinetic contractions are usually performed maximally (Engardt et al., 1995) producing a parabolic force curve. Taking the peak force as maximum, contractions which are produced sub-maximally at 80% and 40% could be used as the basis for intensity differentiated progressive resistance exercise.

Figure 3.1 shows a parabolic maximal voluntary isokinetic contraction overlaid with high intensity (80% MVC) and low intensity (40% MVC) submaximal contractions. The work completed during the contraction would be equivalent to the area under the force curve (Hislop and Perrine, 1967).

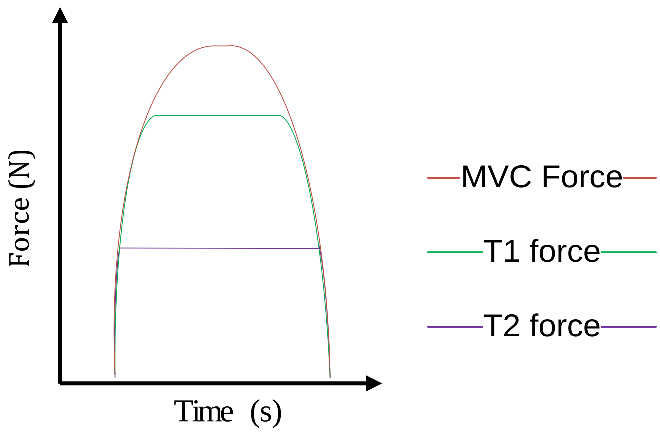


Figure 3.1. Hypothetical force curves produced during the MVC contraction and high (T1) and low (T2) intensity contraction

Figure 3.2 shows two hypothetical submaximal contractions performed at 80% (T1 force) and 40% (T2 force) of MVC. Theoretically, assuming that the force curve was rectangular, the total work completed per repetition in the high intensity contraction (80% of MVC) would be double the total work completed per repetition in the low intensity contraction. Due to the parabolic nature of the force curve, producing submaximal contractions at a specified intensity would be associated with an error, dependent on time to peak force. Such an error is expected to be higher at higher intensities as the target force is higher.

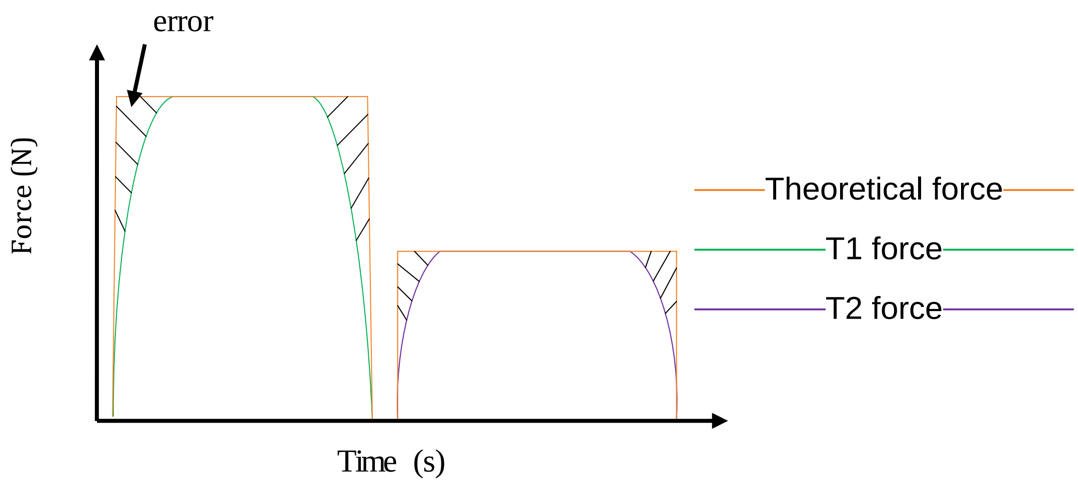


Figure 3.2. The degree of error between theoretical total work and actual work for the low and high intensity protocols

Training at 40% MVC for 20 repetitions per set should be equivalent in total work when compared to training at 80% MVC for 10 repetitions per set. Therefore, over a 10 repetition training set, the total work completed is expected to be relatively double in the high intensity training set compared to the low intensity. The performance of 20 repetitions at 40% MVC should equate to a matched total work compared to a high intensity 80% MVC 10 repetition protocol.

Submaximal isokinetic contractions could form the basis of evaluation of intensity-differentiated training whilst recording training performance variables including total work. There is currently very limited information on performance characteristics of progressive resistance exercise training protocols. Although some studies have evaluated accuracy of force generation against a visual target (Tracy and Enoka, 2006), this has been limited to isometric contractions.

This study aimed to measure training performance (intensity and total work) during progressive resistance exercise using sub-maximal isokinetic training sets performed by sedentary participants. This evaluated whether sub-maximal isokinetic training can be used to dynamically train participants at a differentiated intensity and volume. By recording the forces exerted during the muscle contractions this study evaluated whether participants could achieve the target training intensity and whether the total work can be matched between high intensity low repetition and low intensity high repetition protocols.

The hypotheses of this study are as follows:

- It was hypothesised that participants will be able to train at a differentiated training intensity such that T1 will be performed at a higher intensity than T2 and T3. Participants will perform T2 and T3 at the same training intensity.
- It was hypothesised that there would be no difference between T1 and T2 for the total work completed. It was also hypothesised that the total work completed in T1 and T2 would be higher than the total work completed in T3.
- It was hypothesised that there would be no difference between T1 and T2 for the total work completed. It was also hypothesised that the total work completed in T1 and T2 would be higher than the total work completed in T3.
- It was expected that participants would be able to achieve the total work as expected for the protocol, such that there was a strong level of agreement between theoretical and achieved total work.
- It was hypothesised that the force fluctuation would not differ between each of the three training protocols, T1, T2 and T3.

3.2 Methods

3.2.1 Study Design

The study compared the training performance of three protocols, defined as the ability to train at the specified intensity and total work: T1 (high intensity low repetition protocol), T2 (low intensity high repetition protocol) and T3 (low intensity low repetition protocol) which are explained further below. In order to compare the training performance between these protocols, a within subject design was used to minimize inter-subject variation. An experimental design was utilized where each participant performed one set of each of the three protocols. The study design and procedures were approved by the University Ethics Committee (Appendix 8.1).

3.2.2 Participants

Participants were fully informed of study aims and procedures and gave their consent in writing (appendix 8.2). A convenience sample of staff and students at the University of East London was recruited. Participants who met the inclusion criteria were invited to the Human Motor Performance Laboratory on one occasion.

3.2.2.1 Inclusion Criteria

Participants were included in the study if they were aged between 18 and 40 years. As outcomes following progressive resistance exercise are influenced by the training status of the participants involved (Rhea et al., 2003), this study recruited participants of a similar training status. This study aimed to recruit participants that were generally inactive in their daily life. This is because high activity levels may contribute to higher levels of training status despite an individual not being involved in structured exercise (Mikalacki et al., 2011).

Participants were selected based on the short version International Physical Activity Questionnaire (Craig et al., 2003), a self-report questionnaire about physical activity in the last 7 days (Appendix 8.3). Those who were categorised as inactive, falling into category 1 of the questionnaire, were included as the inactive population. This was defined on the basis that they did not participate in 3 or more days of vigorous-intensity physical activity for a minimum of 20 minutes a day; or 5 or more days of moderate-intensity activity and/or walking for a minimum of 30 minutes per day; or 5 or more days of any combination of walking, moderate-intensity or vigorous intensity activities that resulted in at least 600 MET-minutes.week^{-1} (IPAQ, 2004).

3.2.2.2 Exclusion Criteria

Participants were screened using a health questionnaire (Appendix 8.4) and excluded if they presented with history of heart conditions (including chest pain during exercise), anaemia, diabetes, or lower limb musculoskeletal injury exacerbated by exercise.

3.2.3 Equipment

Participants' height was measured using a stadiometer (Hadlands Photonics, Australia). Weight was measured using standard weighing scales (UC-300 Tokyo, Japan) and was recorded in kilograms to the nearest one decimal place. A Lode Corival™ (Lode, Netherlands) electro-magnetically braked cycle ergometer was used to warm-up participants at the start of the session. A Kin-Com® 500H isokinetic dynamometer was used to test and train participants.

3.2.4 Procedures

3.2.4.1 Height and weight

Participants were asked to change into shorts and were barefooted throughout the testing period. To measure height, participants were asked to stand on the platform with their legs straight, heels close together and their back parallel to the vertical stand. The head beam was lowered until it came in contact with the crown of the participant's head. Height was recorded in centimetres to the nearest one decimal place.

The weighing scales were placed on a flat surface and the needle was zeroed. Participants' weight was measured by asking participants to stand on the scale facing forwards. The measurement was taken when the measurement needle was steady against the scale.

3.2.4.2 Warm Up

Participants were seated on the stationary bicycle with the seat height adjusted for comfort. They were instructed to cycle between 50-60 repetitions.minute^{-1} using the cycle's display as a guide. The resistance against movement was set at 20W and they cycled for five minutes.

3.2.4.3 Dynamometry

Participants were instructed to sit on the isokinetic dynamometer so that their lumbar spine was in contact with the backrest. The limb that was trained first was randomised. The bottom seat length was adjusted so that the calf muscle was approximately 0.5 cm from the edge of the seat. To isolate joint movement at the knee, their position was secured using a belt around the pelvis and another over the anterior aspect of the femur. The rotating arm was aligned with the axis of rotation of the knee joint. An ankle cuff, connected to the strain gauge, was fastened two finger's breadth above the ankle joint (Figure 3.3). The correction for gravity was completed using the procedure reported by Finucane et al. (1994). A spirit level was used to position the lever arm parallel to the floor to provide knee point of reference.

All manoeuvres were performed isokinetically at 60°.s^{-1} using concentric/concentric mode. The range of movement was set from 90˚ knee flexion to the full available range of knee extension. The acceleration and deceleration phase of the Kin-Com was set to 'medium' and participants were required to exert a minimum force of 20N in order to start the manoeuvres. The computer display was used to give real-time feedback of the force recorded at the strain gauge.

Figure 3.3. Participant positioned on the Kin-Com Isokinetic Dynamometer

3.2.4.4 MVC Procedure

Once participants were positioned on the Kin-Com, they were taken through the procedure to assess maximal isokinetic strength. Participants were familiarised with the movement and were asked to perform concentric knee extension to the end of their available knee extension range and then perform concentric knee flexion back to the starting position (defined as one repetition) for two repetitions. They were instructed to push the cuff forwards & upwards (knee extension) with maximal effort to the end of their available range and then pull backwards & downwards (knee flexion) with maximal effort to the starting position. Verbal encouragement was given to all participants whilst doing the movements. Following the two repetitions for familiarisation, they given a one minute rest. During the rest period, they were given instructions that they would now be performing the same movement for five repetitions continuously. As soon as the rest period was over, they were then taken through five repetitions of concentric knee extension and concentric knee flexion movements.

3.2.4.5 Training Procedure

Once the MVC was been performed by the participant, they were then asked to rest whilst the experimenter retrieved the MVC performance data. This took less than three minutes but the participant was asked to rest for three minutes.

The maximum intensity was derived from the peak torque achieved during maximal voluntary contractions. To account for variations, the mean of the peak torques from five maximal voluntary contractions was defined as the maximum. The target torque for extension and flexion was calculated from the maximum and corresponding visual targets were set on the feedback screen. The visual gains of the targets were adjusted to the maximum possible whilst ensuring both were still visible.

A visual display provided feedback of the force produced during movement. A visual target force was placed corresponding to the intensity of contraction and participants were instructed to produce a force to meet the target (Figure 3.4). The 40% and 80% intensity training protocols both incorporate a skill component where force is controlled through the range.

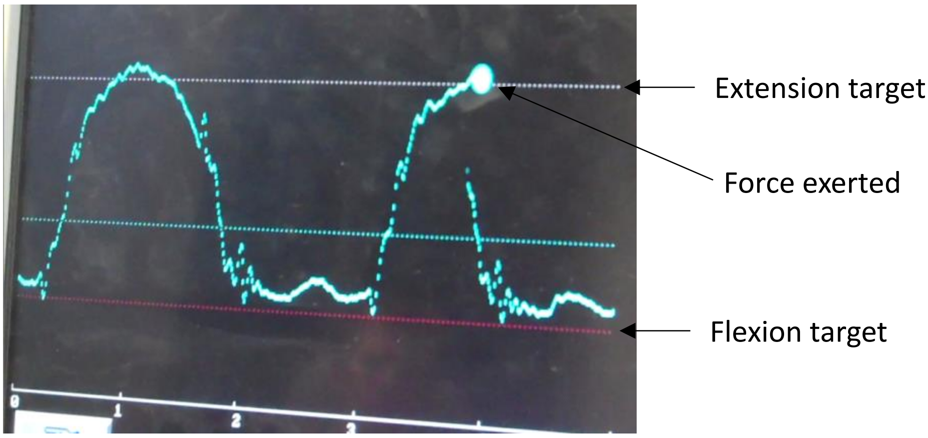


Figure 3.4. Visual feedback of targets and force being produced by during knee extension and flexion

Following this and as soon as the rest period finished, participants were taken through one set of each of the training protocols in a random order, with a one minute rest period between protocols. Before the start of each protocol, participants undertook two practice repetitions to familiarise them with the target training intensity. The procedure, including evaluation of MVC was then repeated on the contralateral limb.

The training protocols were as follows:

- **T1 –** Ten contractions at 80% mean peak torque
- **T2 –** Twenty contractions at 40% mean peak torque
- **T3 –** Ten contractions at 40% mean peak torque

The protocols were designed to be theoretically differentiated by intensity and volume such that:

- T2 and T3 was performed at half the intensity compared to T1
- T1 and T2 completed an equal amount of work per set
- Participants completed half the amount of work in T3 compared to T1 and T2
- T1 and T3 completed the same number of repetitions

3.2.5 Measurement of training performance

The isokinetic dynamometer recorded the force, velocity and angle of each millisecond of the training set. This allowed measurement of the forces produced during the muscle contractions. The force exerted during the contraction was used to assess the intensity of training and the total work completed. The continuous force trace was then analysed to assess whether participants achieved the target force consistently during the training sets.

3.2.5.1 The ability to train at the specified intensity

In order to account for the different muscle groups/actions involved, training performance of the knee extensors and flexors was analysed separately. Due to the variability in the force produced over a contraction, the peak torque of each contraction was recorded as the representative force of the contraction. To ensure all peak torque measures were recorded during the dynamic part of the contraction, parts of the contraction where the velocity was less than $55°.s^{-1}$ were removed before analysis. This ensured the peak torque was not derived for example if the dynamometer had stopped mid-way during a contraction - there were isolated instances where the participant changed direction too quickly.

The peak torque of a contraction was defined as representative of the force produced during the contraction. Two measures were used to determine whether participants trained at the specified intensity:

- **Training intensity**: The peak torque of each contraction within a training set was measured and divided by the maximum torque determined from the MVC set. This provided a measure of the intensity of each contraction. The training intensity of each contraction was averaged across all contractions within the training set to give the mean training intensity.
- **Target accuracy**: The peak torque of each contraction recorded within a training set was compared to the target torque. Contractions were considered acceptable if the peak torque value was within ±10% of the target torque. The number of acceptable contractions was reported as a proportion of all contractions within a training set. In addition to this, descriptive statistics were reported on the number of contractions produced above and below the target range.

It is possible that the target accuracy measure may not reflect the intensity of training in contractions where the peak torque falls outside the target range for a brief period during the contraction, as illustrated in the figure below but all instances were recorded as exceeding training intensity.

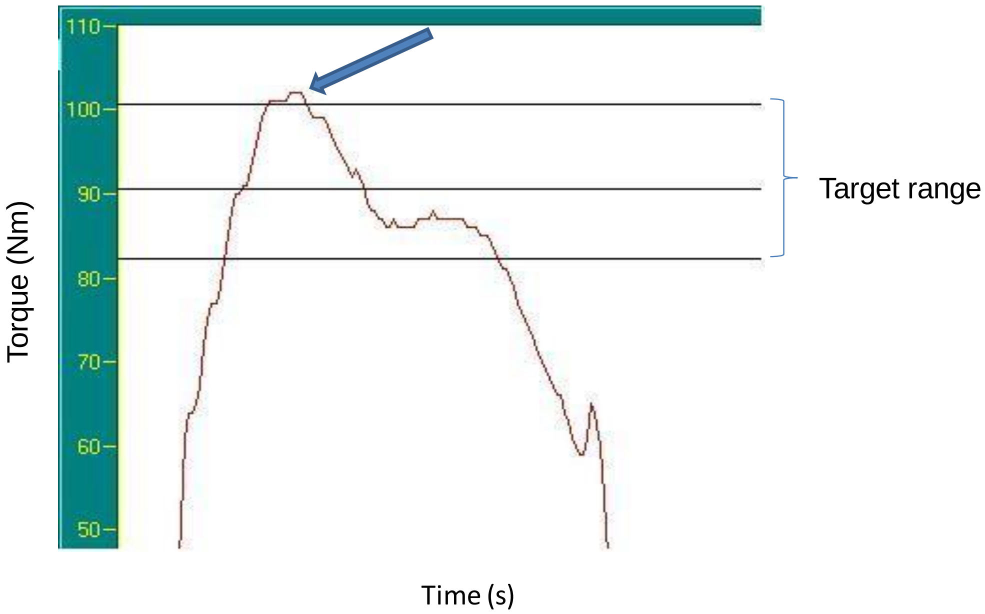


Figure 3.5. An example of an extension contraction where the peak torque exceeded the target range

Previous studies have used coefficient of variation about an isometric contraction to assess participants ability accurately produce force against a target. As there are no previous studies evaluating performance of sub-maximal isokinetic training, this study also explored the possible ways in which to capture training performance and continued with the analysis of target accuracy. The coefficient of variation of individual force contractions was not measured as it was considered that such variation would be captured in the measure of total work.

3.2.5.2 The total work in a training set

The total work in a training set was recorded as the integral for all contractions, for extension and flexion separately. A theoretical total of work done for a training set was determined from the amount of joules that would be achieved if the target torque was maintained over the distance travelled regardless of training intensity. This was calculated as below:

Target torque = intensity of the protocol x mean of peak torques

Distance travelled = (no. of repetitions x (lever arm length x 2 x π)) x (angular displacement / 360))

The distance travelled was determined from the range of movement in radians multiplied by the lever arm length and the number of repetitions completed. This provided the theoretical work value for each participant in kiloJoules.

3.2.5.3 Force fluctuation during training

The variation in the peak torque of each contraction was measured to assess the ability for participants to train consistently at the specified intensity. The coefficient of variation was used as a measure of variability, for both the extension and flexion forces produced during the sub-maximal isokinetic training sets. The standard deviation of the peak torques in a training set was divided by the mean peak torque and multiplied by a hundred to calculate the coefficient of variation. This is referred to as force fluctuation, where a higher value means the variation in the intensity of between contractions was larger.

3.2.6 Data Analysis

Training performance of the left and right limbs were analysed separately to account for potential differences in training performance due to limb dominance. As the order of the training was randomised between sides, no potential effect of cross-education between limbs was expected (Howatson et al., 2013). Four measures were taken to assess the performance of the sub-maximal training protocols: total work, training intensity, target accuracy, and force consistency. In addition to this, the number of contractions below and above the target range was recorded for each training set. The training performance of extension and flexion was analysed separately to account for the different muscle groups involved. Due to the differences in muscle composition between quadriceps and hamstrings, particularly with the high prevalence of hamstring injury in performance sport (Orchard and Seward, 2002) raises the importance of looking at these muscle groups separately.

Descriptive statistics were presented to explore the target accuracy, training intensity, force consistency and total work performed by participants in the three training protocols. IBM® SPSS® Statistics Version 20 was used to conduct repeated measures

ANOVA in order to determine whether there was a difference in the target accuracy, training intensity, total work and force fluctuation between training programmes. Mauchly's test was used to test the assumption of sphericity and Greenhouse-Geisser values were used where this assumption was violated.

Where there was a significant difference between training protocols, post-hoc t-tests were conducted to determine whether there was a difference between: T1 and T2; T2 and T3; T1 and T3. Bonferroni correction was applied which adjusted for the significance value for p to account for the number of statistical tests performed. Intra-class correlation coefficient ($ICC_{3,1}$) was used to determine the level of agreement between the theoretical work and total achieved work for each training set completed (Shrout et al., 1979).

3.3 Results

3.3.1 Participant characteristics

Fifteen adult participants (10 female, 5 male) were recruited from the staff and student cohort at the University of East London that fulfilled the criteria of being in category 1 of the International Physical Activity Questionnaire (Craig et al, 2003). Table 3.1 shows the demographic characteristics of the participants in study 1.

Table 3.1. Physical characteristics of the participants (n=15) in study 1 (mean ±SD)

Age (years)	Height (cm)	Mass (kg)	Mean Peak Torque (N·m) at 60°.s^{-1}			
			Left Extension	Right Extension	Left Flexion	Right Flexion
28 ± 6	167 ± 6	67 ± 10	112 ± 40	127 ± 37	65 ± 18	65 ± 19

3.3.2 Training Intensity

The reported training intensity of each training set was averaged across all training sets completed for extension (Figure 3.6) and flexion manoeuvres (Figure 3.7).

Repeated measures ANOVA showed that there was a significant difference in the training intensity between protocols, ($F_{(1.12,\ 15.72)} = 425.00$, $p < 0.001$) but not between right and left side ($F_{(1.00,\ 14.00)} = 0.74$, $p = 0.79$) or the interaction of side and protocol ($F_{(1.12,\ 15.71)} = 1.64$). On average, participants performed T1 (Left: 77.63 ±11.16; Right:

79.85 ±16.00) at a significantly higher intensity than T2 (Left: 46.54 ±4.91; Right: 44.54 ±3.59), $t_{(14)}$ = 10.66-31.43, p < 0.001 for left and right sides. T1 was also performed at significantly higher intensity than T3 (Left: 44.03 ±4.90; Right: 42.52 ±4.19), $t_{(14)}$ = 10.99-38.07, p < 0.001 for left and right sides. There was a significant difference between T2 and T3 for the left ($t_{(14)}$ = 3.71, p < 0.005) and right sides ($t_{(14)}$ = 3.31, p < 0.01).

