A COMPARISON OF
FULL RANGE AND LIMITED RANGE OF MOTION
STRENGTH TRAINING

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John Edwin Crocker

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ABSTRACT

In strength training, intensity is considered the most important variable for developing maximal strength. A possible way of increasing intensity is through the use of limited range of motion (LROM) strength training. Previous studies that have investigated LROM training have found conflicting results and have used questionable testing protocol. Thirty-one male university students were divided into three groups: a full range of motion (FROM) group (n=11), a LROM group (n=11), and a control group (n=9). All groups performed initial tests of the one repetition maximum parallel (1RM) squat and countermovement vertical jump (CMJ). The two experimental groups trained twice a week for seven weeks in supervised sessions that consisted of three sets of either parallel squats or half squats. All groups were monitored with respect to other activities they performed during the training period. Video analysis was performed on the training groups to compare movement patterns. The 1RM squat and CMJ were then tested again after the training period.

The FROM group showed significantly ($p < .05$) greater increases in the 1RM squat and CMJ than the other groups. The LROM group showed significantly greater ($p < .05$) increases in the 1RM squat than the control group. The video analysis revealed the LROM group trained with a movement pattern that was significantly different ($p < .05$) than the FROM group. The results indicated that LROM training was not as effective as FROM training for the tested performances. However, the LROM training was found to be effective in increasing strength outside the trained ROM. The difference in the movement pattern between the two groups may have confounded the results because the FROM group trained with a movement pattern that was similar to the performances being tested.

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LIST OF ABBREVIATIONS

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
CM	Centre of Mass
cm	Centimetre
CMJ	Countermovement Jump
CSA	Cross Sectional Area
EMG	Electromyography
FROM	Full Range of Motion
GRF	Ground Reaction Force
Hz	hertz (cycles per second)
kg	kilogram
LROM	Limited Range of Motion
L_o	Optimal length
<u>M</u>	Mean
MRI	Magnetic Resonance Imaging
MU	Motor Unit
MVC	Maximum Voluntary Contraction
PCr	Phosphocreatine
ROM	Range of Motion
<u>SD</u>	Standard Deviation
1RM	One Repetition Maximum

APPENDICES

CHAPTER ONE
SCIENTIFIC FRAMEWORK

1.1 INTRODUCTION

Coaches, trainers, and athletes all recognize the benefits that weight training can bestow on performance. Weight training can improve strength, power, speed, and endurance, as well as increase body size and reduce the chance of injuries (Bompa, 1993). This current understanding is vastly different from beliefs held decades ago, when few engaged in weight training for a fear of becoming 'muscle bound' or unable to move with any athletic proficiency.

Not only has the interest in weight training increased, but the amount of weight training performed has increased as well. There has been an increase in the number of hours that an athlete must train to reach national or international levels. Weight training alone can require six to eight hours a week for a national level track athlete (Bompa, 1993). If the amount of time spent on flexibility, skill, strategy, and cardiovascular training is also taken into account, it becomes apparent that the workload placed on athletes is reaching staggering levels.

With a limited amount of time and energy available for an athlete to expend on training, it would be advantageous if more efficient strength training methods were developed. There are many opinions as to which technique leads to the most efficient strength gains. Trainers and athletes have argued about and experimented with high volume, high intensity, eccentric, and less mainstream weight lifting methods in attempts to maximize performance.

Limited range of motion (LROM) strength training has often been used in rehabilitation to avoid an injured or painful range of motion (ROM), however, it has received little attention in the athletic setting. LROM training involves weight training in a restricted range. That is, only a portion of the full range of motion (FROM) of the joint or series of joints is exercised. For example, a LROM biceps curl could involve only the upper half of the elbow joint's ROM, about 90 to 150° of elbow flexion.

Legendary strongman Paul Anderson was one of the first individuals to use LROM strength training and was able to achieve tremendous feats of strength. Anderson was a world champion before the age of 21, and later became an Olympic weightlifting champion. He set a Guinness World Record for the "greatest weight ever lifted by a human being" at 6,270 pounds (Little and Sisco, 1993).