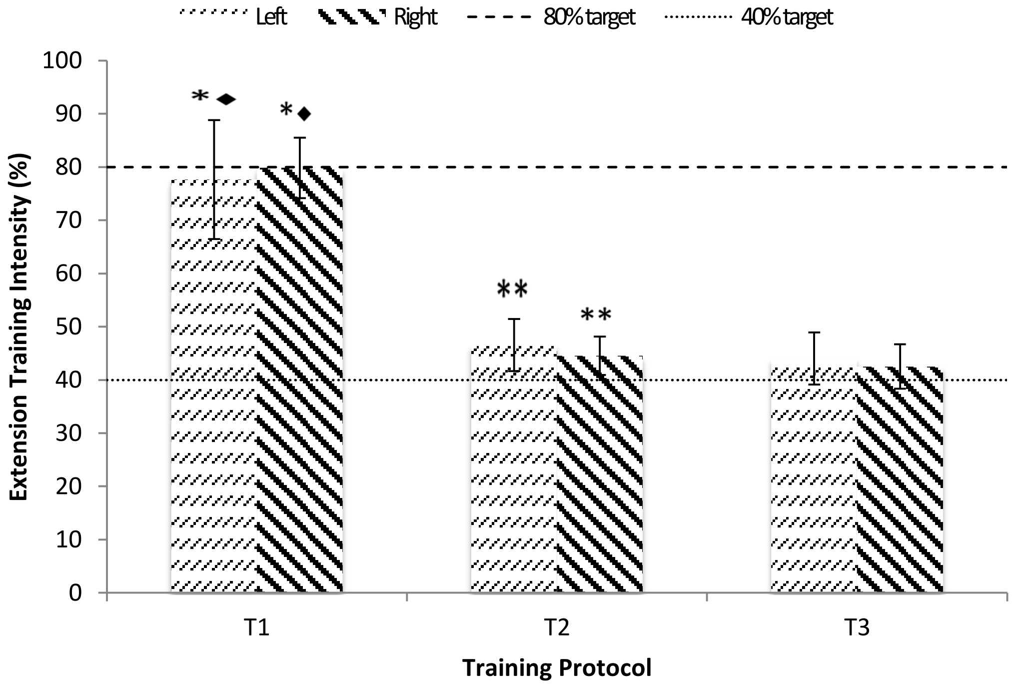
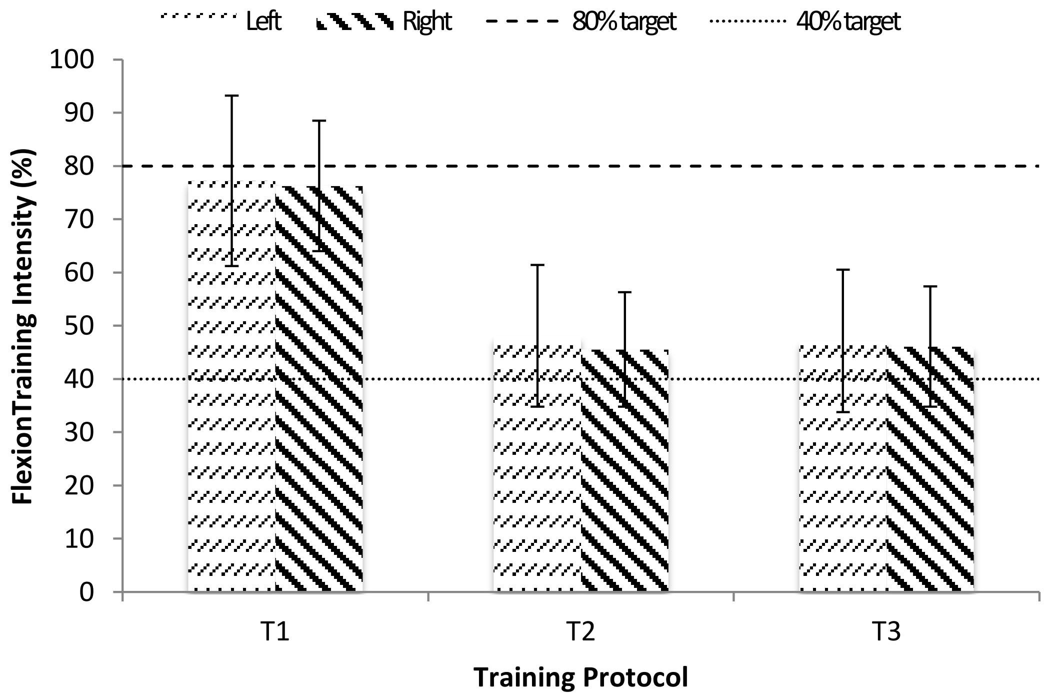


Figure 3.6. Mean (±SD) extension Training Intensity (%) by protocol and limb
* T1 vs. T2, p < 0.001; ◆T1 vs. T3, p < 0.001; **T2 vs. T3 p < 0.01

For the flexion manoeuvres, on average participants performed T1 (Left: 77.21 ±16.00; Right: 76.23 ±12.25) at a significantly higher intensity than T2 (Left: 48.12 ±13.29; Right: 45.53 ±10.75), $t_{(14)}$ = 6.07-14.82, p < 0.001 for the left and right sides. T1 was also performed at significantly higher intensity than T3 (Left: 47.14 ±13.40; Right: 46.08 ±11.31), $t_{(14)}$ = 6.33-17.76, p < 0.001 for the left and right sides. There was no significant difference between T2 and T3 for the left ($t_{(14)}$ = 1.12, p = 0.281) and right sides ($t_{(14)}$ = -0.416, p = 0.683).



* T1 vs. T2, $p < 0.001$; ◆T1 vs. T3, $p < 0.001$; **T2 vs. T3 $p < 0.05$
Figure 3.7. Mean (±SD) flexion Training Intensity (%) by protocol and limb

3.3.3 Target Accuracy

Figure 3.8 shows the mean extension target accuracy achieved by participants in each of the three training protocols for each side. On average, half of the contractions were performed within ±10% of the target force (T1: 50 ± 33% for left and 63 ± 22 for right sides; T2: 42 ± 26% for left and 50 ± 26% for right sides; T3: 56 ± 30% for left and 60 ± 29% for right sides). There was high variation in the proportion of contractions within the target zone as reflected in the standard deviations shown in Figure 3.8. For example target accuracy ranged from 20 to 100 % for participants in T1.

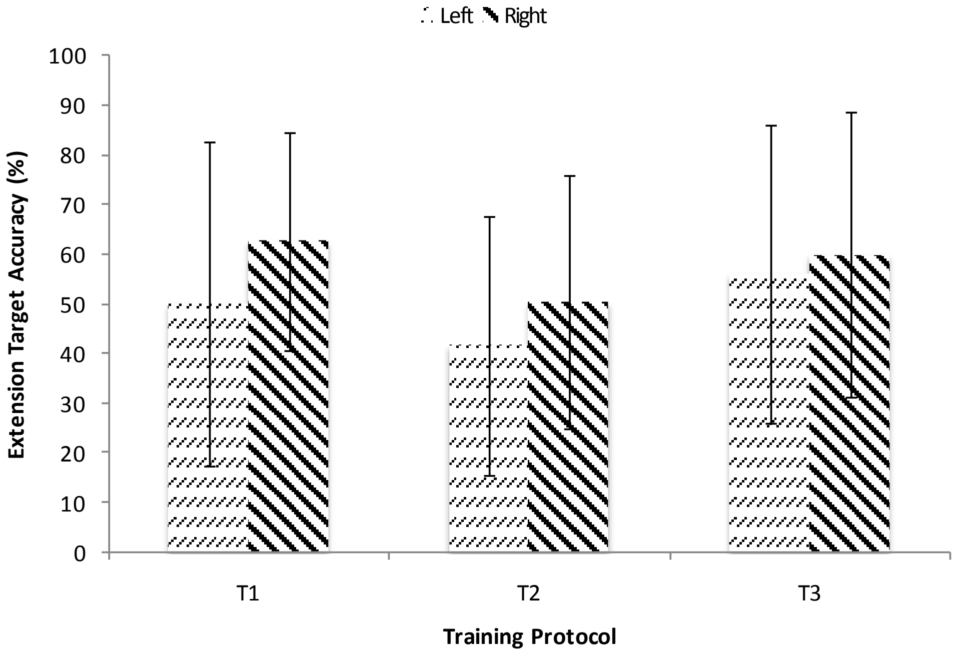


Figure 3.8. Mean extension target accuracy by protocol and limb

The mean flexion target accuracy was lower than extension (Figure 3.9). The mean target accuracy for T1 was 32 ± 25% for left and 35 ± 34% for right sides. For T2, this was 37 ±33% for left and 47 ± 27% for right sides. For T3 this was 51 ± 30% for left and 45 ± 31% for right sides.

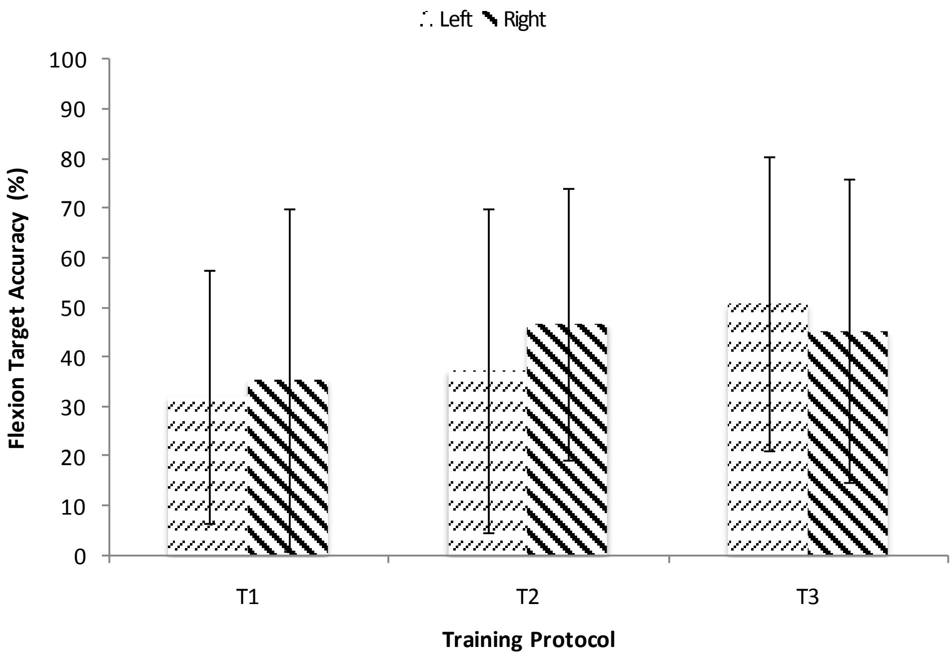


Figure 3.9. Mean flexion target accuracy by protocol and limb

The number of contractions below and above the target range was explored to determine whether there was a difference in attainment of target force between the high and low intensity protocols and presented descriptively. Table 3.2 shows the average number of contractions below and above the target range for each protocol. A higher number of contractions were above the target range in the low intensity protocols for all conditions.

Table 3.2. Average (±SD) number of contractions that were below or above the ±10% target range by protocol for each side and direction

Side/ Direction	Protocol	No. contractions *below* range	No. contractions *above* range
Left Extension	T1 – 10 repetitions	3 ± 3	2 ± 3
	T2 – 20 repetitions	1 ± 1	11 ± 6
	T3 – 20 repetitions	1 ± 4	4 ± 3
Right Extension	T1 – 10 repetitions	2 ± 2	2 ± 2
	T2 – 20 repetitions	1 ± 1	9 ± 5
	T3 – 20 repetitions	1 ± 1	3 ± 3
Left Flexion	T1 – 10 repetitions	4 ± 4	2 ± 4
	T2 – 20 repetitions	3 ± 4	9 ± 8
	T3 – 20 repetitions	1 ± 1	4 ± 4
Right Flexion	T1 – 10 repetitions	4 ± 4	2 ± 3
	T2 – 20 repetitions	4 ± 4	7 ± 7
	T3 – 20 repetitions	2 ± 3	4 ± 4

3.3.4 Total Work

The total work completed in each training set was reported together with the theoretical work. Theoretical work is a predicted amount of work expected for each individual and is calculated from participants' target torque, number of repetitions and lever arm length (table 3.3).

For extension, one-way repeated measures ANOVA showed that there was a significant difference in the total work completed between training protocols ($F_{(1.14,\ 15.97)} = 141.43$, $p < 0.001$). Post-hoc t-test showed that there was a significant difference between all three training protocols in the total work completed for the left (T1 vs T2: $t_{(14)} = -6.93$, $p < 0.001$; T1 vs T3: $t_{(14)} = 7.457$, $p < 0.001$; T2 vs T3: $t_{(14)} = 10.488$, $p < 0.001$) and right sides (T1 vs T2: $t_{(14)} = -9.018$, $p < 0.001$; T1 vs T3: $t_{(14)} = 14.04$, $p < 0.001$; T2 vs T3: $t_{(14)} = 15.565$, $p < 0.001$). The average total work completed by participants in T1 (Left: 859 ±378 kJ; Right: 923 ±246 kJ) was similar to the average total work completed in T2 (Left: 987 ±375 kJ; Right: 1040 ±267 kJ). The average total work completed in T3 (Left: 476 ±188 kJ; Right: 507 ±139 kJ) was approximately half (48-55%) of the total work completed in T1 and T2.

The Intraclass correlation coefficient was performed to assess the level of agreement between theoretical work and total work achieved over the training set. For extension, there was a moderate level of agreement between theoretical and total work ($ICC_{3,1}$ = 0.48-0.84). The level of agreement was weaker in T1 compared to T2 and T3 for both sides.

For flexion, one-way repeated measures ANOVA showed that there was a significant difference in the total work completed between training protocols ($F_{(2,\ 28)} = 67.78$, $p < 0.001$). Post-hoc paired t-test showed that there was a significant difference between all three training protocols for the total work completed for the left (T1 vs T2: $t_{(14)} = -2.275$, $p < 0.05$; T1 vs T3: $t_{(14)} = 5.759$, $p < 0.001$; T2 vs T3: $t_{(14)} = 13.631$, $p < 0.001$) and right sides (T1 vs T2: $t_{(14)} = -2.626$, $p < 0.05$; T1 vs T3: $t_{(14)} = 8.552$, $p < 0.001$; T2 vs T3: $t_{(14)} = 6.982$, $p < 0.001$). The average total work completed by participants in T1 (Left: 490 ±178 Kj; Right: 490 ±188 kJ) was similar to the average total work completed in T2 (Left: 564 ±130 kJ; Right: 562 ±248 kJ). The average total work completed in T3 (Left: 280 ±61 kJ; Right: 272 ±98 kJ) was around half of the total work completed in T1 and T2.

The level of agreement between calculated theoretical work (regardless of velocity) and total work achieved over the training set was lower than for extension but there was a moderate level of agreement between theoretical and total work ($ICC_{3,1}$ = 0.53-0.73). Again, the level of agreement was weaker in T1 compared to T2 and T3 for both sides.

Table 3.3. Mean (±SD) Total Work (J) Completed per Training Set for Each Side and Direction

Side/ Direction	Protocol	Theoretical Work Per Set	Total Work (kJ)	$ICC_{3,1}$	% of T1 Total Work
Left Extension	T1	1167 ± 434	859 ± 378	0.74	-
	T2	1167 ± 434	987 ± 375	0.88	121 ±21%
	T3	584 ± 217	476 ± 188	0.84	58 ±9%
Right Extension	T1	1325 ± 405	923 ± 246	0.48	-
	T2	1325 ± 405	1040 ± 267	0.61	113 ±6%
	T3	622 ± 202	507 ± 139	0.59	55 ±4%
Left Flexion	T1	675 ± 185	490 ± 178	0.56	-
	T2	675 ± 185	564 ± 130	0.60	124 ±37%
	T3	338 ± 93	280 ± 61	0.53	62 ±21%
Right Flexion	T1	677 ± 198	490 ± 188	0.60	-
	T2	677 ± 198	562 ± 248	0.73	114 ±17%
	T3	339 ± 99	272 ± 98	0.69	56 ±7%

3.3.5 Force Fluctuation

Table 3.4 shows the mean extension force fluctuation achieved for T1, T2 and T3. One-way repeated measures ANOVA showed that there was no significant difference in the force fluctuation between the training protocols ($F_{(2.00, 28.00)} = 1.25$, $p = 0.303$).

Table 3.4. Mean (±SD) Extension Force fluctuation (%) Per Training Set for Each Side and Direction

Protocol	Left Extension	Right Extension
T1	13 ± 8	11 ± 4
T2	14 ± 7	14 ± 6
T3	13 ± 10	11 ± 6

*T1 vs. T2, p < .05; ◆T1 vs. T3, p < 0.05

Table 3.5 shows the mean flexion force fluctuation achieved for T1 (Left: 9 ±3%; Right: 10 ±5%), T2 (Left: 13 ±7%; Right: 15 ±5%) and T3 (Left: 13 ±6%; Right: 14 ±6%). One-way repeated measures ANOVA showed that there was a significant difference in the force fluctuation between the training protocols ($F_{(2.00, 28.00)} = 12.49$, $p < 0.001$).

On average, participants achieved lower force fluctuation for T1 (Left: 9 ±3%; Right: 10 ±5%) than T2 (Left: 13 ±7%; Right: 15 ±5%) $t_{(14)}$ = -2.46, p = 0.028 (left side) and $t_{(14)}$ = -4.80, p < 0.001 (right side). T1 was also performed at significantly lower force fluctuation than T3 (Left: 13 ±6%; Right: 14 ±6%), $t_{(14)}$ = -3.25, p < 0.01 (left side) and $t_{(14)}$ = -2.92, p = 0.011 (right side).

Table 3.5. Mean (±SD) Flexion Force Fluctuation (%) Per Training Set for Each Side and Direction

Protocol	Left Flexion	Right Flexion
T1	9 ± 3*◆	10 ± 5*◆
T2	13 ± 7	15 ± 5
T3	13 ± 6	14 ± 6

*T1 vs. T2, p < 0.05; ◆T1 vs. T3, p < 0.05

3.3.6 Summary of Results

The results showed that participants could perform the protocols at the intensity specified by the protocol. T1 (80% MVC 10 repetition protocol) was performed at an average intensity of 77-80% whilst T2 (40% MVC 20 repetition protocol) and T3 (40% MVC 10 repetition protocol) were performed at an average intensity of 43-48%. The average extension total work completed in T1 was 18% and 12% lower than the total work completed in T2 for the left and right side respectively. The average extension total work completed in T3 was on average 48-49% and 54-55% the total work completed in T1 and T2 respectively. There was a moderate level of agreement (Portney and Watkins, 2009) between the theoretical and total work completed for all three protocols but there remained an average variation of 15% in the intensity of contractions within a training set.

3.4 Discussion

Study 1 aimed to assess the performance characteristics of sub-maximal isokinetic training sets performed by sedentary participants. Participants' performance of training sets was evaluated using three measures to determine whether participants trained at the specified intensity, achieved the total work expected and produced contractions at a consistent intensity.

The first aim of this study was to determine whether participants trained at the specified training intensity. There is currently limited information on performance characteristics of progressive resistance exercise training protocols reported in the literature. Two measures were used to determine whether participants produced a force that was equivalent to the target: training intensity and target accuracy. In both cases, the peak torque of each contraction was used as a representative indicator of the intensity that each contraction was performed in. It was found that participants performed T1 at a significantly higher intensity than T2 and T3 for all conditions. The mean training intensity of training was double in the high intensity protocols compared to the low intensity protocols. However, although the mean training intensity for all participants was close to 80% for the T1 protocol and 40% for the T2 and T3 protocol, there was variation in the mean training intensity between participants. In order to assess the influence of intensity on progressive resistance exercise, the protocols must be performed such that there is sufficient differentiation in the intensity between high and low intensity protocol. However, mean training intensity was below 70% MVC for 2 of the 30 extension training sets and 10 of the 30 flexion training sets for T1. For T2, the mean training intensity was above 50% for 5 of the extension training sets and 6 of the flexion training sets. For T3, this was observed in 3 of the extension and 7 of the flexion training sets. Therefore, although the intensity of training was significantly different between training protocols, some participants did not complete the protocols with sufficient differentiation. This indicates some participants were not able to perform the protocols accurately.

Measurement of target accuracy showed that on average 40-60% of the contractions were within ±10% of the target range. However, the level of force exerted may have fluctuated throughout the contraction. Schiffman and Luchies (2001) evaluated the variability of isokinetic contractions in young adults tasked with maintaining a 60% MVC target force. They found that the mean standard deviation of the force was 8 ± 13 (estimated from graphical data). Therefore, target accuracy may not be representative of the force produced throughout the entire duration of the contraction. The measure will not identify occasions where the contraction force exceeds the target force for only a short period of time before returning to the target. Further investigation into the force curves producing during the sub-maximal contractions was conducted. This showed instances where contractions were categorized as being outside the target range where the peak torque exceeded the target range for just a short duration. In addition, there were instances where the peak torque was within the target range despite the majority of the contraction performed below the target range. The effect of classifying contractions in this way may therefore have led to misleading results.

Force fluctuation may better explain the variance in training intensity between participants. There was a variation of 9-15% in the peak torque produced between contractions. The level of variation indicates that, although most participants trained at the specified intensity, it was not consistently achieved for all contractions within a particular training set. The ability to produce a consistent force equivalent to the target may have depended on the ability of participants to use visual feedback to modulate the descending neural drive as visual feedback is processed by the parietal and premotor areas of the cortex as well as the basal ganglia and cerebellum (Vaillancourt et al., 2006). This is supported by Proedoehl and Vaillancourt (2010) who evaluated force fluctuation in healthy adults during an isometric force matching task under different visual gain conditions. They defined visual gain as the relative visual distance created by the display when force was applied. They found force steadiness was greater at higher visual gains, when the visual display showed larger increments of force, suggesting participants used visual feedback to correct the force that was being applied. Visual gain was not standardized in the present study. The settings were adjusted to the maximum available gain before the target forces disappeared off the display. However, the gain depended on participant's target forces. The gain was lower in participants with larger target forces as they were not adjustable to the same degree.

There may also be other factors that may have affected the training performance of participants. The variability in the training intensity performed may be explained also by the lack of practice to learn how to produce a force that is equivalent to the target. Participants needed to learn how to interpret the visual input to produce an appropriate motor command and given that this was a new task, the lack of prior experience seemed to have manifested as poorly executed performance. Motor skills are consolidated even after practice of a motor task has ended as demonstrated by Brashers-Krug et al. (1996) who found that the accuracy of a target reaching task was retained and improved when repeated one day after it was originally performed. However, this was based on a

practice task of 192 targets per set. The current participants performed 10-20 repetitions over 3 conditions and it is possible more practice was needed for accurate performance.
Salonikidis et al. (2009) evaluated the force variability of isometric sub-maximal wrist contractions of the wrist flexors between highly skilled tennis players and sedentary individuals. They measured the variability of force as the coefficient of variation of the force produced during the force-matching task at varying sub-maximal target intensities (5-75% MVC) and joint angles. At 130° for example, sedentary participants demonstrated a coefficient of variation from 4.5% to 2.0% (estimated from graphical data) between 5 and 75% MVC whilst the highly skilled group demonstrated a coefficient of variation from 2.8% to 1.5%. The coefficient of variation was consistently higher by around 0.5-1-5% (estimated from graphical data) in the sedentary group at all target intensities and joint angles. Given that there was no difference in isometric strength or normalized EMG activity between the two groups ($p > 0.05$); this suggests that prior practice may have beneficial effects on controlling the force output. Therefore, the type of activity participants usually perform may also have an influence on training performance. As the activities prescribed by the protocols are novel to typical activities of daily living repeated practice may therefore improve training performance but the amount of practice required is not fully understood.

This study also found that participants performed T2 training sets at a higher intensity than T3. This was not expected as both protocols instructed participants to train at the same intensity and the order of the training protocols was randomised. The skill components and therefore the explicit learning processes were similar for both protocols (Gentile, 1998). However, given that T2 training sets have more repetitions, it is possible that some participants may have begun to lose concentration. It is possible that the strategy for maintaining the target force changed due to this. In order to investigate whether this was the case, the training intensity for the first half of T2 training set was compared to the second half but no difference ($p > 0.3$) in the training intensity between the first half and second half of the T2 training set was found. Given that the mean difference in training intensity between T2 and T3 was small, the differences could be considered negligible.

The results of this study suggested that the mean training intensity was more variable for the left limb compared to the right. This may be due to the effect of limb dominance, as observed in previous findings on motor control between dominant and non-dominant limbs for the upper limbs (Sainburg & Kalakanis, 2000). In right handed participants, Sainburg & Kalakanis (2000) evaluated the reaching strategies of the left and right arm under varying conditions of restricted target paths. They found that although both limbs demonstrated similar accuracy in reaching the target, there were differences in muscle force timing, magnitude and direction. When participants had to adapt the path to reach the target, the right limb showed higher levels of co-ordination to reach the target. The results indicate distinct neural mechanisms between dominant and non-dominant limbs as supported by the findings that limb muscles are controlled primarily the contralateral cortex (Holsetege and Kuypers, 1982). Although hand dominance is indicative of leg dominance (Balogun and Onigbinde, 1992), these findings may not directly transferrable as the ability to control force differs between the upper and lower limbs (Christou et al., 2003).

The variation in the mean training intensity was also higher for the flexion manoeuvres compared to the extension manoeuvres. For T1, only two of the extension training sets were performed below 70% MVC compared to 10 of the flexion training sets. Similarly, 8 of the low intensity extension training sets were performed above 50% MVC as opposed to 13 of the flexion training sets. The current study results indicate the knee flexors are not able to consistently perform sub-maximal isokinetic contractions. The differences may be accountable due to the different muscle group involved in performing the manoeuvres. Knee extension manoeuvres are produced primarily by the quadriceps muscle group whilst knee flexion manoeuvres are produced primarily by the hamstrings muscle group. There are distinct differences in muscle architecture between these groups (Wickiewicz et al., 1983). The hamstrings have more sarcomeres (4.3×10^4 vs 3.12×10^4) and have a larger fibre length to muscle length ratio (56×10^2 vs 22×10^2) compared to the quadriceps. In addition, the hamstrings have a lower proportion of type I muscle fibre (44-54%) (Dahmane et al., 2005) than the quadriceps (Travnik et al., 1995).

Such differences in muscle architecture appear to influence functional characteristics such as rate of force development and fatigue resistance (Brughelli et al., 2010; Abe et al., 2001; Alegre et al., 2006; Kanehisa et al., 2003).

It was expected that the poor performance of knee flexors to accurately achieve target forces would also be manifested in studies evaluating the reliability of maximal strength measurements. However, studies on the repeatability of maximal voluntary knee extension and flexion contractions have found high reliability (ICC > 0.95) for both (Sole et al. 2007, Harding et al. 1999, Philips et al. 2000). Therefore there is no full explanation for the observations in this study.

The second aim of this study was to evaluate whether participants were able to achieve the theoretical total work and whether the total work was equivalent between T1 and T2. Although the total work achieved in T1 was lower than T2 the actual difference in was small. T2 produced on average 128 ± 72 J more work than T1. This represents a mean difference of 13% for the total work completed in T1 compared to T2. This is unlikely to have an additional influence on the training response. For example, Krieger (2010) in a meta-analysis found that there was no difference in the effect size of outcomes following strength training between groups performing 2 and 3 sets per exercise or between 4 and 5 sets (difference = 0.10 +/- 0.10; CI: -0.09, 0.30; p = 0.29), equivalent to an extra third of the total work completed over the training period. In addition, such differences in the total work between T1 and T2 are expected to lower with repeated practice. It is possible that, with repeated practice, participants performing T1 will improve in their ability to reach the target quicker and maintain the target force over the duration of the contraction.

There was a high level of agreement between the total work achieved against theoretical work calculated. However, as the assessment of total work was made against theoretical work as opposed to an assessment for repeated measure, there exists the potential for a ceiling effect. As discussed in the methods, theoretical work was calculated from a flat force curve. But the training contractions were parabolic in nature and therefore it's unlikely that a stronger agreement could be achieved.

In addition to this, the level of agreement between theoretical work and total work achieved was lower for T1 than T2 and T3. This may be due to the inherent differences in the hypothetical sub-maximal force curves between the high and low intensity protocols as described in the introduction. It was also found that participants demonstrated higher than 10% variation in the peak force between contractions. This may partly explain why participants produced less work than theoretical work. Hortobagyi et al. (2001) and Tracy & Enoka (2006) also found participants were not able to maintain a consistent target force at baseline. As progressive resistance exercise has shown to improve rate of force development (Oliveira et al., 2013) and force fluctuation (Hortobagyi et al., 2001) it is hypothesised that the agreement between theoretical work and total work achieved may improve with repeated practice.

The training performance of the flexion manoeuvres was consistently poorer than that of the extension manoeuvres. This was observed through higher variation in the mean training intensity, lower agreement with theoretical work and higher force fluctuation. This may have impeded in the differentiation of training intensity between protocols.

3.5 Study Limitations

The study aimed to investigate whether the sub-maximal training protocols could be performed such that they were theoretically differentiated by intensity and volume. A single session quasi-experimental trial was used to investigate this. This allowed comparison of training performance between training protocols performed by the same individual. However, as each of the protocols was performed once, training performance cannot be inferred over a longer period. Training performance may improve with repeated sessions and therefore would need to be investigated over a longer period, particularly as progressive resistance exercise is typically performed over 8 sessions.

This study did not monitor or control for participants' behaviour before participating in the study which may have affected their performance. Factors such: as the time of day the testing was undertaken (Souissi et al., 2013), the types of daily physical activity undertaken (Jindo et al., 2016), the amount of sleep obtained the night before (Suppiah et al., 2016) was not considered. In addition to this, as many of the participants were students, some may have been studying prior to participation which may have affected their ability to concentrate during the sessions. All these factors may have contributed to the variability in performance between participants.

As sedentary participants were used in this study, the results cannot be inferred to other populations such as active young and older adults. Given the differences in training response between individuals of different training status (Rhea et al., 2003), it is expected that active young individuals would demonstrate a higher level of performance and sedentary individuals may demonstrate similar levels of training performance as older individuals of the same activity levels. On the other hand, the effects of ageing may contribute individually to the ability to perform these protocols.

It was observed that limb dominance had an effect on training performance due to the differences between left and right limbs. Training performance of the left limbs of participants in this study was poorer than the right limbs. However, as this was not determined, it cannot be elucidated for certain.

3.5 Summary

Study 1 evaluated the training performance of sedentary participants undertaking sub-maximal isokinetic exercise. Participants performed T1 at an intensity of around 80% and T2 and T3 at an intensity of around 45%. Despite this, there was a high level of variation between participants in the mean training intensity performed. These variances were consistent with the force fluctuation measure which showed variation in the peak torque between contractions within a training set.

The amount of work completed between T1 and T2 over a training set was similar. The total work completed in T3 was approximately half that of that of the total work completed in T1 and T2. This shows scope for the use of these protocols to evaluate the influence of intensity and volume. However, further evaluation is required to determine whether repeated sessions lead to a higher level of agreement between the total work performed and theoretical work.

The ability of participants to control the level of force equivalent to the target may be influenced by limb dominance, lack of practice and the training status of participants. It is noted that a single session may be insufficient to perform sub-maximal contractions consistently and at the intensity specified. It is expected that with repeated practice, participants will be able to improve their ability to control the level of force exerted during the sub-maximal voluntary contractions. The effect of practice is examined in Chapter 4.0.

4.0 The Effect of Repeated Practice of Sub-maximal Isokinetic Training Protocols on Training Performance

4.1 Introduction

The first study evaluated the training performance of sedentary individuals completing three sub-maximal isokinetic training protocols. This showed that sedentary participants were able to complete high and low intensity protocols at differentiated intensities but matched for the total work completed over the training set. However, there was variation in the intensity performed between participants and some were not able to train at a high intensity for the high intensity protocol or train at a sufficiently low intensity for the low intensity protocol. This was partly explained by the variability between contractions in the force produced. It was noted that the participants were sedentary individuals with no prior experience in performing sub-maximal isokinetic contractions. Previous studies have found this ability is impaired in untrained individuals as demonstrated by Salonikidis et al. (2009), They reported that sedentary individuals demonstrated higher force variability in sub-maximal isometric contractions of the wrist flexors compared to skilled tennis players. The training performance of individuals completing sub-maximal isokinetic protocols must therefore be evaluated over repeated sessions.

It has been established previously that muscles undergo neurological changes during the early phase of progressive resistance exercise (Moritani et al., 1979). These include the summation of motor unit forces and synchronicity of motor neurone discharge (Enoka et al., 2003; Taylor et al., 2003). Tracy et al. (2004) argues that such changes are independent of the changes in force fluctuation as they were not proportional to the change in strength. It is expected that, with repeated practice, sedentary individuals would improve their ability to consistently achieve and maintain forces equivalent to the target force during the sub-maximal isokinetic contractions. Previous work has found the force fluctuation of isometric contractions improve with strength training (Tracy & Enoka, 2006; Hortobagyi et al., 2001).

The main aim of this study was to assess whether sedentary participants improved in their training performance of sub-maximal isokinetic training protocols with repeated practice. This study assessed whether with repeated practice of a single protocol, sedentary participants were more accurately able to achieve the target training intensities, with lower force fluctuation and improve accuracy against theoretical work. In addition to this, the study measured whether participants' strength changes following repeated practice to determine whether there are indications of a differential response to training between the protocols.

The hypotheses of this study are as follows:

- It was hypothesised that with repeated practice, the mean training intensity would be closer to the training intensity as specified by the protocol.
- Following repeated practice, it was hypothesised that there would be an improvement in the level of agreement between theoretical and total work for T1 training group such that it was equivalent to the level of agreement achieved in T2 and T3 training groups.
- Following repeated practice, it was hypothesised that there was a reduction in force fluctuation between set 1 and set 12 for each of the three training groups (T1, T2 and T3).
- It was hypothesised that T1 and T2 would show an improvement in muscle strength and there would be no difference for the change in strength between these two groups. Also, it was hypothesised that the change in strength for T1 and T2 was higher than the change in strength in T3.

4.2 Methods

4.2.1 Study Design

In order to determine whether training performance improved with repeated practice of the training protocols, two study designs were considered. It was considered whether repeated practice could be undertaken where all participants complete one set of each protocol in each session over repeated sessions (within-subject experimental design). This would show whether the training protocols were differentiated by intensity and volume regardless of variations in participant performance. However, the practice of one protocol may have had a compounding effect on the performance of another protocol making it difficult to assess the performance of a single protocol. As previously discussed, neuromuscular adaptations in trained muscle (Carroll et al., 2001) may translate to the contra-lateral limb (Farthing, 2009). Ogaswara et al. (2013) attempted to minimise for such effects by leaving a period of 12 months for the within-subject design. However, even after this period strength had not returned to baseline.

Therefore it was decided to conduct a repeated sessions design where participants were randomly allocated to one of three training groups each completing their respective assigned protocol (between-subject experimental design).

It was decided that there would be four sessions over two weeks for each protocol. Two weeks is the typical time before strength is re-measured as part of a progressive exercise programme (Wernbom et al., 2007). This study aimed to investigate only the initial changes that occur without the additional effect of target adjustment. Therefore, the main aim of study 2 was to assess whether there was a change in training performance with repeated practice of sub-maximal isokinetic training protocols and whether there are indications of a differential response to training between training protocols. A randomized design was employed to determine the change in training performance over repeated sessions. Participants were block-randomised into one of three training groups (T1, T2 and T3 – identical to the training protocols utilised in the first study, see 3.2.4.5) and performed three sets of their allocated training protocol per session on each limb. They attended four sessions of training completing a total of 12 training sets on each limb.

4.2.2 Participants

Thirty participants completed the second study. The study design and procedures were approved by the University Ethics Committee (appendix 8.5). Participants were fully informed of study aims and procedures and gave their consent in writing (appendix 8.6). A convenience sample of staff and students at the University of East London that fulfilled the criteria of being in category 1 of the International Physical Activity Questionnaire (Craig et al, 2003) were recruited. Participants who met the inclusion criteria were invited to the human movement performance laboratory. The inclusion and exclusion criteria were identical to study 1 (see section 3.2.2).

4.2.3 Procedures

Participants attended the Human Motor Performance Laboratory at the University of East London on four occasions. In the first session, baseline characteristics were recorded as described in study 1 (see section 3.2.4). They were then randomly allocated to one of three training groups using a block randomized procedure. Following the warm-up procedure, participants were positioned on the isokinetic dynamometer, with the order of limb training randomised. They performed five MVC to determine their maximal strength which was used to determine their target force. They then performed three sets of their allocated training programme with a one minute rest period between training sets. This procedure was then repeated on the contralateral limb.

Another session was scheduled in the same week, at least one day apart. During the second session, participants completed the warm-up and three sets of their allocated protocol on each limb. Two further identical sessions were scheduled the following week, at least one day apart. On the fourth session, when participants completed the three training sets, they also completed five MVC following a one minute rest on each limb.

4.2.4 Data Analysis

The training performance of 24 sets completed by the two limbs over the 4 sessions was recorded to analyse the training performance measures as reported in study 1. Measurement of the left and right limb was recorded separately due to the potential effect of limb dominance on training performance.

Descriptive statistics were presented to explore the training intensity, force fluctuation and total work performed by participants in each training set completed. A direct comparison of the total work completed between training groups could not be conducted as participants were independent of each other. Evaluation of the total work completed was conducted by comparing the total work completed against the theoretical work for each participant.

IBM® SPSS® Statistics Version 20 was used to conduct repeated measures ANOVA to compare training performance between the first set and the last set completed by participants. Intra-class correlation coefficient ($ICC_{3,1}$) was used to determine the level of agreement between the theoretical total work and total work. Independent t-tests were conducted to assess whether the total work was different between groups and paired t-tests were conducted to assess whether there was a change in strength following repeated sessions for each group. A one-way ANOVA was conducted to assess whether the change in strength following repeated sessions was different between groups.

4.3 Results

4.3.1 Participants

Thirty participants (15 female, 15 male) were recruited from the staff and student cohort at the University of East London. Table 4.1 shows baseline characteristics. One-way ANOVA showed there was no significant difference between training groups in age, height, mass (p ranged from 0.11-0.21) or baseline strength (as measured by the mean peak torque to five MVC) for each side and direction (p ranged from 0.64-0.86).

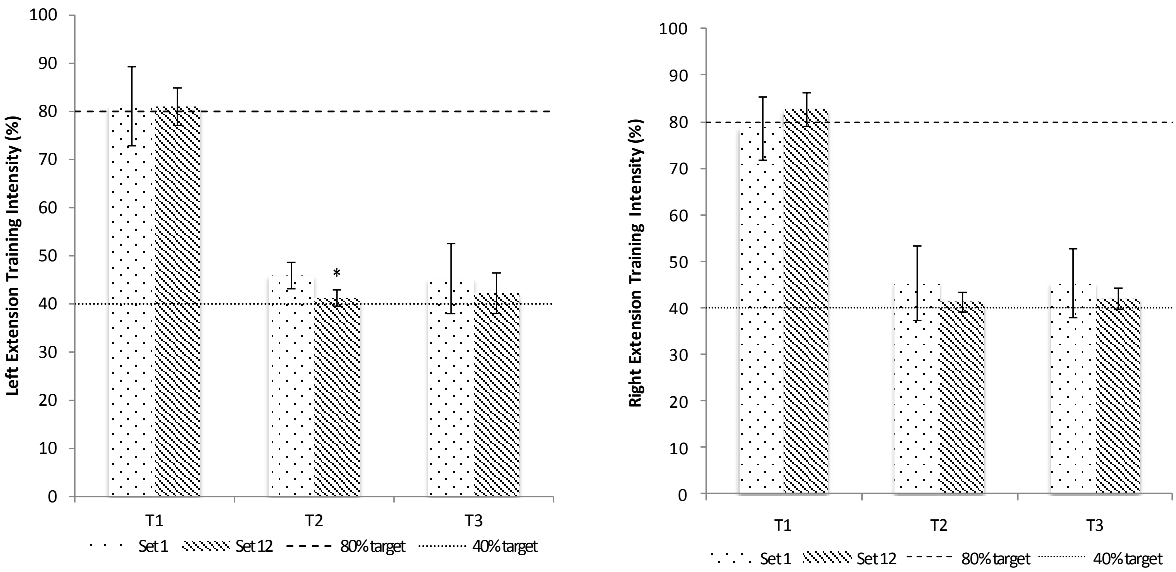
Table 4.1. Physical characteristics of the participants in study 2 (mean ±SD)

Group	Age (years)	Height (cm)	Mass (kg)	Mean Peak Torque (N·m) at $60°.s^{-1}$			
				Left Extension	Right Extension	Left Flexion	Right Flexion
T1 n=10	32 ± 4	173 ± 8	77 ± 14	120 ± 23	127 ± 24	65 ± 17	65 ± 15
T2 n=10	28 ± 7	166 ± 8	67 ± 13	112 ± 24	118 ± 36	62 ± 16	60 ± 18
T3 n=10	27 ± 7	169 ± 8	65 ± 12	123 ± 36	122 ± 36	61 ± 16	60 ± 23

4.3.2 Training Intensity

The training intensity for all training sets was examined and the results for set 1 and 12 are considered in this section. Figure 4.1 shows the mean extension training intensity completed in set 1 and set 12 of the training protocols for the left and right limbs, regardless of the order of training (as the order was randomised). For the left limb, both the first and twelfth set was completed by T1 at the target intensity and was not significantly different ($t_{(9)}$ = 0.0, p = 1.00) with lower variation in set 12 (set 1: 81 ±8%; set 12: 81 ± 4%). For the right limb, T1 was completed at a significantly ($t_{(9)}$ = -2.325, p < 0.001) higher intensity on average with lower variation (set 1: 79 ±7%; set 12: 83 ±4%). For T2, paired t-test showed the left limb trained at a significantly ($t_{(9)}$ = 4.644, p < 0.01) lower intensity in set 12 than set 1 (set 1: 46 ±3%; set 12: 41 ±2%). A similar trend was observed for the right limb, although differences were not significant (set 1: 46 ±8%; set 12: 41 ±2%, $t_{(9)}$ = 1.457 p = 0.18). For T3, paired t-test showed the left limb trained at a lower intensity in set 12 than set 1 (set 1: 45 ±8%; set 12: 42 ±2), although differences were not significant ($t_{(9)}$ = 2.236, p = 0.052). A similar trend was observed for the right limb, but differences were not significant (set 1: 45 ±8%; set 12: 42 ±2%, $t_{(9)}$ = 1.708, p = 0.122). The number of high intensity training sets completed below 70% MVC and low intensity training sets completed above 50% MVC was analysed. For extension, 3 of the T1, 2 of the T2 and 6 of the T3 training sets completed were outside such thresholds in the first set. In the last set completed, none of the training sets were outside threshold.

A) B)

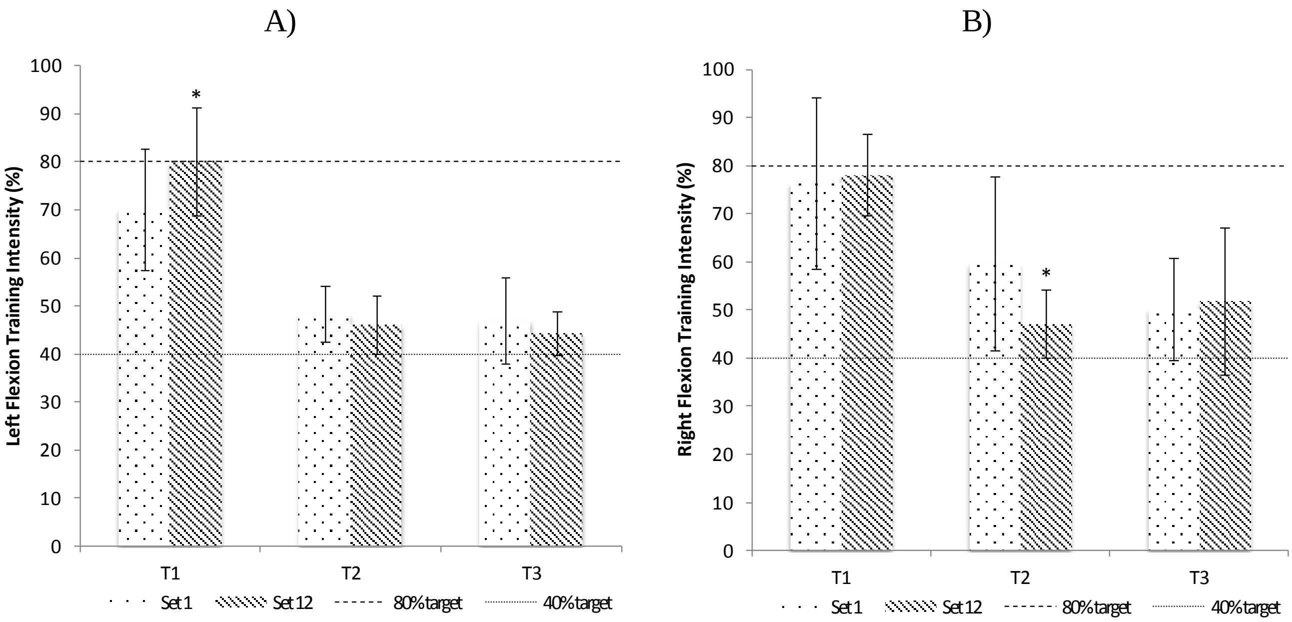


*p < 0.01

Figure 4.1. Mean (±SD) Extension Training Intensity (% of MPT) Achieved in Set 1 and Set 12 for A) left limb and B) right limb

Figure 4.2 shows the mean flexion training intensity completed in set 1 and set 12 of the training protocols for the left and right limbs. For the left limb, training intensity increased significantly ($t_{(9)} = -2.656$, $p < 0.05$) following repeated sessions but the level of variation remained high (Set 1: 70 ±13%; Set 12: 80 ±11%). This was also the case for the right limb, although differences were not significant (Set 1: 76 ±18%; Set 12: 78 ±8%, $t(9) = -2.80$, $p = 0.786$). For T2, the mean training intensity did not change ($t_{(9)} = 1.183$, $p = 0.267$) for the left limb (Set 1: 48 ±6%; Set 12: 46 ±6%) and although there was a significant ($t_{(9)} = 2.422$, $p < 0.05$) reduction in the right limb (Set 1: 60 ±18%; Set 2: 47 ±8%) training intensity remained above 45% following repeated sessions for both limbs. For T3, the mean training intensity there was no change following repeated sessions in the left limb (Set 1: 47 ±9%; Set 12: 44 ±5%, $t_{(9)} = 1.387$, $p = 0.199$) and the right limb (Set 1: 50 ±11%, Set 12: 52 ±15%, $t_{(9)} = -0.405$, $p = 0.695$).

The number of high intensity training sets completed below 70% MVC and low intensity training sets completed above 50% MVC was analysed. For flexion, 8 of the T1, 10 of the T2 and 9 of the T3 training sets were completed outside the threshold in the first set. In the last set completed, 5 of the T1, 6 of the T2 and 4 of the T3 training sets completed were outside the threshold.



*p < 0.05

Figure 4.2. Mean (±SD) Flexion Training Intensity (% of MPT) Achieved in Set 1 and Set 12 for A) left limb and B) right limb

4.3.3 Total Work

There was no significant difference in the total work achieved between T1 and T2 for any of the training sets completed ($p = 0.17 – 0.90$). The total work achieved in T3 was approximately half (44-53%, calculated as T3 total work / T1 (or T2) total work) the total work achieved in T1 and T2 for all conditions.

To determine whether participants improved in their ability to achieve the expected total work, the level of agreement between total work and theoretical work was examined for the first set of the first session and last set of the last session. Table 4.2 shows the extension total work and theoretical work for set 1 and set 12 of the training sets completed. For T1, the level of agreement between theoretical and total work was greater in set 12 than set 1 for the left (Set 1: $ICC_{3,1} = 0.35$; Set 12: $ICC_{2,1} = 0.58$) and right (Set 1: $ICC_{3,1} = 0.42$; Set 12: $ICC_{3,1} = 0.63$) limbs. A good level of agreement was observed in set 1 and set 12 in T2 for the left (Set 1: $ICC_{3,1} = 0.77$; Set 12: $ICC_{3,1} = 0.64$) and right (Set 1: $ICC_{3,1} = 0.73$; Set 12: $ICC_{3,1} = 0.70$) limbs. This was also the case for T3 for both left (Set 1: $ICC_{3,1} = 0.79$; Set 12: $ICC_{3,1} = 0.83$) and right (Set 1: $ICC_{3,1} = 0.76$; Set 12: $ICC_{3,1} = 0.83$) limbs.