LROM training may allow for more intense training by avoiding the weaker areas of a FROM movement strength curve and the strength increases from LROM training may occur throughout the FROM. As well, it can break up training boredom and increase adaptations due to its novelty. LROM strength training is used by numerous strength athletes but has rarely been intentionally inserted into the training programs of other athletes. Used properly, LROM training may lead to greater strength gains and improved athletic performance.

1.2 REVIEW OF LITERATURE

1.2.1 Physiological Adaptations for Strength

Schmidtbleicher (1985) suggests that the cumulative results of training research on optimal training stimulus indicate that strength increases appear to arise from two distinct sources: adaptations to the muscular system and to the nervous system.

Muscular adaptation refers to changes in the muscle itself, which increases its ability to generate force. Muscle tissue from males, females, and elite strength athletes alike have been found to have identical or near identical force generating capabilities per unit of cross sectional area (CSA) (Komi, 1986). Hypertrophy, which is an increase in a muscle's CSA, is therefore thought to be the primary muscular adaptation that increases strength. For hypertrophy to occur in a muscle it must be stimulated (or overloaded) with loads to which it is not accustomed. Muscular adaptations are discussed in more detail in a section 1.2.3.

Increases in strength are also dependent on neural adaptations. Nervous system adaptations improve the efficiency of the contractile mechanism and thus can lead to strength increases without increases in muscle size. Sale (1988) suggests that neural adaptations include improving activation of the prime mover and synergists, and limiting the co-contraction of antagonists (reciprocal inhibition). Nervous system adaptations are discussed in detail in Section 1.2.4.

Different training methods can successfully increase strength by stressing the different systems. Some may stress the nervous system, others, the muscular system. This is evident when one observes the difference in physiques of Olympic weightlifters and bodybuilders. Olympic weightlifters compete in weight classes and do not necessarily want to increase their body mass to get stronger. They want to stress their nervous system and therefore, train accordingly. They use very heavy loads, low volume, and do not train to exhaustion. They tend to have less body mass than other strength athletes but are extremely strong for their bodyweight. Bompa (1993) states that the main factor for hypertrophy training is the cumulative exhaustion effect of numerous sets, not just exhaustion for each set. Olympic weightlifters simply do not train with enough volume to induce large hypertrophy increases. Bodybuilders do have a large amount of muscle mass along with high levels of strength. They train to exhaustion with lighter loads and greater volume than Olympic weightlifters.

1.2.2 Intensity of the Stimulus

For strength increases to occur, an overload must be placed on the body. It must be stressed with a mechanical load greater than that to which it is accustomed. When the body adapts to this initial overload, it must then experience a greater overload to get even stronger. A common factor to training programs is to continually stress the body, which is known as progressive overload (Bompa, 1993).

Overloading can be achieved in several ways: by increasing how hard the muscle works (intensity), or how long (volume), and how often it is worked (frequency). Atha (1981) states that of all the variables incorporated in weight training, intensity is the most important with respect to developing strength and mass. The result of different training intensities can be seen in the strength and physiques of athletes. Endurance runners do not need excessive strength and mass, therefore they do not train with high intensity but rather with high volume. On the other hand, strength athletes train with very high intensities to increase their strength and mass.

Intensity can be defined as the percentage of maximal muscle tension that is developed (Bompa, 1993). Bompa suggests using a load of at least 80 % of an individual's one repetition maximum (1RM) when training for strength. Below this level too few motor units will be recruited to lead to strength gains.

Zatsiorsky (1995) also states the importance of attaining maximal muscle tension. In fact, Zatsiorsky classifies methods of strength training based on the level of muscle tension generated. The first method that Zatsiorsky describes is called the maximal effort method, which uses maximal or near maximal loads that are performed for few repetitions. This method is subscribed to by Olympic weightlifters and creates greater adaptations on the nervous system than the muscular system.

A second method, the repeated effort method, is used to increase strength by stressing the muscle tissues more than the nervous system. It involves using sub-maximal loads for a greater number of repetitions. Zatsiorsky (1995) stresses that this type of training must be performed to failure. At the failure point, the external load is greater than the relative maximal muscle force that can be generated. This relative maximal force generation is less than that achieved in a fresh muscle due to fatigued motor units, which are unable to contribute force generation. Poliquin (1991) uses a similar classification system in which he calls the two methods the Maximal Weight and Hypertrophy methods.