Table 4.2. Mean (±SD) Extension Total Work (J, Theoretical and Actual) Completed for Set 1 and Set 12 for each side

Side	Protocol	Theoretical Work	Set 1	$ICC_{3,1}$	Set 12	$ICC_{3,1}$
Left	T1 – 80% 10 repetitions	1243 ± 255	1003 ± 197	0.35	1016 ± 191	0.58
	T2 – 40% 20 repetitions	1160 ± 259	1046 ± 184	0.77	1010 ± 167	0.64
	T3 – 40% 10 repetitions	634 ± 186	527 ± 158	0.79	535 ± 133	0.83
Right	T1 – 80% 10 repetitions	1322 ± 305	1016 ± 232	0.42	1099 ± 220	0.63
	T2 – 40% 20 repetitions	1223 ± 362	998 ± 394	0.73	988 ± 279	0.70
	T3 – 40% 20 repetitions	623 ± 169	501 ± 91	0.76	504 ± 131	0.83

Table 4.3 shows the flexion total work and theoretical work for set 1 and set 12 of the training sets completed. For T1, the level of agreement between theoretical and total work was greater in set 12 compared to set 1 for the right limb (Set 1: $ICC_{3,1}$ = 0.51; Set 12: $ICC_{3,1}$ = 0.68). The left limb also showed greater agreement in set 12, but not to the same degree (Set 1: $ICC_{3,1}$ = 0.26; Set 12: $ICC_{3,1}$ = 0.37). For T2, the level of agreement was lower in set 12 ($ICC_{3,1}$ = 0.64) than set 1 ($ICC_{2,1}$ = 0.82) for the left limb. The right limb for T2 showed greater agreement in set 12 compared to set 1 (Set 1: $ICC_{3,1}$ = 0.57; Set 12: $ICC_{2,1}$ = 0.72). T3 demonstrated greater agreement in set 12 compared to set 1 for the left (Set 1: $ICC_{3,1}$ = 0.72; Set 12: $ICC_{3,1}$ = 0.77) and right limbs (Set 1: $ICC_{3,1}$ = 0.75; Set 12: $ICC_{3,1}$ = 0.85).

Table 4.3. Mean (±SD) Flexion Total Work (J, Theoretical and Actual) Completed for Set 1 and Set 12 for each side

Side	Protocol	Theoretical Work	Set 1	$ICC_{3,1}$	Set 12	$ICC_{3,1}$
Left	T1	669 ± 167	485 ± 125	0.26	562 ± 123	0.37
	T2	641 ± 152	563 ± 154	0.82	513 ± 111	0.64
	T3	314 ± 75	264 ± 78	0.72	247 ± 47	0.77
Right	T1	678 ± 150	563 ± 183	0.51	562 ± 129	0.68
	T2	618 ± 170	670 ± 288	0.57	503 ± 138	0.72
	T3	306 ± 109	241 ± 76	0.75	264 ± 64	0.85

4.3.4 Force Fluctuation

Figure 4.3 shows the mean extension force fluctuation (%) for each protocol over the 12 sets completed. Force fluctuation values reduced with repeated sessions for T1 (Set 1: 12 ±3%; Set 12: 6 ±2%), T2 (Set 1: 17 ±8%; Set 12: 7 ±3%) and T3 (Set 1: 22 ±12%; Set 12: 9 ±4%). Repeated measures ANOVA showed there was a significant effect of set ($F_{(1, 27)} = 82.794$, $p < 0.001$) and set*training group ($F_{(2, 27)} = 4.143$, $p < 0.05$). Further analysis showed set 2 and subsequent sets were significantly different to set 1 ($p < 0.001$). There was also a significant difference between T1 and T3 ($p = 0.03$) for the change in set 12 compared to the first set.

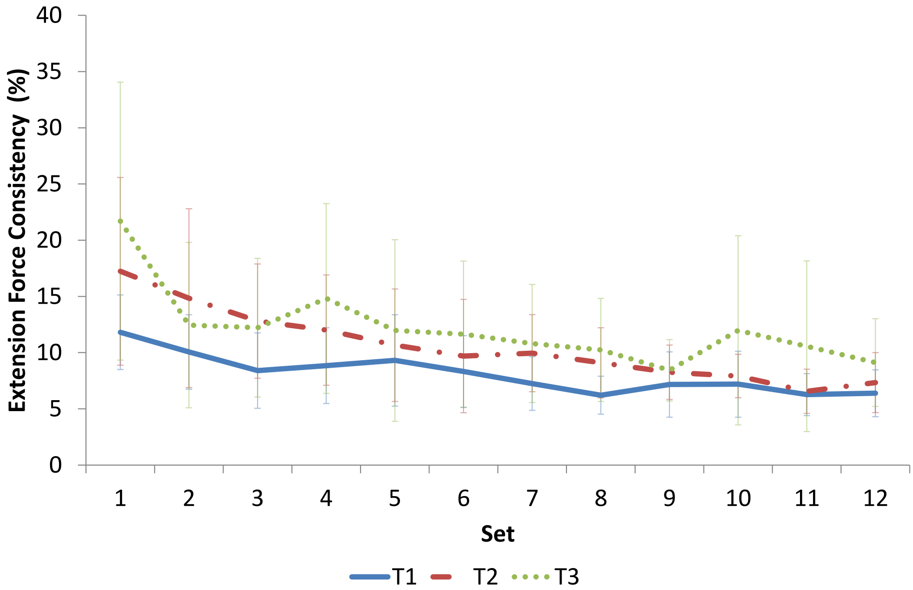


Figure 4.3. Mean Extension Force Fluctuation Achieved in Sets 1-12

Figure 4.4 shows the mean flexion force fluctuation (%) for each protocol over the 12 sets completed. Force fluctuation reduced with repeated sessions for T1 (Set 1: 11 ±5%; Set 12: 9 ±3%), T2 (Set 1: 17 ±5%; Set 12: 12 ±3%) and T3 (Set 1: 17 ±9%; Set 12: 11 ±4%). Repeated measures ANOVA showed there was a significant effect of set ($F_{(1, 27)} = 17.583$, $p < 0.001$) only. Further analysis showed set 4 and subsequent sets were significantly different to set 1 ($p < 0.001$).

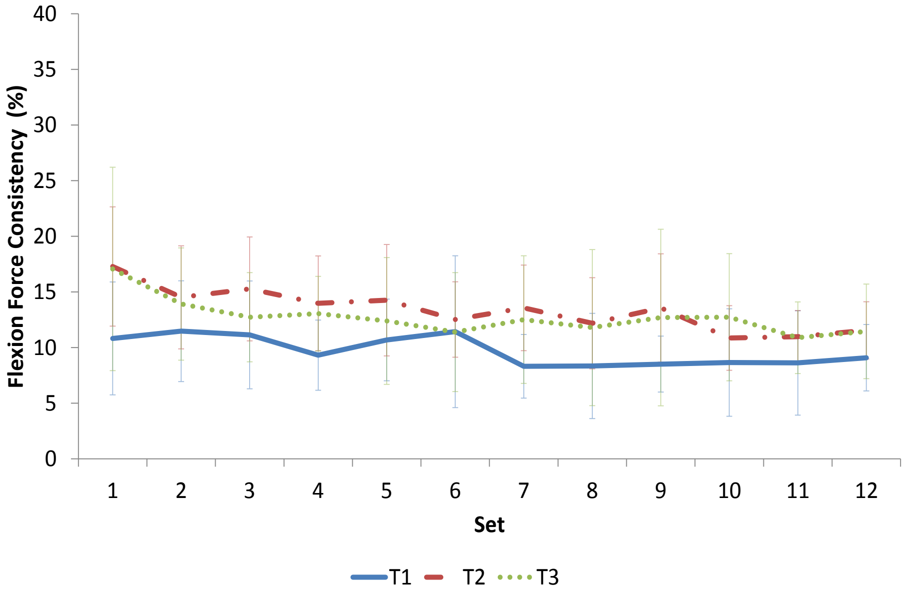


Figure 4.4. Mean Flexion Force Fluctuation Achieved in Sets 1-12

4.3.5 Strength Changes

Table 4.4 shows the peak torque achieved during the five maximal voluntary contractions recorded at baseline and after four sessions of training. The change in strength was compared between training groups using a one-way ANOVA. This showed that there was a significant difference for the change in peak torque between training groups for left extension ($F_{(2, 27)} = 3.46$, $p < 0.05$) and flexion ($F_{(2, 27)} = 4.63$, $p < 0.05$) but not right extension ($F_{2, 27)} = 3.02$, $p = 0.065$) or flexion ($F_{(2, 27)} = 0.11$, $p = 0.90$). Post-hoc paired t-test showed there was a significant difference for the change in peak torque between T1 and T3 for left extension ($p = 0.043$) and flexion ($p = 0.036$). There was a significant difference between T1 and T2 for left flexion ($p = 0.047$) but not left extension ($p = 0.90$).

Table 4.4. Mean (±SD) MVC Peak Torque before and after training for each side and direction

Side/ Direction	Protocol	Peak Torque (N·m)		% Change
		Baseline	After 4 sessions	
Left Extension	T1	130 ± 22	150 ± 28**	18 ± 17
	T2	124 ± 25	135 ± 42	8 ± 20
	T3	136 ± 39	130 ± 38	-3 ± 9
Right Extension	T1	141 ± 24	153 ± 23*	10 ± 12
	T2	128 ± 40	133 ± 38	6 ± 15
	T3	135 ± 38	130 ± 43	-4 ± 8
Left Flexion	T1	71 ± 19	85 ± 18**	22 ± 19
	T2	69 ± 18	70 ± 20	2 ± 22
	T3	67 ± 18	67 ± 16	1 ± 9
Right Flexion	T1	72 ± 18	78 ± 19	9 ± 17
	T2	67 ± 18	71 ± 18	7 ± 14
	T3	69 ± 32	73 ± 25	11 ± 24

*$p < 0.05$; **$p < 0.01$

4.4 Discussion

The main aim of study 2 was to assess whether there was a change in training performance with repeated practice of sub-maximal isokinetic training protocols and whether there were indications of a differential response to the training protocols. Following repeated sessions, the mean training intensity for extension was closer to the target training intensity for all training groups with lower variation between participants. In set 12, all participants performed the extension training set within 10% of target training intensity. The total work achieved in T1 was in greater agreement with the theoretical work, equivalent to the level of agreement for the low intensity training protocols. This shows that there was sufficient differentiation in the training intensity between high and low intensity training protocols. The improvement in the ability of all participants to train at the target intensity indicates that they were able to meet the target force during the resisted contractions. It's possible that this was due to an improvement in the ability to modulate the neural drive (Hodson-Tole & Wakeling, 2009).

For flexion, participants in the low intensity groups trained at an intensity above 45% on average, despite repeated practice. However, there was a moderate level of agreement between theoretical and total work for the low intensity groups. There was an improvement in the force fluctuation with repeated sessions compared to the first set completed for both extension and flexion.

The improved ability to maintain a target force was previously examined by Hortobagyi et al. (2001) by evaluating the effect of strength training on the force error during submaximal isometric contractions in healthy elderly. They found low and high intensity training reduced the absolute force error in maintaining a concentric target force of 25N by 28% and 35% respectively. Interestingly, the high intensity group achieved a greater improvement in maintaining the target force than the low intensity group despite the measure of target accuracy, of using a 25N target force, more closely replicated the low intensity training. However, Hortobagyi et al. (2001) found the force error arose from exclusively overshooting the target force. This can be attributable to the low target force used to measure target accuracy.

In the current study, the variation in training intensity for the high intensity protocol resulted from performing a number of training sets below 70% MVC whilst for the low intensity protocol a number of training sets were performed above 50% MVC. With repeated practice, all participants were able to generate the forces required for the high intensity target for extension and given the lower variation in the mean training intensity shows that this was achieved more consistently. The changes are likely to have resulted from the neural changes associated with progressive resistance exercise.

Previous studies have shown an improvement in motor unit recruitment and firing frequency as shown by an increase in the amplitude of surface electromyography following training (Moritani and de Vries, 1979). As these changes are observed without changes in muscle cross-sectional area in the early stages of progressive resistance exercise (Hickson et al., 1994; Akima et al., 1999), it is suggested that changes in the neural drive are solely responsible for the improvement in achieving the training intensity. As neural activity has been shown to increase in the primary motor cortex as greater force is exerted (Dettmers et al., 1996), Caroll et al. (2001) suggested fewer motor neurons would need to be recruited following training to achieve the same level of force. In terms of motor control they suggested that this would reduce the magnitude of cortical activation which in turn would reduce the extent of activation of neural elements that interfere with motor task performance leading to more efficient task performance (Caroll et al., 2001). The current study adds evidence to the potential effect of resistance training on motor control. However the exact mechanisms responsible for the transfer of increased muscle strength to an improvement in motor control are uncertain due to a lack of evidence.

As sedentary participants were used in this study, it is likely that some of them may not have been able to fully activate their muscles voluntarily. Several studies have shown, using the interpolated twitch technique, that healthy individuals are not able to activate all available motor units at an optimal firing frequency (Dowling et al., 1994; Knight & Kamen, 2001). Hartman et al. (2011) found that participants who were experienced in resistance training were able to maintain their ability to activate their muscles, as measured by the interpolated twitch technique, following bouts of fatiguing exercise whilst untrained participants could not. Although the trained participants in their study had years of experience, the results of the current study suggest the improvement in the ability to achieve target forces may have resulted from an improvement in muscle activation, even over a short training period.

The synchronicity of motor unit activation as described by Gabriel et al., (2006) may provide another explanation for the improvement in achieving the target training intensity. Single muscle action potentials can have significant effects on the force produced by muscles (Clamann and Schelhorn, 1988). The ability to simultaneously activate motor units and modulate activation may have improved following repeated practice resulting in the ability to produce a consistent force throughout the contraction. It was previously observed the untrained individuals demonstrated lower synchronicity than trained individuals (Semmler and Nordstrom, 1998) and training resulted in the improved ability to activate motor units synchronously (Milner-Brown, 1975). However, some studies have found increased synchronicity increases the force fluctuation during isometric contractions (Halliday et al., 1999; Yao et al., 2000)

Improved performance during training may also be attributable to improved resistance to fatigue. Muscle fatigue is characterized by a reduction in maximal force following the performance of activity due to various physiological factors, such as the accumulation of metabolites within muscle fibres (Enoka & Duchateau, 2008). Accumulation of metabolites may have restricted the ability to perform sub-maximal contractions at the beginning of training. Lorist et al. (2002) described fatigue as a decline in an individual’s ability to produce force after performing motor task for relatively long periods (typically 7 minutes). They noted that sub-maximal contractions are sustained by progressively increasing central drive as shown by a reduction in cognitive performance during fatiguing protocols. Given that the protocols involved sub-maximal contractions and the extent to which participants demonstrated a change in central drive was not measured, it is unclear how fatigue influenced the ability to perform the protocols. However, it is likely that the neuromuscular changes during training would have improved participants ability to be resistant to fatigue.

Improvements were observed for extension contractions but large variation in the mean training intensity of flexion contractions remained with repeated practice. A number of training sets for flexion were performed at intensity lower than 70% for T1 and higher than 50% for T2. The poorer training performance may be attributable to the differences in muscle composition and anatomy between the quadriceps and hamstrings, as noted in chapter 3. Concentric motor control of the hamstrings may be poorer than the quadriceps due to differences in the way these muscles are used in activities of daily living. The quadriceps are frequently used concentrically activities of daily living such as the sit to stand movement. However, the hamstrings are typically utilized eccentrically during the late swing phase of walking, to decelerate the distal limb (Perry and Burnfield, 2010). Montgomery et al. (1994) investigated EMG patterns of the hamstrings and found that hamstrings are most active during the late swing phase. Therefore control of force in a sitting position, with the hips and knees flexed where the length of the muscle is much shorter may be more difficult to achieve. In addition to this, impairment in motor control in the hamstrings may also be responsible for this. Cameron et al. (2003) found that the high prevalence of hamstring injury in sport (Orchard and Seward, 2002) may be explained by the lack of ability to control the limb during the swing phase of gait as they found movement discrimination predicted hamstring injury.

The main finding in study 1 was that there was a larger deficit in the total work relative to theoretical work in T1 compared to T2. This was also the case in the first set of study 2, where the total work produced by T1 group was much lower than the theoretical total work with an agreement of 0.35-0.51 ($ICC_{3,1}$). With repeated practice however, the level of agreement for the extension training sets improved from 0.35 to 0.58 for the left limb and from 0.42 to 0.63 for the right limbs. With the exception of left flexion, all conditions showed, through its agreement with theoretical work, that the T1 and T2 protocols were matched for the total work completed whilst T3 produced relatively half the total work per training set. An improvement in the agreement between total and theoretical work indicates participants improved in their ability to meet the target force and/or maintain this for a longer period for over the contraction. This is supported by

Tracy & Enoka (2006) and Hortobagyi et al. (2001) who found force fluctuation of an isometric contraction around a fixed target reduced following strength training. However, as previously discussed, potential ceiling effects may be present using ICC to compare theoretical work and total work due to the parabolic nature of the force curve. This study shows indications of this as there was no apparent increase in ICC for T2 or T3 training groups.

There remained a difference between the left and right limbs for the agreement between total work achieved and theoretical work. Although there was an improvement in the agreement between total and theoretical work for the left limb, the level of agreement at baseline was lower in the left limb and subsequently the agreement in the last set completed was also lower when compared to the right limb. This indicates that both limbs showed equivalent improvements in the ability achieve the specified total work but the actual agreement is lower in the left limb.

The differences observed may have been due to the effect of limb dominance. Limb dominance is characterized by the ability to execute movements with more accuracy and consistency with the dominant limb (Grouios, 2006). In terms of neuromuscular control, Bagesteiro and Sainburg (2002) found that the dominant upper limb has greater anticipation of planned movements with distinct neural control compared to the non-dominant limb. This may contribute to the ability to control the level of force exerted during the sub-maximal isokinetic contractions. Although hand dominance is indicative of leg dominance (Balogun and Onigbinde, 1992), these findings may not directly transferrable as the ability to control force differs between the upper and lower limbs (Christou et al., 2003).

Following repeated sessions, the force fluctuation reduced. For extension, the force fluctuation immediately reduced following first set as the force fluctuation in set 2 and subsequent sets were significantly lower. For flexion, this occurred slightly later as set 4 and subsequent sets demonstrated significantly lower force fluctuation.

Participants were instructed to control the level of force produced during the dynamic contractions. This process relies on the afferent feedback mechanisms (such as muscle visco-elasticity, feedback from muscle spindles and Golgi tendon organs), which give a sense of how much force is being exerted as well as central processing to modulate the force according to the visual target. As such, the ability to perform these protocols depended on the ability of participants to use these systems to accurately control the level of force exerted. This is achieved through the synchronous mechanical summation of motor unit forces and the pattern of output from the motor neurone pool (Enoka et al., 2003; Taylor et al., 2003). The results in the current study concur with previous findings where resistance training resulted in a reduction in force fluctuation for dynamic contractions (Tracy, 2004).

The improvement in force fluctuation with repeated sessions shows a learning effect where participants improve their ability to control the force that is exerted during the dynamic contractions. Instructing participants to control the level of force exerted may have an additional effect on the neural adaptations following PRE due to this learning effect. This is consistent with Tracy et al. (2004) who, in a sample of older adults (65-80 years old) found larger improvements in MVC for their high intensity group that were instructed to control the velocity of movement through visual feedback (31%) compared to their high intensity group without the visual feedback (25%) following 16 weeks (48 sessions) of training.

Following four sessions of training, participants in the T1 group observed an increase in extension strength of 18 ± 17% for the left side and 10 ± 12% for the right side. These changes are large considering the short duration of the training programme which may be explained by the participants' low training status. It should also be considered whether the explicit learning processes involved had an additional positive effect on outcomes. This is supported by Tracy et al. (2004) who found resistance training by older adults who were asked to produce steady resistive contractions, by controlling the velocity of movement, achieved larger strength gains than older adults producing resistive contractions without controlling the velocity of movement.

Short term improvements in progressive resistance exercise are seldom reported despite strength commonly being re-evaluated every 2 weeks as part of adjustment of load to maintain the intensity of training. In older adults, Tracey et al. (2004) reported a similar improvement of 12% (estimated from graphical data) in knee extension MVC after 6 sessions of training over 2 weeks. In untrained males, Ogasawara et al. (2013) reported an improvement of 7% (estimated from graphical data) in strength in the high intensity group after 9 sessions over 3 weeks. However, this study conducted progressive resistance exercise on the upper limb so results are not directly comparable.

Due to the short training period, improvement in muscle strength is likely to have resulted from neural adaptation rather than muscle hypertrophy (Aagaard et al., 2002). Hickson et al. (1994) and Akima et al. (1999) only found overt changes in muscle hypertrophy after the eighth and subsequent weeks of training.

There were indications of a differential response to training between the protocols which favoured T1 in some conditions. However, differences between training groups were not always significant. The changes observed in the T1 protocol are indicative of task-specificity, as the T1 protocol more closely replicates the MVC. This may account for the differences observed between T1 and T2 over the four sessions. Over a longer period however, participants performing T2 could show similar changes to T1. In the study by Ogasawara et al. (2013), the authors did not observe an increase in strength in the low intensity group at 3 weeks, but did observe a significant increase at the end of training after 6 weeks, although the change observed in the high intensity group was significantly higher.

4.5 Study Limitations

This study raises the importance of measuring training performance in the evaluation of the effects of training parameters on outcomes. However, within the results there were also indications of other factors that may affect the response to training. Training status is a key factor identified in the literature reviews when considering dose response. Therefore capturing participants' activities levels as an additional variable should be considered when evaluating outcomes. As previously cited in 3.5 there are many factors which could affect the potential outcomes which should also be considered and brought into the evaluation of training parameters on outcomes.

As this study was conducted over four sessions, there was no re-evaluation of MVC and adjustment of target forces as conducted in progressive resistance exercise programmes performed for over 2 weeks. It's therefore unknown whether the training performance would be maintained when targets are re-evaluated after the second week. Although the relative intensity of training would remain the same after readjustment, the initial improvements in neural drive may have contributed to the ability to maintain target forces. Evaluation of training performance over a longer period is therefore recommended.

It is also important to note that there was real-time visual feedback to participants and the experimenter on participants training performance. This may have had a behavioural effect where participants were influenced to maintain their training performance. These results cannot therefore be applied to the traditional forms of resistance training using physical weights. It is therefore expected that the training performance in previous studies using isoinertial equipment was inconsistent between participants and so not all participants trained at the intensity and volume as specified by the protocol.

Although there were indications of a differential response to training, it must be noted that the five MVC contractions recorded at the end of training were recorded at the end of session 4. They therefore may have had an impaired ability to generate maximal forces. Given that participants had completed three sets of training prior to the MVC and only one minute of rest was provided after the three sets of training, the actual changes may have been larger if they had been recorded in a separate session.

4.6 Summary

With repeated practice, all participants improved in their ability to perform extension manoeuvres more accurately at the intensity specified by the protocol. This resulted from an improvement in the consistency of the achieved training intensity between contractions. The high intensity training protocol was performed such that there was a greater level of agreement in total work with theoretical work indicating participants learnt how to control the level of force exerted so they improved in the ability to achieve and maintain the target force throughout the contraction. Therefore there is a need to measure and monitor training performance when evaluating the effectiveness of progressive resistance exercise. Without reporting training performance, it is difficult to evaluate whether participants performed the training according to the training protocols. It may explain the lack of consistency in the evaluation of optimal training parameters as well as the magnitude of change observed following progressive resistance exercise. This is particularly relevant for older adults and those with specific impairments as they may demonstrate a much lower ability to perform training as specified by the training protocol.

Training performance may also vary between different types of muscle groups involved as well as limb dominance. For flexion manoeuvres, many participants were still not able to train at the specified intensity or produce consistent force contractions in a set. Although outcomes for flexion muscle strength have consistently been reported separately to outcomes for extension muscle strength, the outcomes between non-dominant and dominant limbs have not been reported separately. Limb dominance may have an effect on training performance and as such the response to training may differ. It is therefore recommended that outcomes for left and right limbs be reported separately.

5.0 Evaluating the Training Performance of Stroke Survivors Completing Three Sub-maximal Isokinetic Training Protocols

5.1 Introduction

Stroke is a common neurological disorder where interruption of the blood supply to the brain causes damage to the neural tissue (WHO, 2001). Muscle weakness is a common impairment resulting from stroke (Knutsson & Martensson, 1980, Bohannon, 1995). Despite the spontaneous recovery which occurs in the first six months following a stroke (Cramer, 2008), those affected are significantly weaker than healthy matched controls (Clark et al, 2006). A number of studies have reported that muscle strength correlates with timed activity measures (Kim & Eng, 2003; Canning et al., 2004; Lin 2005; Flansbjer et al., 2006) leading researchers to investigate the importance of strength training to improve physical activity (Ada et al., 2006). Progressive resistance exercise forms part of a number of interventions that can be utilized post-stroke depending on observed impairments such as: sensory intervention, arm re-education, gait retraining, fall prevention, speech therapy and management of spasticity (RCP, 2012).

Studies that have evaluated the effectiveness of progressive resistance exercise in stroke survivors have utilised a range of different training methods and parameters making it difficult to determine the influence of training parameters. Identifying the training parameters that give the optimal training response is important for effective service delivery. However optimal strength training regimes that deliver the most beneficial effect on strength and activity have yet to be understood (Ada et al., 2006).

In order to evaluate optimal training parameters, recording training performance is a key factor. Recording training performance during intervention will aid in the evaluation of progressive resistance exercise. The previous two studies have shown that training performance can be recorded using submaximal isokinetic training programmes. Although training performance improved with repeated practice, stroke survivors may present with an impaired ability to train at the intensity and work specified. This is because they present with motor impairments that may limit the ability to control motor unit recruitment and firing frequency. In a pilot study, using a surface electromyogram Suresh et al. (2011) reported the paretic limb demonstrated a lower mean motor unit firing rate and motor unit recruitment range compared to the non-paretic limb.

The training protocols established allow for the evaluation of intensity and volume on the effectiveness of progressive resistance exercise whilst recording the training performance during the intervention. The main aim of this study was to evaluate whether stroke survivors could perform sub-maximal isokinetic training protocols and explore whether training performance changed with repeated practice. The second aim of this study was to assess whether impairments and activity limitations were altered following participation in the progressive resistance exercise programme. This required the evaluation and selection of outcome measures to form an assessment battery.

5.1.1 Selection of outcome measures

Normal function and life role participation is the goal of rehabilitation (Daly, 2007). Exercise interventions target impairments and activity limitations which in turn are intended to improve functioning in daily life. The selection of outcome measures should therefore be guided by the intended effect of the intervention (Barak and Duncan, 2006). As stroke survivors present with multiple deficits in health and functioning (RCP, 2012), no single outcome measure is able to capture all aspects of disability as well as the effects of an intervention.

The International Classification of Functioning and Disability (ICF) is a globally agreed framework which classifies outcomes into the three categories: impairment (reported problems in body functions), activity limitations (reported problems activities of daily living) and participation restrictions (reported problems in participating in societal situations) (WHO, 2001). It is used to guide the identification of measures so that the assessment battery together measures all aspects of functioning and disability relevant to stroke survivors. For the purposes of this study, measures of impairment and activity limitations were the main focus.

Progressive resistance exercise is specifically designed to improve muscle strength and has been shown to be effective at increasing strength in stroke participants (Ada et al, 2006). Therefore, the first and most obvious group of measures for assessing for impairment of muscle strength and function were identified (ICF group b730). Studies have evaluated changes in strength isometrically (Cramp et al., 2006), and isokinetically at different speeds (Engardt et al. 1995; Cramp et al., 2006). This provided a comprehensive view of how progressive resistance exercise had an effect on the different muscle functions.

Activity measures have commonly been utilised in studies utilising progressive resistance exercise in stroke survivors (see chapter 2). The lower limb musculature is responsible for providing the forces necessary to perform mobilisation activities such as getting out of bed, sit to stand and walking (Perry and Burnfield, 2010). In walking, lower limb musculature is activated in a specific pattern to cause forward movement. The quadriceps are activated during the loading phase of gait to maintain knee extension whilst the hamstrings are activated at terminal swing to decelerate the extending knee (Perry and Burnfield, 2010). Targeted training of these muscles has shown to lead to changes in walking such as gait velocity (Engardt et al., 1995; Sharp, 1997; Teixeira-Samela, 1999; Cramp et al., 2006).

Gait is a major problem for stroke survivors. It is described under level 3 in the ICF (d450), which is further split into walking: short distances (d4500), long distances (d4501), on different surfaces (d4502), around obstacles (d4503) or other/unspecified. A variety of measures can be used to measure gait (ICF, 2004). Gait velocity has been the most commonly used measure for walking function which can predict health status and service use (Studenski et al., 2003). Although initially thought of as an ideal measure for function (Wade, 1992), recent reports show dissociation between gait velocity and the quality of gait. In a cross-sectional study, Patterson et al. (2010) measured gait velocity and gait symmetry (as measured by swing time and step length) in groups of stroke survivors 0-3, 3-12, 12-24, 24-48 and >48 months following stroke. They found no difference in gait velocity between the different stages ($p = 0.36$) but swing time symmetry and step length symmetry were significantly worse in the later stages following stroke. Therefore, in addition to gait velocity, measures that are able to record the gait symmetry may also be of interest as they show improvements in the pattern of walking which may not directly translate to improvements in gait velocity. Teixeira-Samela et al. (2001) found stroke survivors improved spatial-temporal parameters of gait such as cadence, strength length and the symmetry ratio following progressive resistance exercise.

Measurement of walking distance over long durations is a useful indicator of community ambulation. When ambulating outside to reach a particular destination, the physical ability to walk for long periods may be a limiting factor and thus successful community integration. It should be noted that the measurement of walking distance alone does not reflect ability to walk in the community, especially as it does not measure the ability to negotiate uneven terrain or attentional demands which are environmental factors faced by individuals walking in the community (Haggard et al., 2000; Bowen et al., 2001). However, improving walking distance may be important for individuals that are limited in this capacity.

Changes in sit to stand performance has been observed by Flansbjer et al. (2008) who utilised progressive resistance exercise in stroke survivors. Sitting to standing is a complex task as it involves transition from a 3-point support to a 2-point support (Galli et al., 2008) and is one of the frequently reported activities associated with falls (Hyndman et al., 2002). The timed up and go was used to measure sit to stand performance. The sit-to-stand and stand-to-sit tasks performed in the TUG are an essential aspect of activities of daily living (Dehail et al., 2007). Goulart & Valls-Solé (1999) investigated EMG patterns of the leg, trunk and neck muscles in different patterns of sit to stand movement. They found for all conditions, only the paraspinal, quadriceps and hamstring muscles were consistently activated denoting that these muscles were the prime movers for performing the sit to stand movement. Moving from sitting to standing positions and vice versa is accompanied by movements of centre of mass in the coronal and sagittal planes simultaneously. Therefore muscle strength as well as the ability to coordinate muscle actions could influence time to task completion.

5.2 Methods

5.2.1 Participants

Ethical approval was obtained from the University of East London Ethics Committee (appendix 8.7) and the East London REC-3 National Research Ethics Service (appendix 8.8). Stroke survivors were identified from the Newham University NHS Hospital Trust and community stroke registers. Potential participants were identified by clinicians based on the inclusion/exclusion criteria (see below) and were given an invitation letter (appendix 8.9). Potential participants expressing interest were contacted by the researchers to explain the study and obtain written consent (appendix 8.10).

5.2.1.1 Inclusion Criteria

Potential participants were recruited according to the following inclusion criteria:

- Able to provide informed consent and follow simple instructions
- Suffered their first ever stroke incident which occurred 6 months to 5 years prior to the study
- Mobile without human instance either with or without assistive devices such as a walking stick

5.2.1.1 Exclusion Criteria

Potential participants who presented with any of the following conditions were excluded from the study:

- Uncontrolled: hypertension, diabetes, cardiac disease
- Implanted devices such as cardiac pacemaker
- Myocardial infarction or cardiac surgery in last 3 months
- Known untreated aortic stenosis
- Any other cardiac condition precluding them from exercising
- Pulmonary embolism or deep vein thrombosis in last 3 months
- Known untreated aneurysms
- Musculoskeletal condition exacerbated by exercise
- History of other neurological conditions

5.2.2 Study Procedures

Participants attended the Human Movement Performance laboratories at the University of East London on 15 occasions. The first occasion was a familiarisation session where participants undertook assessment of muscle performance, gait velocity and spatial and temporal parameters. This session also incorporated recorded assessment of the Berg

Balance scale. On the second occasion, participants undertook the assessment procedures by a blinded assessor including repeat assessment of muscle performance and also of gait velocity, spatio-temporal parameters, timed up and go test and the six minute timed walk test.

Participants were then randomly allocated to a training programme (T1, T2 or T3 – identical to the protocols utilised in the first two studies) and undertook 12 supervised sessions of progressive resistance exercise over 6 weeks. Following this, they undertook a final assessment session incorporating all the timed performance measures previously reported. For the purposes of illustration, the participant undertaking T1 protocol will be labelled P1, the participant undertaking T2 protocol will be labelled P2 and the participant undertaking T3 protocol will be labelled P3.

5.2.3 Assessment Procedures

Literature that maps the content of outcome measures to the categories of the ICF was used to identify and group potential outcome measures currently used in stroke rehabilitation research (Salter et al, 2005a; Salter et al., 2005b; Mudge et al, 2007). The outcome measures used in studies in stroke participants completing progressive resistance exercise were also identified and grouped. Given there is no general consensus for the battery of measures used in clinical stroke trials, Barak and Duncan (2006) give guidelines for the selection of outcome measures. This includes evaluation of psychometric properties including floor and ceiling effects, their results in the population of interest and administrative issues. Specifically for the current study, measures that have demonstrated responsiveness to progressive resistance exercise were given preference to final selection.

5.2.3.1 Equipment

Participants' height was measured using a stadiometer (Hadlands Photonics, Australia). Weight was measured using standard weighing scales (UC-300 Tokyo, Japan) and was recorded in kilograms to the nearest one decimal place. A Lode Corival™ (Lode, Netherlands) electro-magnetically braked cycle ergometer was used to warm-up participants at the start of the session. A Biodex Multi-Joint System II isokinetic dynamometer was used to assess muscle strength and function whilst the Kin-Com® 500H isokinetic dynamometer was used for the training procedure. The electromyography equipment consisted of a Neurolog NL824 pre-amplifier NL820 4 channel isolator and NL135 low pass filter. The low pass filter was set to 1 kHz, high pass was set to 10Hz, with the 50Hz notch turned on. The gains started at x1 and were increased as necessary. The EMG signals were recorded using a single disc ground electrode and two adhesive electrodes 2 cm apart. The signals were passed through an analogue to digital signal converter (CED 1401, Cambridge electronic design Ltd) and collecting on a computer using Spike 5.2 software.

5.2.3.2 Muscle Impairment Measures

Muscle performance of the paretic and non-paretic limbs was assessed using the Biodex Multi-Joint System II isokinetic dynamometer. As training was conducted on the Kin-Com, use of another dynamometer for muscle assessment minimised the effect of familiarity. With the knee in 90˚ flexion, isometric muscle strength of the knee extensor and flexor muscles were recorded for two repetitions each with a one minute rest between repetitions. Isokinetic muscle strength was recorded from five repetitions, at each of the three speeds: 30, 60 and $90^{\circ}s^{-1}$ (Cramp et al, 2006). Electrical activity of the agonist (vastus lateralis) and antagonist (biceps femoris) was measured during these muscle contractions, using electromyography (Engardt et al, 1995). Voluntary activation of the knee extensor muscles, of the paretic and non-paretic limbs, was then recorded by electrically stimulating the muscle using single twitch stimulation at 1Hz (Rutherford et al, 1986). Only the muscle strength assessments are reported in this study.

5.2.3.3 Activity Measures

Balance performance was assessed using the Berg Balance Scale (Berg et al., 1992) and was only recorded at the beginning of the study to establish baseline activity levels. A range of timed performance measures were used to assess the effect of progressive resistance exercise on activity limitations (gait velocity, six minute timed walk, time up and go). Spatial and temporal parameters of gait were recorded using the GaitRite mat (Youdas et al., 2006). Gait velocity was measured during a self-selected speed of walk over a 10m walkway with the GaitRite mat forming part of this walkway. Sit to stand performance was measured using the standardised timed up and go test (Podsialdo & Richardson, 1991). Walking endurance was measured using the 6 minute timed walk test (Enright, 2003).

5.2.4 Training Procedure

Participants were allocated randomly to one of the three training programmes (T1, T2 and T3 – identical to the training protocols utilised in the first study, see 3.2.4.5). They were asked to attend 12 training sessions over 6 weeks. A minimum of 10 training sessions were required for the results to be included in the analysis. It was important that participants completed, as much as possible, an equal number of sessions to standardise the volume between groups in regards to the training frequency.

Participants cycled for 5 minutes at 20W at the beginning and end of each session for a warm up and cool down. Participants then completed three sets of their allocated training protocol for the paretic and non-paretic limb knee extensor and flexor muscles on the Kin-Com isokinetic dynamometer. Participants trained isokinetically at $60^{\circ}s^{-1}$ at a percentage of the peak force they produced during the isokinetic assessment at $60^{\circ}s^{-1}$. Similar to the previous studies, T1 protocol involved training for ten repetitions per set at 80% of the peak force produced during maximal voluntary contractions. T2 trained for twenty repetitions per set at 40% of the peak force. T3 trained for ten repetitions per set at 40% of the peak force. Isokinetic muscle strength at $60°s^{-1}$ was re-assessed every two weeks and the targets adjusted to maintain them at the specified training intensity.

5.2.5 Data Analysis

Training performance for the extension and flexion manoeuvres were reported separately for all performance measures to account for the different muscle groups involved. The measures were also reported separately for the non-paretic and paretic limbs.

As previously reported, three measures were recorded to assess the performance of the sub-maximal training protocols: training intensity, total work and force fluctuation. These variables were recorded for each set completed in the training protocol. As muscle assessment was repeated every two weeks, calculation of these measures was based on the last available recorded assessment of muscle strength. Each participant was assessed for their ability to train within ±5% of the target training intensity. Training performance after the 12th set was of particular interest as it had taken the healthy sedentary individuals this long to perform at the specified intensity consistently.

The force fluctuation was also recorded as previously reported and represented as a time series for each set completed. Participants were assessed with how consistent they were able to perform the protocols in comparison to healthy sedentary individuals and whether there were any apparent trends over repeated sessions.

The total work completed over the training period was compared to the theoretical work over the training period as an integral of the total work and theoretical work for each training set completed. The percentage difference in total and theoretical work was reported.

Due to the lack of sufficient data to conduct statistical analysis, observations were made as to whether there was a differentiation in the training intensity achieved and judgement was made as to whether stroke survivors completed the training as specified by the protocol.

5.3 Results

It was intended that a minimum of 8 participants would be recruited to each training group. During the first year of recruitment, 90 stroke survivors were identified by clinicians. Of these survivors, 13 expressed interest and of these, four survivors consented to participate. Three stroke survivors completed the training programme and are presented as individual case studies.

5.3.1 Participant Characteristics

Table 5.1 shows the physical characteristics of the three stroke participants. Table 5.2 shows the baseline training target values set for each participant and following reassessment. Participant P1, who was female, suffered a left hemiplegic stroke 11 months before commencement of the studies. P1 was independently mobile and able to independently extend and flex their paretic and non-paretic limbs against resistance. P1 achieved a score of 50 on the Berg Balance Scale. Due to data corruption, set 3 of session 1 for the paretic limb and set 3 of session 10 of the non-paretic limb was not available for subsequent analysis.

Participant P2, who was male, had suffered a right hemiplegic stroke 21 months before commencement of the studies. P2 was independently mobile and able to independently extend and flex their paretic and non-paretic limbs against resistance. P2 achieved a score of 56 on the Berg Balance Scale. At the time of the study, P2 was also participating in martial arts three times a week. During the study, this participation reduced to 1 time per week.

Participant P3, who was female, had suffered a left hemiplegic stroke 28 months before commencement of the studies. P3 was independently mobile and was able to independently extend and flex their paretic and non-paretic limbs against resistance. P3 achieved a score of 56 on the Berg Balance Scale. P3 was not participating in any routine exercise but was working part time up to 20 hours per week. Due to data corruption, data for sessions 2, 4, 11 and 12 were not available for subsequent analysis.

Table 5.1. Physical characteristics of the three stroke participants

Partic-ipant	Age (years)	Height (cm)	Mass (kg)	BBS	Gait velocity ($m.s^{-1}$)	Isometric Non-paretic Strength (N·m) Extension (Flexion)	Isometric Paretic Strength (N·m) Extension (Flexion)
P1	69	159.5	99	50	0.91	117 (34)	55 (11)
P2	48	181.5	81	56	1.64	184 (103)	188 (104)
P3	42	166.5	98	56	0.77	103 (32)	113 (36)

Table 5.2 Target values (N·m) for training at baseline and following re-assessment

Participant	Direction	Limb	Target 1	Target 2	Target 3
P1	Extension	Non-paretic	35	64	65
		Paretic	28	36	35
	Flexion	Non-paretic	28	28	32
		Paretic	16	21	22
P2	Extension	Non-paretic	53	53	62
		Paretic	44	58	66
	Flexion	Non-paretic	30	32	35
		Paretic	26	32	34
P3	Extension	Non-paretic	28	30	31
		Paretic	28	36	35
	Flexion	Non-paretic	19	14	9
		Paretic	14	15	11

5.3.2 Training Performance

5.3.2.1 Training Intensity

The mean training intensity for each set was measured for each set, limb and direction. Figure 5.1 - 5.4 shows the mean training intensity of each participant for the extension and flexion manoeuvres respectively. Training intensity was differentiated between the high and low intensity protocols for the extension manoeuvres but not for the flexion manoeuvres. Accurate performance of training intensity was achieved from session 5 onwards.

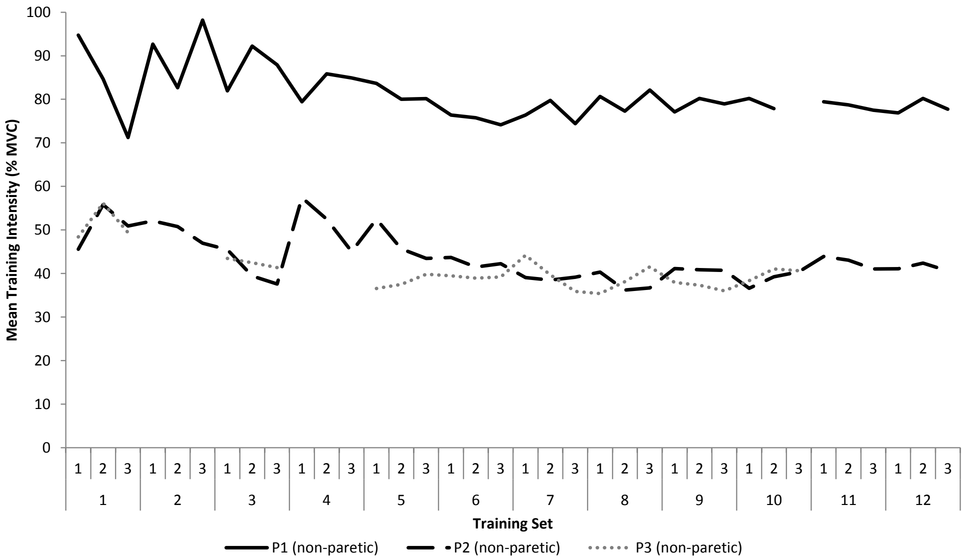


Figure 5.1. Mean non-paretic extension training intensity for participant P1, P2 and P3

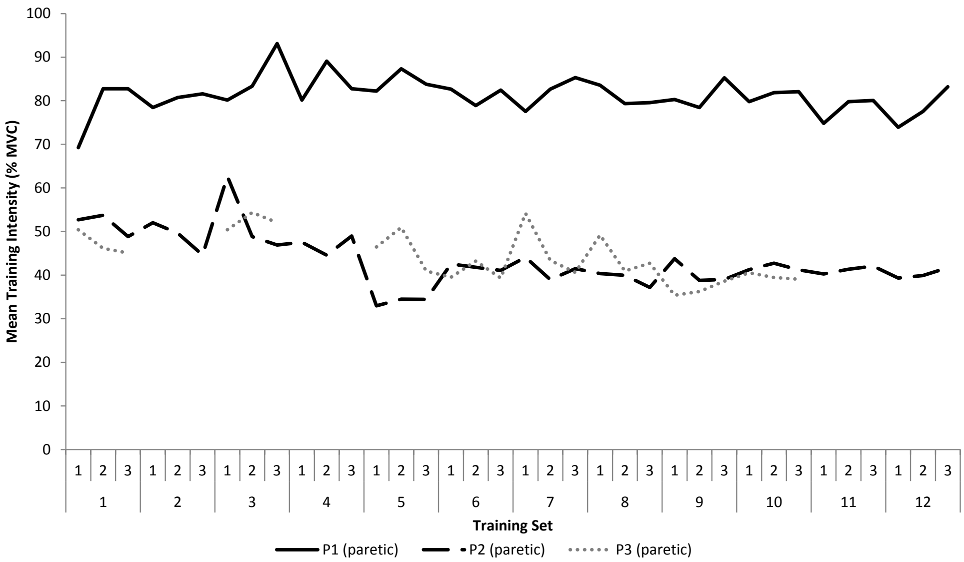


Figure 5.2. Mean paretic extension training intensity for participant P1, P2 and P3

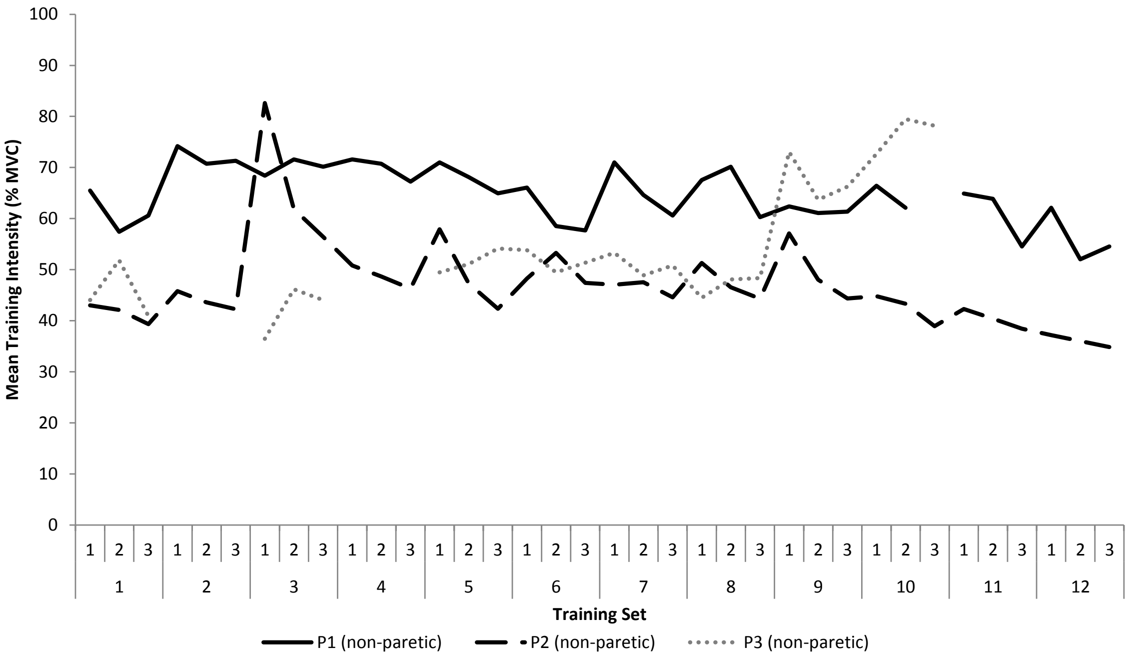


Figure 5.3. Mean non-paretic flexion training intensity for participant P1, P2 and P3

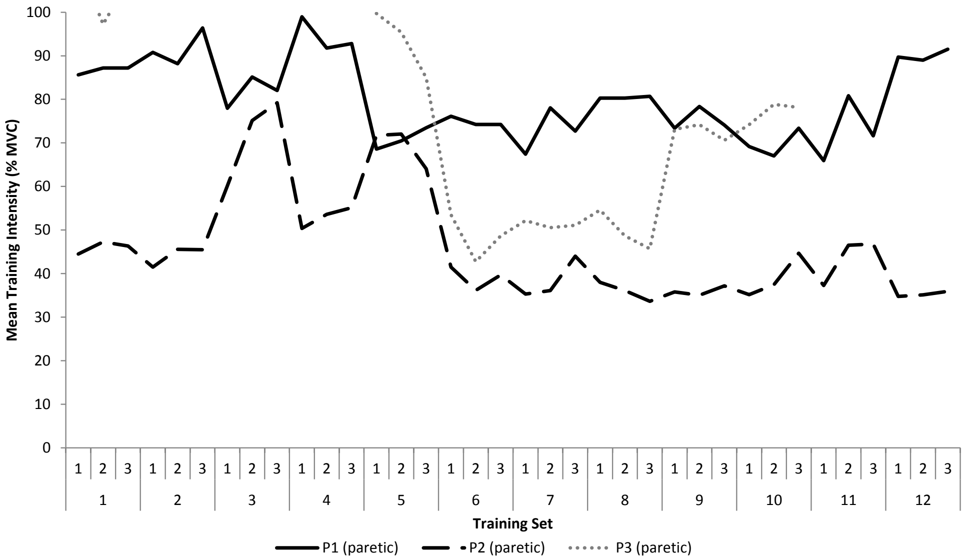


Figure 5.4. Mean paretic flexion training intensity for participant P1, P2 and P3

5.3.2.2 Force Fluctuation

Force consistency, measured as the coefficient of variation of the peak torques in each training set is reported below. Figure 5.5 – 5.8 show the force fluctuation for each training set for the extension and flexion manoeuvres respectively. There was no distinction in force fluctuation between training protocols.