Zatsiorky (1995) states that for an individual muscle fibre to be stimulated into hypertrophy it must reach this fatigued state. A maximal load that can only be lifted once will cause the fatigue of fewer fibres than a submaximal load that is lifted several times to failure. Because the submaximal load is lifted for a longer time period, more muscle fibres reach a fatigued state (Figure 1.1).

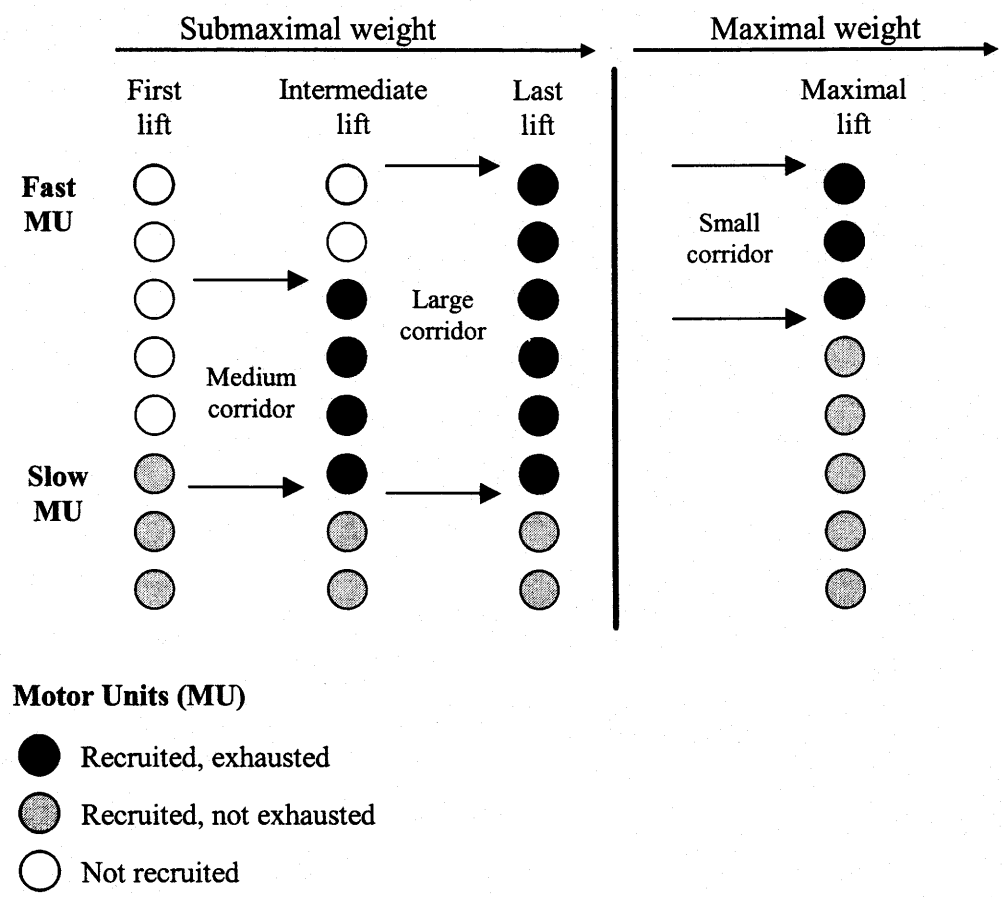


Figure 1.1 The different subpopulations of motor units (MU) that are utilized during different methods of strength training. A maximal lift will recruit the most MUs but will fatigue only a small number of MUs, namely the larger fast twitch MUs. Submaximal lifts to failure will recruit fewer MUs per lift but as more repetitions are performed, the exhausted MUs will not be able to fire and other MUs will be recruited in their place. This will lead to more fatigued MUs and muscle fibres.
(from Zatisorsky (1995), p. 103.)

Finally, the dynamic effort method uses a submaximal load that is moved with the fastest velocity possible. This method applies specifically to training for throwing and jumping events. This method involves an attempt to accelerate the load through the entire ROM, whereas it must be decelerated at the end ROM with the other training methods. In weight training, accelerating a weight as fast and for as long as possible is desired in order to increase muscle tension. Intensity is determined not only by the load but the acceleration as well.