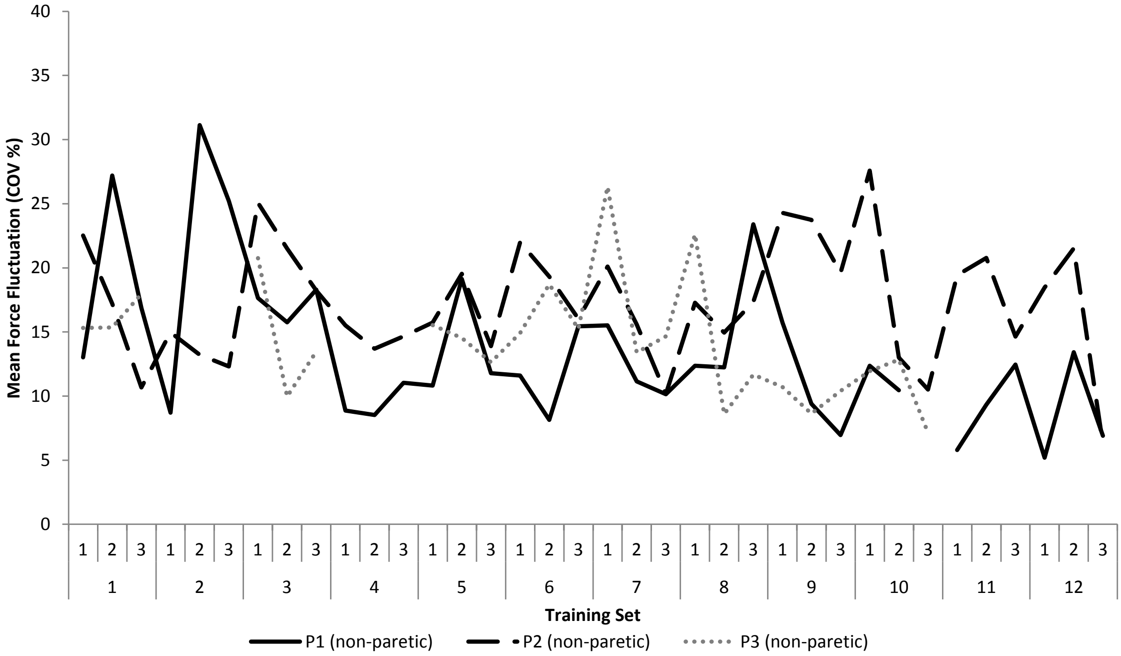


Figure 5.5. Non-paretic extension force fluctuation for participant P1, P2 and P3

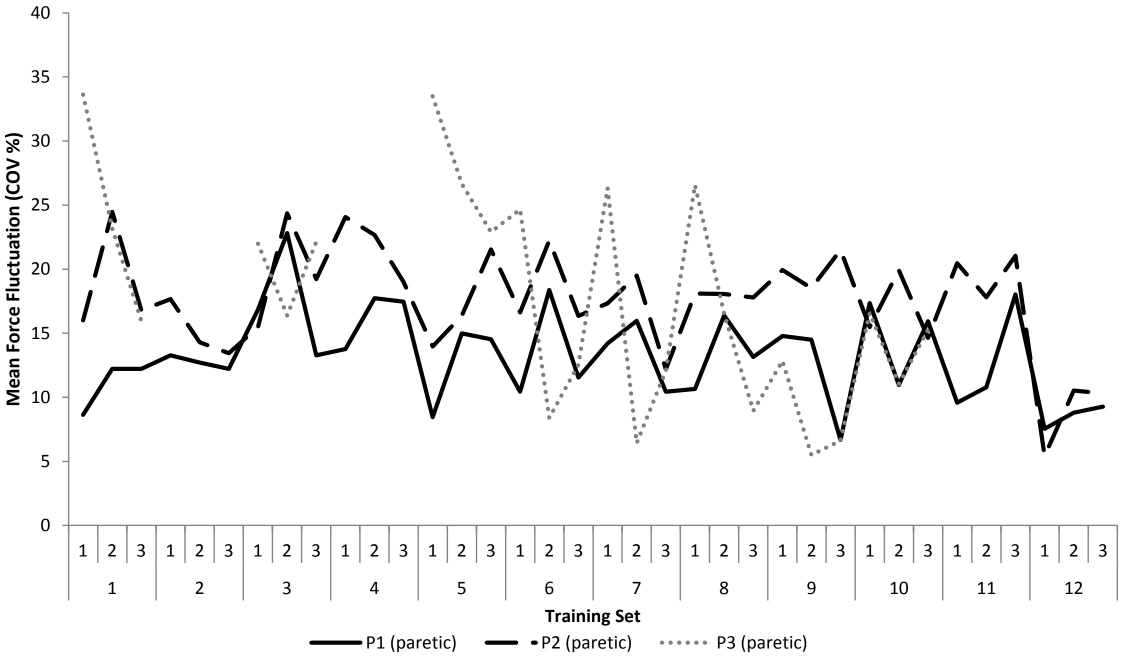


Figure 5.6. Paretic extension force fluctuation for participant P1, P2 and P3

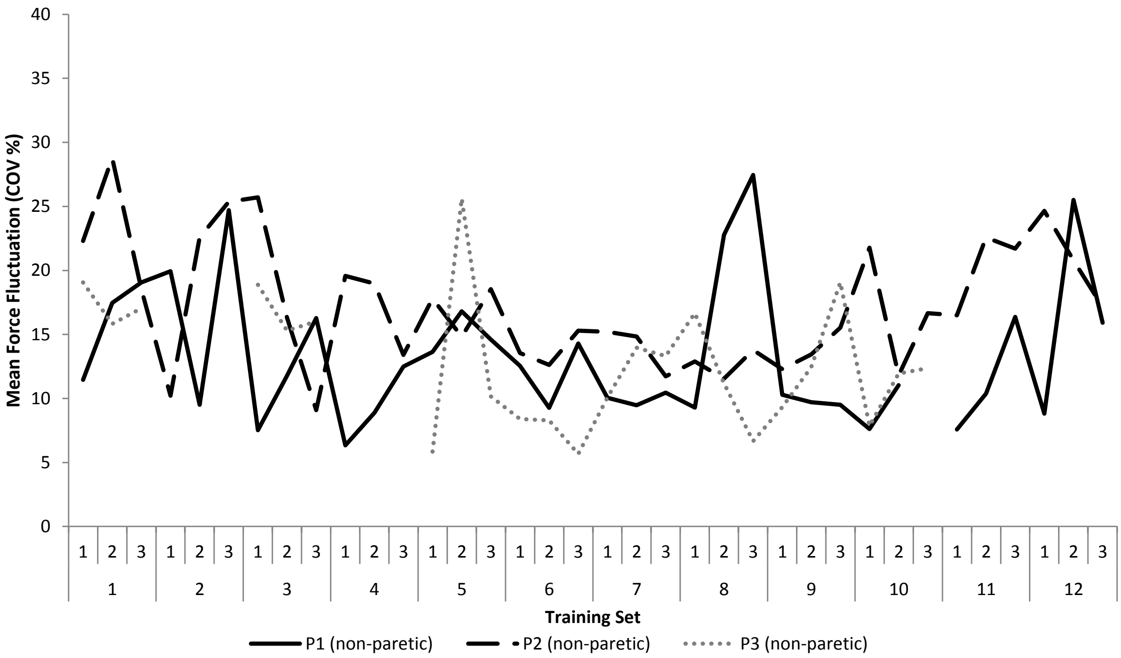


Figure 5.7. Non-paretic flexion force fluctuation for participant P1, P2 and P3

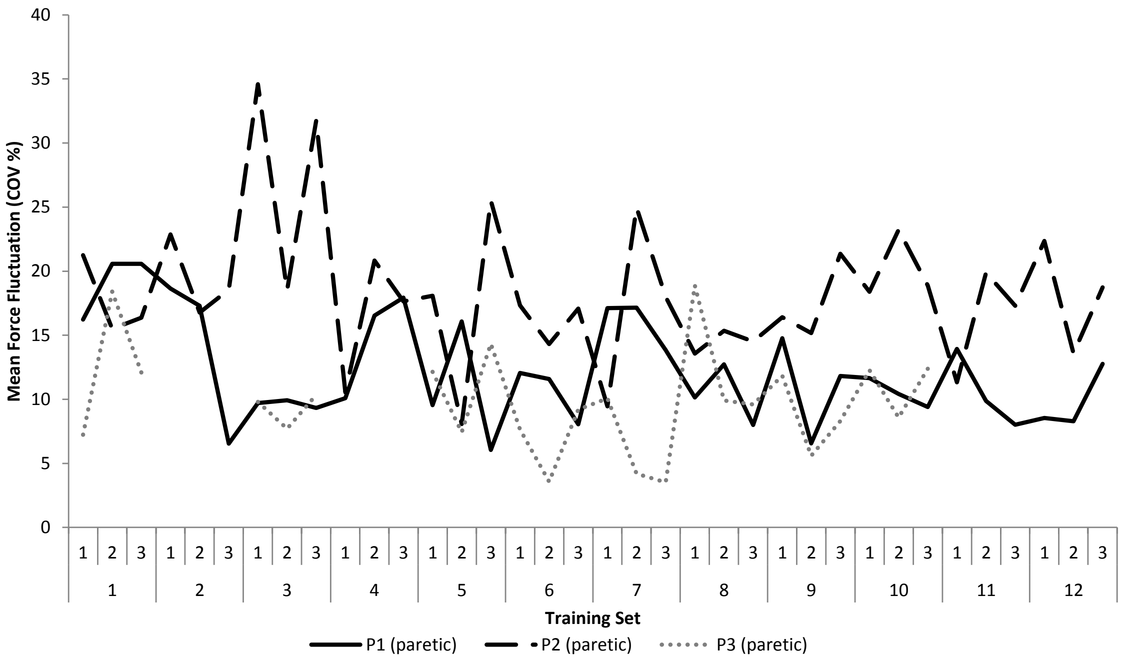


Figure 5.8. Paretic flexion force fluctuation for participant P1, P2 and P3

5.3.2.3 Total Work

The total work performed in each training set was recorded for each limb and direction. The total work completed over the training period was compared to the theoretical work over the training period (Table 5.3). As expected, participants completed less work over the training period than theoretical work. Participant P1 and P3 achieved 30- 32% less work than expected over the training period for non-paretic extension manoeuvres whilst P2 achieved 15% less. For paretic extension this difference was 41% for P1 and P3.

Table 5.3. The theoretical work (kJ) and total work (kJ) achieved over the training period and percentage difference

Side and direction	Participant	Theoretical Work (kJ)	Total Work (kJ)	Difference (%)
Non-paretic extension	P1	28259	21693	-30
	P2	60823	52871	-15
	P3	10715	8119	-32
Paretic extension	P1	16701	11873	-41
	P2	56115	49936	-12
	P3	10478	7453	-41
Non-paretic flexion	P1	14997	9287	-61
	P2	36356	28883	-26
	P3	5115	4003	-28
Paretic flexion	P1	9312	5314	-75
	P2	37180	24787	-50
	P3	4862	5541	12

As the three stroke survivors improved in their ability to train at the specified intensity for the extension manoeuvres, total work and theoretical work was calculated for the first and second half of training separately. Table 5.4 shows the total and theoretical work for the first and second half of training sets. As there was limited data available for participant T3, these data were split by the first 12 and last twelve training sets completed.

For non-paretic and paretic extension manoeuvres P1 and P3 completed more work in the second half of training than the first half. This was attributed to the higher targets set following re-assessment of muscle strength, as opposed to increased target accuracy because theoretical work was also higher whilst the difference between theoretical and total work remained high. For non-paretic extension all participants achieved less total work relative to theoretical work in the second half of training sets completed. This indicates that although they were able to train at the intensity specified, they were not able to achieve the total work and this was attributed to not achieving the target force consistently throughout the contraction. For paretic extension, participant P1 and P3 showed a small improvement in achieving the total work expected in the second half of training. However, for P1 and P3the difference between total and theoretical work remained over 30%.

Table 5.4. The theoretical work (kJ) and total work (kJ) achieved in the first and second half of training as well as the percentage difference

Side and direction	Partici-pant	First half			Second half		
		Theoretical Work (kJ)	Total Work (kJ)	Difference (%)	Theoretical Work (kJ)	Total Work (kJ)	Difference (%)
Non-paretic extension	P1	11942	9360	-28	16318	12334	-32
	P2	28329	26578	-7	32494	26293	-24
	P3	5230	4042	-29	5485	4077	-35
Paretic extension	P1	8332	5645	-48	8369	6228	-34
	P2	24425	22333	-9	31690	27603	-15
	P3	4407	2969	-48	6071	4484	-35
Non-paretic flexion	P1	7370	4568	-61	7627	4719	-62
	P2	17272	14948	-16	19084	13935	-37
	P3	2985	2241	-33	2129	1762	-21
Paretic flexion	P1	4109	2357	-74	5202	2957	-76
	P2	17236	13625	-27	19944	11162	-79
	P3	2544	3650	30	2318	1891	-23

5.3.2.5 Summary of training intensity and total work achieved

The table below summarises whether there was sufficient differentiation in the training intensity performed by participants. With repeated practice, all participants were able to train at the specified training intensity for the extension manoeuvres on the non-paretic and paretic limbs. However, despite being able to train at the specified intensity in these conditions, participant P1 and P3 completed much less total work over the training period compared to the theoretical work. The high force fluctuation observed for these conditions may explain why these participants did not complete the amount of work that was expected.

As participants could not achieve the specified intensity for the flexion manoeuvres, assessment changes for the hamstrings are not presented. As participants P1 and P3 did not achieve the expected total work for the extension manoeuvres, this may have impacted on their degree of change.

Table 5.5. Summary of training performance for the three participants across all conditions

Participant	Side and direction	Training Intensity	Total Work
P1	Non-paretic extension	OK	X
	Paretic extension	OK	X
	Non-paretic flexion	X	X
	Paretic flexion	X	X
P2	Non-paretic extension	OK	OK
	Paretic extension	OK	OK
	Non-paretic flexion	X	X
	Paretic flexion	X	X
P3	Non-paretic extension	OK	X
	Paretic extension	OK	X
	Non-paretic flexion	X	X
	Paretic flexion	X	OK

OK – Achieved the specified training intensity or total work

X – Did not achieve the specified training intensity or total work

5.3.3 Assessment Outcome Measures

5.3.3.1 Baseline performance

5.3.3.1.1 Baseline muscle performance

Only assessment of extension manoeuvres is presented as no differentiation in flexion training performance measures was achieved. Figure 5.9 shows the extension isometric and isokinetic strength at baseline for the non-paretic and paretic limbs. Participant P2 demonstrated the highest isometric extension peak torque at baseline for both limbs. Participant P1 demonstrated a large non-paretic to paretic extension peak torque ratio. The peak torque was lower at increasing velocities for all participants but this was much more apparent for participant P1 and P3.

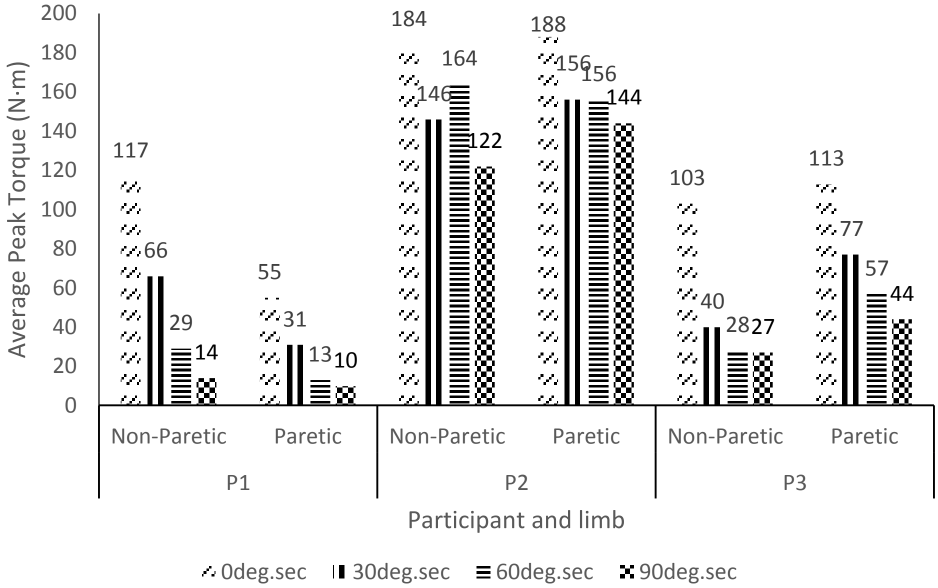


Figure 5.9 Non-paretic and paretic isometric and isokinetic extension peak torque at 30, 60 and 90°.s^{-1}

5.3.3.1.2 Baseline activity measures

Table 5.6 shows the baseline activity measures and spatial and temporal parameters recorded for the three stroke survivors.

Table 5.6 Baseline recorded activity and spatial temporal parameters.

Participant	Gait Velocity (m.s^{-1})	6MTW (m)	TUG (s)	Cadence (steps.min^{-1})	Non-Paretic Stride Length (mm)	Paretic Stride Length (mm)
P1	0.91	376.5	7.0	111	108	107
P2	1.64	581.7	12.1	115	173	175
P3	0.77	283.5	12.2	81	113	112

5.3.3.2 Changes following training

5.3.3.2.1 Strength Changes

Figure 5.10 shows the percentage change in isometric and isokinetic extension peak torque of the non-paretic limbs and paretic limbs following training for isometric ($0^{\circ}.s^{-1}$) and concentric strength measures ($30^{\circ}.s^{-1}$, $60^{\circ}.s^{-1}$, and $90^{\circ}.s^{-1}$). Participant P1 and P2 showed a small positive change in isometric peak torque whilst participant P3 showed a reduction. Participant P1 and P3, who were weaker than P2, demonstrated a positive increase in isokinetic strength following training whilst participant P2 demonstrated little change. Although participant P1 and P3 completed much less total work than the expected theoretical work, they demonstrated a large increase in isokinetic extension peak torque at 60 and $90^{\circ}.s^{-1}$.

Despite completing much less total work than expected, participant P1 showed much larger changes paretic isometric extension strength compared to participant P2. A similar pattern was also observed for isokinetic peak torque at increasing speeds. Participant P3 demonstrated very little change for all conditions in the paretic limb.

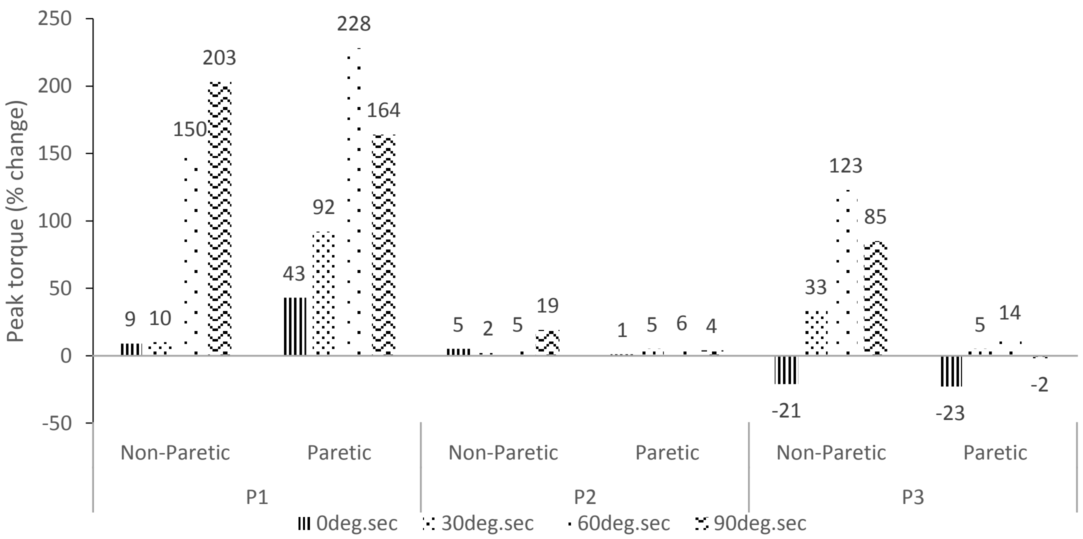


Figure 5.10. Percentage change in extension isokinetic peak torque of non-paretic and paretic limbs

5.3.3.2.2 Activity Changes

The percentage change in gait velocity, six minute timed walk, cadence, step length and stride length was calculated for each participant (table 5.7). Participant P1 showed an improvement in gait velocity of 15%. However, they did not improve in the six minute timed walk and were 2.2 seconds slower performing the timed up and go. Their spatial temporal parameters improved and they were able to take longer steps with the paretic and non-paretic limbs. Participant P2 showed a slower gait velocity and traversed a shorter distance in the 6MTW following training but were 0.5 seconds faster in completing the timed up and go. Their spatial temporal parameters showed little change. Participant P3 also traversed a much shorter distance in the 6MTW following training and took 0.4 seconds longer completing their timed up and go. However, they showed the greatest improvement in gait velocity. However, their spatial temporal parameters improved and they were able to take longer steps with the paretic and non-paretic limbs.

Table 5.7. Percentage change in the activity and spatial-temporal measures for each participant

Measure	**P1**	**P2**	**P3**
Gait Velocity ($m.s^{-1}$)	15.3	-4.4	16.3
6MTW (m)	-0.1	-29.9	-19.4
TUG (s)	17.3	-5.5	-3.5
Cadence (footfalls.min^{-1})	3.5	0.5	12.5
Non-Paretic Stride Length (m)	7.8	-2.3	9.6
Paretic Stride Length (m)	9.7	-4.1	9.9

5.4 Discussion

The main aim of these case studies was to explore whether stroke survivors could perform the sub-maximal isokinetic training protocols at the specified training intensity and do this consistently. This study also applied a number of outcome measures and the relevance of these was looked at. Three stroke survivors were recruited from Newham and participated in a 6 week training period accompanied by assessments on muscle performance, activity and participation. Training performance was measured for each training set completed by the stroke survivors, for extension and flexion as well as non-paretic and paretic limbs separately accounting for the different muscle groups involved and the generally unilateral effect of stroke on motor control.

In line with the studies presented in chapter 3 and 4, training performance for the flexion manoeuvres was worse than the extension manoeuvres. This was more apparent for P1 and P3 in comparison to the healthy sedentary population. There was a lack of differentiation in the training intensity performed for these two participants. Of the last three training sets in which data was available, P1 performed the training sets at an intensity less than 65% for non-paretic flexion and at intensity greater than 88% for paretic flexion. P3 performed the last three training sets at an intensity above 72% for the non-paretic and paretic limbs. A reason for this could be due to the known reduction in motor control after stroke, which affects both the ipsilateral and contralateral limbs (Arene and Hidler, 2009). Compared to older adults, stroke survivors present with impaired force-velocity relationships (Clark et al. 2006). They also present with impaired rate of strength development in the paretic limb compared to the non-paretic limb (Pohl et al., 2002). Although this was not measured in the current study, the high force fluctuation achieved by these participants support this.

For the extension manoeuvres, with repeated practice all of the participants trained at the specified training intensity. For the first half training sets completed for non-paretic extension (first 18 for P1 and P2 and first 12 for P3 due to loss of data), only 52% of the training sets achieved a mean training intensity ±5% of the target intensity. For the second half of training sets, 98% of the training sets achieved a mean training intensity ±5% of the target intensity. Similarly, for the first half training sets completed for paretic extension, only 48% of the training sets achieved a mean training intensity ±5% of the target intensity. For the second half of training sets, 88% of the training sets achieved a mean training intensity ±5% of the target intensity. This shows that the three stroke survivors demonstrated the ability to learn new motor skills. This is supported by

Boyd et al. (2010) who found that stroke survivors who undertook repeated task-specific practice of the upper limb showed neuroplastic changes compared to a control group performing general upper limb exercises. However, consistent achievement of the target training intensity in this study was observed much later compared to the previous study in chapter 4 where sedentary participants achieved consistent training intensity after 4 sessions. This may be due to the impaired ability of stroke learn new motor skills. Due to the neuron damage caused by stroke, learning of new motor skills involves the functional reorganization of the undamaged part of the motor cortex adjacent to the infarct (Nudo et al., 2006). Although many regions of the brain attribute to motor learning (Poldrack et al., 2005), both the severity of the stroke and regions that are affected impact on learning capability (Boyd et al., 2009). It was observed that the stroke survivors required more repeated instruction of how perform the protocols, which should be considered in future studies.

As it took nearly 6 sessions for the stroke survivors to train at the target intensity raises question on whether stroke survivors in previous studies trained at the intensity specified by the protocol. For the paretic limb, consistent practice was not observed until the 16th training set. This is equivalent to around half of the sessions completed in studies by participants in Flansbjer et al. (2008), a third of session completed by participants in Kim (2001), and a quarter of sessions completed by participants in Cramp et al. (2006). Therefore, the prolonged time to learn how to train at the specified intensity raises question as to whether the stroke survivors in previous studies trained at the intensity specified by the protocol during training, particularly when there is no visual feedback on training performance.

While the participants learned how to train at the specified training intensity for the extension manoeuvres, the total work completed over the training period was lower than the theoretical work for extension, particularly for participant P1 and P3. These participants completed 30-41% less total work than the theoretical work over the training period. Although it was expected for total work to be lower than theoretical work, sedentary participants achieved a smaller deficit (13-20%).

The additional deficit in total work was not explained by the mean training intensity of the set. The primary reason for the deficit in total work completed could be due to the lack of ability to produce a force equivalent to the target force *throughout* the contraction and achieve this consistently for all contractions in the training set. Figure 5.5 shows that the force curves for the stroke survivors. It is possible that the increased time to peak torque, as observed by Pohl et al. (2002) and Gerrits et al. (2009), was responsible for not being able to achieve the target force at the beginning of the manoeuvres.

Higher force fluctuation was observed in stroke survivors compared to the healthy sedentary participants. Chow & Stokic (2011) evaluated the coefficient of variation of isometric extension at submaximal intensities (10-50% MVC) in subacute stroke survivors compared to healthy matched controls. At 50% MVC they found the coefficient of variation was significantly greater in stroke survivors (5.1%) compared to healthy matched controls (1.7%). It should be noted that their measure of force fluctuation was taken as the fluctuation in force about a target measured from within a sustained isometric whilst the current study evaluated the fluctuation in peak torque between contractions in a training set. However, it can be seen that the findings are similar with stroke participants showing higher force fluctuation and therefore poorer performance than the healthy sedentary participants. In addition to this, there was no apparent improvement in the force fluctuation with repeated sessions. Therefore, although the mean extension training intensity was consistent for the second half of training, there remained a high variation (above 10%) in the peak force over all contractions.

Tracy & Enoka (2006) evaluated whether training improved the coefficient of variation of a steady isometric force with a 30% MVC target in healthy elderly adults. They found the coefficient of variation of the force improved from 3.9% at baseline to 2.3% after 16 weeks of steadiness training. This was a modest improvement and it is possible that the participants in this study also showed only modest improvements in the ability to maintain the target force that was difficult to detect with the variance in performance. Although this study did not measure force fluctuation of a single contraction, rather the variation in peak torque of each contraction, there was no apparent improvement in any of the three participants. Most of the training sets achieved a force fluctuation above 10% for the extension manoeuvres. As such, not all of the contractions were performed consistently. In addition to this, it is likely that participants learnt to achieve a force close to the target force at one point during the contraction rather than maintain the target force throughout the contraction despite verbal encouragement. Further investigation is required to explore and elaborate on these observations.

Training status may have affected potential outcomes in strength and activity. Participants P1 and P3 demonstrated large increases in isokinetic extension strength, particularly at 60 and 90 $^{\circ}.s^{-1}$. However, participant P2 who was able to perform the training at the specified intensity quickly and who achieved total work close to the theoretical total work showed little change in strength and activity following training. Their isometric and isokinetic peak torque at 30° and 60$^{\circ}.s^{-1}$ only showed a 1-6% change following training in the non-paretic and paretic limbs. This could be due to the lower level of impairment demonstrated by this participant. At baseline, their isokinetic peak torque at 60$^{\circ}.s^{-1}$ was 164N·m and 156N·m for the non-paretic and paretic limbs respectively. This was within the 95% CI normal values of isokinetic peak torque for males of 154-172 N·m established by Ostchega et al. (2004). Their gait velocity (1.6 $m.s^{-1}$) was also in line with normative values observed in healthy males in their forties (Bohannon, 1997). This is supported by previous findings that the response to training differs between individuals of different training status. Participant P2 was the only participant who participated in regular exercise.

P1 and P3 demonstrated weaker isokinetic extension strength even when compared to other independently ambulatory stroke survivors. For example, P1 and P3 non-paretic limbs demonstrated extension peak torque of around 29N·m at 60°.s^{-1} whilst Flansbjer et al. (2006) found strength at 60°.s^{-1} to be 101 ±26N·m for their female participants. The lower training status of these participants compared to P2 may explain why they demonstrated a large response to training. If training status has such a large effect on training response, this may explain the variation in outcomes in the sedentary and older adult literature where there has been a lack of description in the criteria for population sampling.

In both the non-paretic and paretic limbs, participant P3 demonstrated a reduction in isometric strength of 21-23% following training. Although there were improvements in isokinetic strength, this was only observed in the non-paretic limb. This indicates that the intensity/volume of the protocol may have been insufficient to elicit changes. Participant P1 on the other hand demonstrated an improvement of 9% and 43% in isometric extension strength for the non-paretic and paretic limbs respectively. Therefore, despite completing 30-40% less total work as specified by the protocol, it was sufficient to elicit an improvement in muscle strength.

Despite completing less work than specified by the protocol and showing a reduction in isometric muscle strength following training, participant P3 improved gait velocity and spatial and temporal parameters of gait similar to that of P1. The improvement in non-paretic dynamic knee extension strength alone may have contributed to the improvement in activity observed. But there could also be a number of other reasons for this such as: an increase in daily physical activity associated with attending training sessions, individual variability in the training response, or due to repeated exposure of the assessment task. General activity levels have been found to be very low in in community dwelling stroke survivors (2837 steps/d vs 5000 in sedentary older adults) (Michael et al., 2005). Participating in training sessions involved walking outside, taking a taxi and walking in University campus to the laboratory. This may have increased activity levels, which in turn may have improved gait as a result of repetitive practice (Eng, 2011). On the other hand, participating may have resulted in participating less in other activities – either due to clashes in scheduling or due to not physically being able to. For example, P2 noted they were unable to participate in martial arts whilst they were participating in the training.

5.4.1 Study Limitations

Case studies are generally utilised in research to aid in the development of theory of complex scenarios, or to develop a qualitative perspective of a phenomenon (Domholdt, 2005). However, by nature there are limits to how conclusive the findings are due to the lack of power, particularly where individual variability is expected. As this was a case-study design, the findings cannot be generalised to the wider population.

Comparison of the results of P1 and P3 against P2 is difficult, as the training status of participant P2 was much higher at the start of the study as they were participating in martial arts sessions three times a week. This study highlights the individual variability in baseline strength and activity between stroke survivors. Selecting independently ambulatory stroke survivors, commonly used as a criterion in stroke studies utilising progressive resistance exercise (e.g. Flansbjer et al., 2008), may therefore be insufficient to recruit participants of a similar training status. Also, the degree of strength impairment may have on training performance and subsequent outcomes which needs to be explored. Considering also the region and extent of the stroke, individual variability makes it ever more difficult to extrapolate optimal parameters in this population.

In addition to monitoring training performance, measuring other activity performed during the training period may also be required, particularly where participants attend other forms of exercise. However, accurate measurement of such activities may prove very difficult. On the other hand, a randomised controlled trial with a sufficiently large sample should account for these differences.

It is also worth considering the types of participants recruited. Participation requires commitment and may have interfered with daily lifestyles. For example, participant P2 and P3 said that participation made it difficult to keep up with other leisure and work activities. Their stroke had affected how much they could do in a week and participation in the programme meant they needed to prioritise key activities a lot more. This may have an influence on the consistency of training sessions completed but there is little reported evidence on this.

5.4.2 Summary

All three stroke survivors successfully completed the training programme. There remained a significant deficit in the total work completed by participants compared to the theoretical work. This deficit was much larger than that seen in the studies undertaken on sedentary individuals. The larger deficit could be explained by the prolonged time needed for stroke survivors to learn how to achieve the target force, the lack of ability to reach the target force at the beginning and end of the range of the movement and the inability to learn how to produce a consistent force between contractions within a training set. This draws question as to whether stroke survivors can perform progressive resistance exercise as specified by the protocol. The large deficit in total work observed in these case studies may explain the variation in outcomes between studies utilizing progressive resistance exercise in stroke survivors. Measurement of the intensity of training and total work completed may be necessary to fully extrapolate the influence of training parameters on the effectiveness of progressive resistance exercise and explain differences in outcomes.

6.0 General Discussion

Physical activity is prescribed in the form of exercise as part of medical interventions to manage illness and improve quality of life (RCP, 2012). It has been shown to have direct impact on many aspects functioning, disability and health, as defined by the ICF (WHO, 2001). This thesis has focused on one type of exercise, progressive resistance exercise and examined training performance. Progressive resistance exercise is specifically designed to improve skeletal muscle strength through the performance of movements against a progressively increasing resistance (Latham et al., 2004; ACSM, 2009). It is widely used in physical rehabilitation but there is a lack of consensus on the optimal training regimes that are effective and elicit the greatest improvements. Identification of optimal training regimes may be specific to various populations but the principles of examining training performance may be similar.

Despite a number of studies evaluating the influence of training parameters on the effectiveness of progressive resistance exercise, optimal training parameters remain equivocal. Even in studies utilising almost identical training regimes (Ouellette et al., 2004; Flansbjer et al., 2008), there remained a difference in outcomes following training. One possible explanation for the variability was attributed to the performance of training protocols by participants. There are differences between high and low intensity training protocols in the length of the acceleration phase during dynamic isotonic manoeuvres (Cronin et al., 2003), which may affect the total external work produced during the training period.

Training performance of progressive resistance exercise has seldom been reported in literature. Previous authors have attempted to match the theoretical work produced between high and low intensity protocols (Hortobagyi et al., 2001). Hortobagyi et al. (2001) cited that the total work lifted between the high and low intensity groups were equal. However, this seems to be assumed on the basis of the theoretical work, which is calculated by multiplying the intensity of training and total repetitions (Wernbom et al., 2007). But without recording the actual force produced during the training period, it is not known for certain whether participants achieved the expected total work. Finni et al. (1998) attempted to measure the actual force exerted by muscles using an optic fibre inserted into the muscle tendon (Finni et al., 1998). But this was considered invasive and it may have an effect on muscle mechanics making it difficult to draw conclusions.

Computational models have also been considered (Erdemir et al., 2007) but these essentially only provide an estimate of muscle force.

This thesis developed training protocols using isokinetic dynamometers which could record the forces exerted during resisted manoeuvres allowing measurement of training performance including the training intensity and total work. The first study was conducted to assess whether sedentary participants could perform training at the intensity and work as specified by the training protocols using real-time visual feedback. A second study was conducted, also on sedentary participants, taking them through allocated training protocols over 4 repeated sessions. These protocols were then applied to three stroke survivors, over 12 training sessions and using a battery of assessments. These studies uncovered a number of issues surrounding the evaluation of training performance in progressive resistance exercise but the applicability of sub-maximal isokinetic training to other forms of resistance training is limited, because the biomechanical characteristics of isokinetic and isotonic manoeuvres are inherently different (Guilhem et al., 2011).

The first study focused on the training performance measurements recorded by the sedentary participants completing three training protocols differentiated by training intensity and/or total work. This showed that assessment of training performance was possible and could form essential part of evaluating the effectiveness of progressive resistance exercise. The variability in training performance observed is concurrent with the literature looking at the variability in force during isometric contractions (Tracy et al., 2004) and shows that some participants may not be able to achieve the external force as prescribed by the training protocol. This may partly explain the variability in outcomes in previous training studies and why there is a lack of consensus on the optimal training parameters for progressive resistance exercise (Raymond et al., 2013).

Despite the variability in training performance, the second study showed that with repeated practice sedentary participants were able to demonstrate an improvement in the ability to train at the specified intensity and achieve the expected total work.

For the extension manoeuvres only, these protocols demonstrated that they could be used to train participants at a sub-maximal intensity in a consistent way. Therefore, these protocols could be used to train participants at differentiated intensities and specified volumes of work. This can be useful for future research concerned with the effects of training parameters on various outcomes. For example, these protocols could be used to compare the effects of intensity on acute metabolic and hormonal responses to progressive resistance exercise.

However, these findings were limited to the extension manoeuvres only. Despite repeated practice, the second study showed that some of the sedentary participants were not able to achieve the intensity specified by the protocol and there was only a small improvement in force fluctuation. This was not expected as both muscle groups have shown to be reliable in the production of maximal voluntary isokinetic contractions (Flansbjer et al., 2005). In addition to this, there were also indications that training performance varies between the left limb and right limb. This thesis has therefore shown potentially a number of factors that can affect training performance which in turn affects the interpretation of optimal training parameters in published guidelines. There has been a lack of reporting of training performance in previous studies and an acceptance that participants performed training as specified by the protocol. Future research utilising progressive resistance exercise should therefore aim to record and report participant training performance. In addition, outcomes should be evaluated separately for dominant and non-dominant limbs.

Previous guidelines on progressive resistance exercise indicate optimal training parameters are population dependent with untrained individuals advised to train at a lower intensity for more sets compared to trained individuals (Rhea et al., 2003). The first two studies indicated untrained individuals may initially struggle to achieve high intensity training. Therefore, differences in outcomes of training may be explained by the poorer training performance and deficit in total work when untrained populations completed high intensity exercise.

There is a sensorimotor element of performing training accurately (Thaler and Goodale, 2011). There was a learning component where participants learnt how to control the force exerted during resisted contractions. Instructing participants to control the level of force exerted may have an additional effect on the outcomes due to this learning effect. This is consistent with Tracy et al. (2004) who, in a sample of older adults (65-80 years old) found larger improvements in MVC for their high intensity group that were instructed to control the velocity of movement through visual feedback (31%) compared to their high intensity group without the visual feedback (25%).

This implicates how results from future studies should be inferred. The majority of previous resistance training studies have compared outcomes between baseline and following the training period. Although this is in accordance with standard research protocol (Carter et al., 2010), the lack of accurate training performance from the start of training suggests that previous studies may have made comparisons of training groups that did not necessarily perform the training as specified by the protocol. Therefore, it is recommended that outcomes should be interpreted on the basis of the actual training achieved, and not solely the training protocol that was prescribed. One approach could be to analyse results of only the participants who were able to achieve the target training intensity and work.

Nonetheless, these studies showed that there was a considerable learning effect and repeated practice was required to improve training performance. As these protocols used real-time visual feedback of the force produced during the training manoeuvres, it was expected that participants would have been able to rectify their performance by adjusting the level of force exerted to more accurately achieve the target force. This did seem to occur, but the learning effect was much longer and gradual than anticipated. As such feedback is not given to participants in studies utilising isotonic resistance equipment this draws question as to whether participants in previous studies conducted training as specified by the protocol.

Only one study (Beneka et al. 2005) attempted to control for training performance factors. Beneka et al. (2005) instructed participants to control the time that each repetition was completed. But there is no evidence that this may have normalised the differences in the acceleration phase between high and low intensity protocols as demonstrated by Cronin et al. (2003). Without recording the force exerted and total work achieved there can be no real confirmation of whether all participants completed training as specified by the protocol. . The second study showed that the learning effect was gradual over the over four sessions of training. Therefore, it is hypothesised that the variability in training performance between participants is partly responsible for the variability outcomes observed in previous studies.

A third study was conducted to assess the training performance of stroke survivors conducing sub-maximal isokinetic training. Given that these protocols required repeated practice to perform accurately, clinical populations such as stroke survivors may also present with difficulty in achieving accurate training performance. This would have implications on studies evaluating progressive resistance for such populations. It was intended that thirty stroke survivors would be recruited but the study only achieved recruitment of three and thus analysis was conducted on a case study basis. Despite repeated practice there remained a deficit in the total work achieved relative to the total work expected. The three stroke survivors took longer to achieve the target training intensity than sedentary participants, and for the paretic limb consistent performance not achieved until the 16th training set. The deficit in total work was partly explained by the inability to achieve the target training intensity for the duration of the contraction. A reason for this could be due to the known reduction in motor control after stroke, which affects both the ipsilateral and contralateral limbs (Arene and Hidler, 2009). The period of learning is equivalent to around half of the sessions completed in studies by participants in Flansbjer et al. (2008). The prolonged learning period, which appears attenuated in the three stroke survivors, draws question as to whether stroke survivors in previous studies completed training as specified by the training protocol, particularly when there was no visual feedback on training performance. These findings have implications on clinical practice as currently there are no clear guidelines on how to monitor training performance following prescription. Prescribing training according to optimal training protocols may not be sufficient to ensure that the training is delivered effectively. There should be some form of feedback following exercise prescription which captures whether participants are performing training as specified by the protocol.

The findings from these studies suggest that lack of accurate training performance may partly explain the differences in outcomes in previous studies. It is recommended that training performance is recorded and reported in future studies utilising progressive resistance exercise.

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8.0 Appendices

8.1 Ethics Approval

Dr Mary Cramp
HAB
Stratford

ETH/09/88

09 March 2009

Dear Dr Cramp,

Application to the Research Ethics Committee: Reliability of muscle strength and aerobic function after stroke (K Hastings/P Barchha)

I advise that the University Research Ethics Committee has now approved the above application on the terms previously advised to you. The Research Ethics Committee should be informed of any significant changes that take place after approval has been given. Examples of such changes include any change to the scope, methodology or composition of investigative team. These examples are not exclusive and the person responsible for the programme must exercise proper judgement in determining what should be brought to the attention of the Committee.

In accepting the terms previously advised to you I would be grateful if you could return the declaration form below, duly signed and dated, confirming that you will inform the committee of any changes to your approved programme.

Yours sincerely

Debbie Dada
Administrative Officer for Research
d.dada@uel.ac.uk
02082232976

Research Ethics Committee: ETH/09/88/0

I hereby agree to inform the Research Ethics Committee of any changes to be made to the above approved programme and any adverse incidents that arise during the conduct of the programme.

Signed:..Date: ....

Please Print Name:

8.2 Participant information sheet and consent form

University of East London, School of Health and Biosciences, Stratford Campus, Romford Road, London, E15 4LZ
University Research Ethics Committee

If you have any queries regarding the conduct of the programme in which you are being asked to participate please contact the Secretary of the University Research Ethics Committee: Ms D Dada, Administrative Officer for Research, Graduate School, University of East London, Docklands Campus. London E16 2RD (telephone 0208 223 2976 e-mail d.dada@uel.ac.uk)

The Principal Investigators

Pritesh Barchha
University of East London
School of Health & Biosciences
Romford Road
Stratford
London
E15 4LZ
0208 223 4260

Consent to Participate in a Research Study

The purpose of this letter is to provide you with the information that you need to consider in deciding whether to participate in this study.

Project Title

The feasibility of strength training procedures on healthy individuals.

Project Description

What is the purpose of this study?

This study will evaluate the feasibility of muscle training procedures we would like to use in a future study to strengthen muscles of people who have had a stroke. We want to measure how strong your muscles are, and how well you can perform exercises at varying levels of work on a machine designed to test and train muscle performance. We are looking to recruit participants who are in good health but who do not participate in regular exercise or sporting activities.

What will I have to do if I take part?

You will be asked to attend the Human Motor Performance Laboratory at the University of East London on one occasion lasting approximately one hour.

The procedures you will be doing have been used previously to assess and train muscle strength. To determine whether it is suitable for you to complete the tests, you will be asked to complete a medical screening questionnaire and a questionnaire to determine your current level of physical activity. We will test both legs and you will be asked to wear a pair of shorts which we can provide if you wish.

To start with, strength of the muscles around the knee will be tested using the machine and you will push or pull your leg against a moving resistance. You will then be taken through resistance exercises for three different training protocols which will include high resistance and low number of repetition exercise, low resistance and high repetition exercise and low resistance and low repetition exercise. You will need to do warm-up and cool down exercises at the start and end of the session and there will be rest intervals between the testing and exercise bouts.

What are the possible advantages of taking part?

There are no direct benefits to you of taking part in this study but you will gain a better idea of the strength of the muscles controlling your knee joint movement.

What are the possible disadvantages of taking part?
During the session, you will feel as if you are working your muscles hard. You may experience some muscle discomfort or muscle fatigue whilst performing the exercises. After the session, you may experience some muscle soreness/heaviness for a day or so, just like after any unaccustomed exercise. It should only last about one to two days.

Do I have to take part?
You are under no obligation to take part in this study. If you do decide to take part, you are free to withdraw at any time. This will not affect your future relationship with the researcher if you are involved with them professionally in other circumstances i.e. in teaching and assessment. If you do decide to withdraw part way through the study, it will not disadvantage you in any way.

Who should I contact for further information?
We are very happy to discuss any causes for concerns or to answer any of your questions relating to this study. If at any time you are concerned about your participation or you feel that you are experiencing any adverse effects, please contact Kim Hastings or Pritesh Barchha (see details below).

What will happen to the information collected?
All of the information gathered in this study will be kept strictly confidential. Where appropriate, the personally identifiable information will be coded. It is our intention to use the information from this research to confirm the robustness of the protocols in order to use them in future research projects.

What happens if something goes wrong?
We believe that this study is safe and that we have taken all necessary precautions to make it so by way of the completion of a risk assessment. We have rigorous procedures in place should first aid or medical assistance be required.

The University of East London Research Ethics Committee has reviewed and approved this study. If you are interested in taking part in this research, please contact one of the researchers below:

Confidentiality of the Data
The data that is collected will be kept confidential by the researchers – no other people will have access to this information as it will be kept in a locked cupboard. In addition to this, any data that is made public will be anonymous.

Once the data has been collected and analysed, the results may be published. On the date eleven years after publication, data sheets will be destroyed. For the time period before this happens, the data sheets will be securely locked.

Location
All sessions will be carried out at the University of East London – Stratford Campus in the human movement performance laboratory (UH207).

Disclaimer
You are not obliged to take part in this study, and are free to withdraw at any time during the tests. Should you choose to withdraw from the programme you may do so without disadvantage to yourself and without any obligation.

Contact details:

Mr Pritesh Barchha 0208 223 4256; mobile: 07872960135; email p.barchha@uel.ac.uk

University of East London
School of Health and Bioscience
Romford Road
Stratford
London
E15 4LZ

Written Consent Form

Project title: The feasibility of strength training using the Kin-Com™ isokinetic dynamometer

Name of participant:

Address:

Have been given a copy of the information sheet to keep?	Yes/No
Do you understand the details provided in the information sheet and feel sufficiently informed?	Yes/No
Have you been given the chance to talk about the study and ask questions?	Yes/No
Do you understand the procedures and time involved in this study?	Yes/No
Have you been given the information and do you understand the risks involved in participating?	Yes/No
Have you recently (past 1 month) been involved or are simultaneously involved in another research study?	Yes/No
Have you been informed of the confidentiality procedures and do you accept them to be adequate?	Yes/No
I understand that my personal information may be stored on a computer. If this is done then it will not affect the confidentiality of this information. All such storage of information must comply with the 1998 Data Protection Act.	Yes/No
Do you consent to taking part in this study?	Yes/No
Are you aware of your right to withdraw from the study at any time without having to give reasons?	Yes/No
Do you know who to contact if there are problems?	Yes/No

Participant Name: (block capitals) ……………………………………………..
Participants signature: ……………………………………………………………
Date & Time: ………………………………………………………………………

Investigators name: (block capitals) ……………………………………………..
Investigators signature: ………………………………………………………….
Date & Time: ………………………………………………………………………

8.3 Physical Activity Questionnaire

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.
Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

    _____ **days per week**

    ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

    _____ **hours per day**
    _____ **minutes per day**

    ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only abo about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

    _____ **days per week**

    ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**
_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**
_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**
_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

8.4 Health and Medical questionnaire

Health and Medical Questionnaire

Study ID: ……..……   DOB: …………   Age: … Gender: ……   Date: ……………

Please give the following information to help us assess your current health status. This will help us assess your suitability to participate in this research.

1. Have you been told by your GP that you suffer from any cardiovascular complaint e.g. heart condition, high or low blood pressure etc?

   If yes, please give details …………………………………………………..

   …………………………………………………………………………………

   ……………………………………………………………………………........

2. Have you been told by your GP that you are anaemic?

   If yes, how are you being treated for it? …………………………………

3. In the past month have you experienced shortness of breath or difficulties with your breathing?

   If yes, please give details …………………………………………………

4. Have you been told by a doctor you have asthma?

   If yes, please give details: ………………………………………………...

5. Do you experience dizziness or loss of balance?
   If yes, please give details: ………………………………………………...

6. Have you been told by your GP that you have diabetes, epilepsy or eczema?

If yes, please give details ……………………………………………….

………………………………………………………………………………….

7. Have you been told by your GP that you have high cholesterol?

8. Have you been told by your GP that you have any form of cancer?

9. Have you had a neurological problem that has been diagnosed by your Doctor and/or hospital?

   If yes, please give details including date, type and resultant effects:

   …………………………………………………………………………………

   ………………………………………………………………………………….

10. Have you suffered any injury in the past six months?

    If yes, please give details ……………………………………………………

    …………………………………………………………………………………….

11. Have you visited a Doctor in the past six months?

    If yes, please give details ……………………………………………………

    …………………………………………………………………………………….

12. Do you take regular drugs or medication?

    If Yes: Do they affect your ability to take part in physical activity?

    If yes, please give details ……………………………………………………

    …………………………………………………………………………………….

13. Is there any other information regarding your health that you think that we should know, or might affect your ability to exercise?

If yes, please give details …………………………………………………

……………………………………………………………………………….

…………………………………………………………………….

	Date
Medical and health screening questions completed	…………..
IPAQ completed	…………..

Declaration:

To the best of my knowledge and belief, the answers I have given above are true and accurate.

Name …………..……….. Signature ………………………………….

8.5 Ethics Approval

University of East London

Dr Mary Cramp
HAB
Stratford

ETH/09/88

09 December 2010

Dear Dr Cramp,

Application to the Research Ethics Committee: Reliability of muscle strength and aerobic function after stroke (K Hastings/P Barchha)

I advise that Members of the Research Ethics Committee have now approved the amendments to the previously approved application. The Research Ethics Committee should be informed of any significant changes that take place after approval has been given. Examples of such changes include any change to the scope, methodology or composition of investigative team. These examples are not exclusive and the person responsible for the programme must exercise proper judgement in determining what should be brought to the attention of the Committee.

In accepting the terms previously advised to you I would be grateful if you could return the declaration form below, duly signed and dated, confirming that you will inform the committee of any changes to your approved programme.

Yours sincerely

Debbie Dada
Administrative Officer for Research
d.dada@uel.ac.uk
02082232976

Research Ethics Committee: ETH/09/88/0

I hereby agree to inform the Research Ethics Committee of any changes to be made to the above approved programme and any adverse incidents that arise during the conduct of the programme.

Signed:................................Date: ....

Please Print Name:

8.6 Participant information sheet and consent form

University of East London, School of Health and Biosciences, Stratford Campus, Romford Road, Stratford, London, E15 4LZ

University Research Ethics Committee

If you have any queries regarding the conduct of the programme in which you are being asked to participate please contact the Secretary of the University Research Ethics Committee: Ms D Dada, Administrative Officer for Research, Graduate School, University of East London, Docklands Campus. London E16 2RD (telephone 0208 223 2976 e-mail d.dada@uel.ac.uk)

The Principal Investigators

Pritesh Barchha & Kim Hastings

University of East London

School of Health & Biosciences

Stratford Campus

Romford Road

Stratford

London

E15 4LZ

0208 223 4260 / 0208 223 4515

Consent to Participate in a Research Study

The purpose of this letter is to provide you with the information that you need to consider in deciding whether to participate in this study.

Project Title

The feasibility of strength training procedures on healthy individuals.

Project Description

What is the purpose of this study?

This study will evaluate the feasibility of muscle training procedures we would like to use in a future study to strengthen muscles of people who have had a stroke. We want to measure how strong your muscles are, and how well you can perform exercises at varying levels of work on a machine designed to test and train muscle performance. We are looking to recruit participants who are in good health but who do not participate in regular exercise or sporting activities.

What will I have to do if I take part?

You will be asked to attend the Human Motor Performance Laboratory at the University of East London twice a week for two weeks making a total of four individual sessions. Each session should last less than an hour each.

The procedures you will be doing have been used previously to assess and train muscle strength. To determine whether it is suitable for you to complete the tests, you will be asked to complete a medical screening questionnaire and a questionnaire to determine your current level of physical activity. We will test both legs and you will be asked to wear a pair of shorts which we can provide if you wish.

To start with, strength of the muscles around the knee will be tested using the machine and you will push or pull your leg against a moving resistance. You will be asked to do this using your maximum effort for five repetitions. You will then be taken through resistance exercises using a selected target load. These can be explained to you on the day. You will be asked to complete three sets of these exercises. You will need to do warm-up and cool down exercises at the start and end of the session and there will be rest intervals between the testing and exercise bouts.

What are the possible advantages of taking part?

There are no direct benefits to you of taking part in this study but you will gain a better idea of the strength of the muscles controlling your knee joint movement.

What are the possible disadvantages of taking part?

During the session, you will feel as if you are working your muscles hard. You may experience some muscle discomfort or muscle fatigue whilst performing the exercises. After the session, you may experience some muscle soreness/heaviness for a day or so, just like after any unaccustomed exercise. If this occurs, it should not last more than one or two days.

Do I have to take part?

You are under no obligation to take part in this study. If you do decide to take part, you are free to withdraw at any time. This will not affect your future relationship with the researcher if you are involved with them professionally in other circumstances i.e. in teaching and assessment.

Who should I contact for further information?

We are very happy to discuss any causes for concerns or to answer any of your questions relating to this study. If at any time you are concerned about your participation or you feel that you are experiencing any adverse effects, please contact Kim Hastings or Pritesh Barchha (see details below).

What will happen to the information collected?

All of the information gathered in this study will be kept strictly confidential. Where appropriate, the personally identifiable information will be coded. It is our intention to use the information from this research to confirm the robustness of the protocols in order to use them in future research projects.

What happens if something goes wrong?

We believe that this study is safe and that we have taken all necessary precautions to make it so by way of the completion of a risk assessment. We have rigorous procedures in place should first aid or medical assistance be required.

The University of East London Research Ethics Committee has reviewed and approved this study. If you are interested in taking part in this research, please contact one of the researchers below:

Confidentiality of the Data

The data that is collected will be kept confidential by the researchers – no other people will have access to this information as it will be kept in a locked cupboard. In addition to this, any data that is made public will be anonymous.

Once the data has been collected and analysed, the results may be published. On the date eleven years after publication, data sheets will be destroyed. For the time period before this happens, the data sheets will be securely locked.

Location

All sessions will be carried out at the University of East London – Stratford Campus in the human movement performance laboratory (UH207).

Disclaimer

You are not obliged to take part in this study, and are free to withdraw at any time during the tests. Should you choose to withdraw from the programme you may do so without disadvantage to yourself and without any obligation.

Contact details:

Miss Kim Hastings 0208 223 4515; mobile: 07904103545; email k.hastings@uel.ac.uk

Mr Pritesh Barchha 0208 223 4256; mobile: 07928555458; email p.barchha@uel.ac.uk

University of East London

School of Health and Bioscience

Romford Road

Stratford

London

E15 4LZ

Written Consent Form

Project title: The feasibility of strength training using the Kin-Com™ isokinetic dynamometer

Name of participant:

Address:

Have been given a copy of the information sheet to keep?	Yes/No
Do you understand the details provided in the information sheet and feel sufficiently informed?	Yes/No
Have you been given the chance to talk about the study and ask questions?	Yes/No
Do you understand the procedures and time involved in this study?	Yes/No
Have you been given the information and do you understand the risks involved in participating?	Yes/No
Have you recently (past 1 month) been involved or are simultaneously involved in another research study?	Yes/No
Have you been informed of the confidentiality procedures and do you accept them to be adequate?	Yes/No
I understand that my personal information may be stored on a computer. If this is done then it will not affect the confidentiality of this information. All such storage of information must comply with the 1998 Data Protection Act.	Yes/No
Do you consent to taking part in this study?	Yes/No
Are you aware of your right to withdraw from the study at any time without having to give reasons?	Yes/No
Do you know who to contact if there are problems?	Yes/No

Participant Name: (block capitals) ……………………………………………..

Participants signature: ………………………………………………………..

Date & Time: …………………………………………………………………

Investigators name: (block capitals) ……………………………………………..

Investigators signature: ……………………………………………………...

Date & Time: …………………………………………………………………

8.7 Ethics approval

EXTERNAL AND STRATEGIC DEVELOPMENT SERVICES
uel.ac.uk/qa

Quality Assurance and Enhancement

MR PRITESH BARCHHA
6 SELKIRK ROAD
OFF PEEBLES ROAD
LEICESTER
LE4 7ZQ

Date: 18 August 2011

Dear Pritesh,

Project Title:	***How does intensity and training volume affect the response to progressive resistance exercise by stroke survivors?***
Researcher(s):	***Pritesh Barchha***
Supervisor(s):	***Mary Cramp***

I am writing to confirm that the review panel appointed to your application have now granted ethical approval to your research project on behalf of University Research Ethics Committee (UREC).

Should any significant adverse events or considerable changes occur in connection with this research project that may consequently alter relevant ethical considerations, this must be reported immediately to UREC. Subsequent to such changes an Ethical Amendment Form should be completed and submitted to UREC.

Approval is given on the understanding that the 'UEL Code of Good Practice in Research' (www.uel.ac.uk/qa/manual/documents/codeofgoodpracticeinresearch.doc) is adhered to.

Yours sincerely,

Merlin Harries
University Research Ethics Committee (UREC)
Quality Assurance and Enhancement
Telephone: 0208-223-2009
Email: **m.harries@uel.ac.uk**

Docklands Campus, University Way, London E16 2RD
Tel: +44 (0)20 8223 3322 Fax: +44 (0)20 8223 3394 MINICOM 020 8223 2853
Email: r.carter@uel.ac.uk

8.8 NHS ethics approval

NHS
National Research Ethics Service

NRES Committee London - East
REC Offices
Room 10
4th Floor West
Charing Cross Hospital
Fulham Palace Road
London
W6 8RF

Telephone: 020 331 10100

26 July 2011 *(Revised- Corrected approved non-NHS SSI details)*

Mr Pritesh Barchha
University of East London
School of Health and Biosciences
Water Lane, London
E15 4LZ

Dear Mr Barchha

Study title:	**How does intensity and volume of work affect the response to progressive resistance exercise by stroke survivors?**
REC reference:	**11/LO/0300**

Thank you for your letter of 20 June 2011, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair .

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Non-NHS sites

Notification(s) of no objection have been received from local assessors for the non-NHS site(s) listed in the table below, following site-specific assessment (SSA).

I am pleased to confirm that the favourable opinion applies to the following research site(s), subject to site management permission being obtained prior to the start of the study at the site (see under 'Conditions of the favourable opinion below').

Research Site	Principal Investigator / Local Collaborator
University of East London	Mr Pritesh Barchha

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Evidence of insurance or indemnity		
GP/Consultant Information Sheets	4	20 June 2011
Investigator CV		
Letter of invitation to participant	6	25 April 2011
Other: Site-specific Information Form- only if study requires SSA and main REC is also the SSA REC for a non-NHS research site (signed/authorised copy)	2	28 February 2011
Other: summary CV for student		02 March 2011
Other: summary CV for supervisor		02 March 2011
Other: letters of invitation to participants	4	09 February 2011
Other: letters of invitation to participants- participant identification sheet for clinicians	2	09 February 2011
Participant Consent Form	2	09 February 2011
Participant Information Sheet	4	20 June 2011
Protocol	12	28 February 2011
REC application		
Referees or other scientific critique report		07 December 2010
Referees or other scientific critique report		29 November 2010

Response to Request for Further Information		20 June 2011

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

Further information is available at National Research Ethics Service website > After Review

11/LO/0300	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project

Yours sincerely

Revd Dr Joyce Smith
Chair

Email: laura.keegan@nhs.net

Enclosures: "After ethical review – guidance for researchers"

Copy to: *Mr Martin Longstaff*

Newham University Hospital NHS
NHS Trust

Research & Development Office
c/o Academic Centre
Newham University Hospital NHS Trust
Glen Road, Plaistow
E13 8SL

Tel: 0207 363 8923 / 9266 Direct Line
Fax 020 7363 9463 external (3463 internal)
Email: doreen.ampomahasiedu@newhamhealth.nhs.uk

Dr Shanti Vijayaraghavan, Director of R&D
Ms Neeta Patel, R&D Manager
Ms Doreen Ampomah - Asiedu, R&D Co-ordinator

Mr Pritesh Barchha
Graduate Teaching Assistant
University of East London
School of Health and Bioscience
Water Lane
London
E15 4LZ

6 September 2011

Dear Mr Barchha

Re: Training parameters for optimal resistance exercise after stroke.

R&D No: 2011/14
UKCRN ID: N/A

Thank you very much for contacting us about the above study and providing us with the relevant documents.
As the role of Newham University Hospital will be restricted to referring potential participants to the research team (based in another organisation) for assessment and possible recruitment to the study, then, in this instance the Trust is considered as a 'patient identification centre' (PIC) and not a 'research site'.

We have reviewed this request and are happy to provide approval as a PIC; according to the data protection details given. Patients must be happy for their details to be passed onto the researchers and made aware that the Trust is independent of the research team.

The Trust accepts no responsibility, and provides no indemnity, for any patient-related research procedures, including recruitment and informed consent.

Many thanks and best wishes,

Dr Shanti Vijayaraghavan,
Director of R&D

cc: Ronke Kensington – Oloye, Business Manager (Elderly), NUHT; Sara Lightowlers, Clinical Director, NUHT; Deidre Barr, Deputy Chief Operating Officer, NUHT; Dr Ava Jackson, Consultant, Care of the Elderly, NUHT; Dr Hafiz Syed, Consultant, Care of the Elderly, NUHT; Mr Premchand Daboo, Stroke Information Officer, NUHT; Ms Claudia Bull, Physiotherapist, NUHT; Neeta Patel, R&D Manager, NUHT

8.9 Invitation letter

On University Headed Paper

Date

Dear

A group of people who have had a stroke and received their care from Newham University Hospital NHS Trust Stroke Services are being invited to take part in a research study. The research is being undertaken at the University of East London in conjunction with Newham University Hospital NHS Trust. The research will look at the effects of progressive resistance exercise and how training parameters influence outcomes. It is hoped that the information from this study will help with developing advice about exercise prescription for people who have had a stroke.

We are contacting you because we think that you may be suitable to take part in the study and we would like to provide your details to the researchers so that they can contact you about the study. If you would like more information about the study, please tick the appropriate statement on the next page, fill in your name and contact number and return this letter in the envelope provided in the next 14 days. The researchers will provide you with more information about the study and you will have the opportunity to think about whether or not you would like to take part. Any decision you make about participation in this study will not affect any future treatment you may require.

If you prefer not to be contacted, please tick the appropriate statement and return this letter in the envelope provided in the next 14 days.

Yours Sincerely

Pritesh Barchha

Principal Investigator

Tel: 0208 223 4260

Email: p.barchha@uel.ac.uk

☐ I am interested in finding out about the study, please send me more information.

My Name is: ________________________

My Phone Number is: ________________________

My Home Address is: ________________________

____

____

____

____

☐ I am not interested in finding out more about the study.

8.10 Participant information sheet consent form

[On letter headed paper]

Dear

We would like to invite you to participate in our research study. The study will be conducted by physiotherapists at the University of East London. It will investigate what the best way is to make muscles in the leg stronger for people who have had a stroke. To help you know more about the study, please read the question and answer section below. It should help you decide if you would like to be part of our study. Ask us if you would like more information.

What is the purpose of the study?

People who have had a stroke may have weak muscles as a result of the stroke. Previous research has shown strength training can improve muscle strength but the amount of improvement that has been reported varies markedly. We believe that improvements in muscle strength is influenced by the volume of exercise completed. The purpose of this study is to identify the optimal volume of strength training for people who have had a stroke. We want to compare improvement in muscle strength between groups doing different volumes of training.

We have invited you to take part in the study because you have had a stroke which has resulted in your leg muscles being weak. We want to pilot the research to see if it is feasible so we will only be recruiting a small number of people. The research is part of a PhD research programme for Mr Pritesh Barchha.

What will I be asked to do if I decide to take part?

You will be asked to attend the University of East London for assessment of your muscle strength and function and for regular strength training exercise. On the first two occasions you attend, we will familiarise you with the equipment and take you through the assessment procedures. We will take measurements of muscle strength, and in particular the strength of the muscles that move your knee, by asking you to move your legs as hard as you can against a resistance using a specialised chair. To see whether you are able to fully use your knee muscles, we will also stimulate your muscles using a small electrical current that makes your muscle contract. We will measure your functional ability such as your walking speed, walking endurance and getting out of a chair. We will also ask you to fill out questionnaires that assess your current activity and how your stroke has affected your life. Following the assessment procedures, you will participate in an exercise programme, aimed to strengthen your knee muscles. You will be randomly allocated to one of the three training groups. Whichever group you're allocated to, you will be doing strength training. The groups will do different variations of the strengthening programme.

To participate in the training programme you will be asked to attend the University twice a week for six weeks where you will be guided through your structured exercise programme. For your results to be useful, we will need you to attend at least ten training sessions. There will be another assessment session after completion of training identical to the initial assessment. We will also ask you return for one further session after 3 months.

Do I have to take part?

It is entirely up to you whether or not you would like to take part. Any participation in this study does not affect the care you would normally receive outside the study. If you decide to take part but change your mind, you are still free to withdraw at any time.

What are the possible advantages of taking part?

You should feel that your muscles are stronger because of the training. Some people also notice that activities such as walking and climbing stars are improved after strength training.

What are the possible disadvantages or risks of taking part?

Because you will be doing unaccustomed exercise, you may experience some muscle stiffness or soreness a day or so after the first assessment and training sessions. This should be short-lasting (1-2 days) and will not stop you doing your everyday activities.

When people exercise, the risk of having a heart attack is increased. The risk of having a heart attack is increased from 1 in 1,000,000 when not exercising to 3 in 1,000,000 when people are exercising. Overall, this risk is small and previous studies doing strength training in stroke participants have not reported such events.

During the assessment of your muscle function, we will be using small electrical currents for a very short time (5 to 15 seconds). This causes a tingling sensation that makes your muscles contract. Some people find this uncomfortable but it will be set at a level that is tolerable to you. There is a small risk of a trip or fall but the room is set up to be a safe environment to walk in and the researcher will be there to assist you.

What happens if something goes wrong?

We believe that this study is basically safe and do not expect you to suffer any harm or injury because of your participation in it. In the unlikely event that something does go wrong and through our negligence, you are harmed, you will be compensated. However, you may have to pursue your claim through legal action. The University will consider any claim sympathetically. If you are not happy with any proposed compensation, you may have to pursue your claim through legal action. If you would like further information on our insurance cover, please contact:

Martin Longstaff, University of East London, Docklands Campus, Knowledge Dock, London, E16 2RD. Telephone number: 0208 223 7485.

Who should I contact for further information or if I have any problems/concerns?

If you are interested in taking part in this study but you have further questions, please contact me and I'll be very happy to help. If at any time you are concerned about your participation in this study or note any untoward effects, please contact Pritesh Barchha (details below). Alternatively, you may contact Dr Mary Cramp (Research Supervisor at the University of East London), on 0208 223 4544 or by email on m.c.cramp@uel.ac.uk.

If you are unhappy about any aspect of your participation in the study and wish to report a complaint, please contact:

Martin Longstaff, University of East London, Docklands Campus, Knowledge Dock, London, E16 2RD. Telephone number: 0208 223 7485.v

Where will this study take place?

The study will take place in University House at the University of East London in Romford Road, London. There is a room with the equipment for undertaking this type of research.

How will I travel there and get back home?

We will discuss with you the best means of transport for you and help with these arrangements and the costs of your travel.

What will happen to the information collected?

All of your personal information that we collect will be confidential. Only the researchers will have access to this information. The data that we gather about your health will be anonymous.

Once you complete the study, we can tell you about your individual results and what we found from doing the study when it is completed. We will keep your information securely for ten years after the study is completed and then the data will be destroyed.

Involvement of the General Practitioner/Family doctor (GP)

If you agree to participate, your GP will be informed of your participation and we will send them a copy of this information sheet. However, this will not affect any current and future consultation or treatment you have with your GP.

Who should I contact for further information?

We are happy to talk to you about our study. Please feel free to contact Dr Mary Cramp, Dr Jane Culpan or Mr Pritesh Barchha (details below).

Contact details:

Dr Mary Cramp; 0208 223 4544; email m.c.cramp@uel.ac.uk

Dr Jane Culpan; 0208 223 4566; email j.culpan@uel.ac.uk

Mr Pritesh Barchha; 0208 223 4260; email p.barchha@uel.ac.uk

Research Ethics Committee

The NRES East London Ethics Committee has given their approval for this study to take place. If you would like to speak to the regulators, please contact:

Laura Keegan, Research Ethics Co-ordinator, REC Offices, Block A, South House, Royal Free Hospital, Pond Street, London, NW3 2QG

Thank you for your time.

Yours Faithfully,

Pritesh Barchha

Principal Investigator

Project title: Training parameters for optimal progressive resistance exercise after stroke

REC Number:

Name of participant (Print):

Allocated participant number:

Have been given a copy of the information sheet to keep?	Yes/No
Do you understand the details provided in the information sheet and feel sufficiently informed?	Yes/No
Have you been given the chance to talk about the study and ask questions?	Yes/No
Do you understand the procedures and time involved in this study?	Yes/No
Have you been given the information and do you understand the risks involved in participating?	Yes/No
Have you recently (past 1 month) been involved or are simultaneously involved in another research study?	Yes/No
Have you been informed of the confidentiality procedures and do you accept them to be adequate?	Yes/No
I understand that my personal information may be stored on a computer. If this is done then it will not affect the confidentiality of this information. All such storage of information must comply with the 1998 Data Protection Act.	Yes/No
Do you consent to taking part in this study?	Yes/No
Are you aware of your right to withdraw from the study at any time without having to give reasons?	Yes/No
Do you know who to contact if there are problems?	Yes/No
Do you agree for your GP to be informed of your participation?	Yes/No

Participant Name: ....
Participants signature: ....
Date & Time: ....
Researcher Name: ....
Researcher signature: ....
Date & Time: ....
Witness Name (participants that cannot sign): ....
Participants signature: ....
Date & Time: ....