1.2.3. Muscular Adaptations

Amino acid transport into the muscle fibres is thought to be a precursor to protein synthesis, which is required for hypertrophy. Goldberg, Jablecki, and Li, (1974) found that amino acid uptake is increased more in muscle fibres that are recruited as compared to inactive fibres. Goldberg (1968) compared muscle fibres and found that the more active fibres had a greater amino acid uptake than the inactive fibres. They also found that protein catabolism was reduced in active fibres. This is important as muscle hypertrophy can occur either from an increase in protein (amino acid) synthesis or a decrease in protein breakdown. Physical activity appears to shift both of these mechanisms in favour of hypertrophy.

Higher levels of intensity are critical in affecting protein balance and hypertrophy (Goldberg, Etlinger, Goldspink, and Jablecki, 1975). A study involving electrical stimulation demonstrated that increasing the frequency of stimuli in a given time (i.e. greater intensity) led to greater amino acid transport in isolated muscle fibres (Avrill, 1967). Numerous studies have been performed on animals in an attempt to investigate muscle overload and hypertrophy. Animals were used so that full muscle samples and more invasive techniques could be used to examine the training effects. The evaluation of human training studies is mainly limited to muscle biopsies and external force measurements which give limited results. Timson (1990) grouped the animal studies into three categories: compensatory (ablation) hypertrophy, stretch-induced hypertrophy, and exercise induced hypertrophy.

Studies involving the removal of synergistic or assistory muscles in rats have produced rapid and large amounts of hypertrophy in the remaining muscles due to a tremendous increase in tension and workload because the intact muscles is required to work on its own. Stone, Brannon, Haddad, Qin, and Baldwin (1996) looked at the effect of endurance training and the removal of various ankle plantar flexor muscles. They found significant increases in the overloaded plantaris muscles weight (59 % heavier than the control plantaris) as compared to control rats as well as endurance trained rats. Other studies by Roy, Meadows, Baldwin, and Edgerton (1982), and Roy, Baldwin, Martin, Chimarusti, and Edgerton (1985) also found significant increases in muscle weight and CSA in overloaded rat muscles.

Goldberg (1972) performed studies with rats where the tendons of synergistic muscles (tenotomy) were cut to prevent muscle tension. Goldberg looked at the effects of lack of food, insulin, and hormones on hypertrophy of plantar flexor muscles. Even in these extreme conditions, significant amounts of hypertrophy in the overloaded muscles were observed. This suggests that work induced hypertrophy depends on muscle tension or other stimulus whereas normal growth hypertrophy requires the stimulus of hormones, insulin, and food.

Stretch-induced hypertrophy tries to induce muscle growth by increasing the amount of passive tension (i.e. stretch) on the muscle. Holly, Barnett, Ashmore, Taylor, and Mole (1980) investigated passive stretch on chickens. Springs were used to keep a constant stretch on the wing muscles. By using electromyography (EMG) they noticed no increase in muscle activity with the increased passive tension. However, they did notice a large increase not only in muscle's CSA but in its length as well. After one week, Holly et al. (1980) found the longitudinal increases stopped, as well as the rapid amounts of total muscle hypertrophy. Adding sarcomeres in series increases the length of a muscle fibre which can help allieviate the amount of passive tension (Tabary, Tabary, Tardieu, Tardieu, and Goldspink, 1972). Growing bones continually stretch developing muscles, thus requiring constant additions of sarcomeres to increase the muscle fibre's length. This longitudinal hypertrophy could explain the initial rapid increase in total muscle hypertrophy from passive tension.

Sola, Christianson, and Martin (1973) also investigated the effect of passive stretch on the wing muscles of chickens, but they used weights instead of springs. They found that as greater amounts of weights and hence passive tension were placed on the wings, greater amounts of hypertrophy occurred. An external weight of 100 g increased the stretched muscle weight 120 % as compared to controls while 200 g lead to 180 % increase in muscle weight.

Timson (1990) points out that the training stimulus, magnitude of enlargement, and muscle fibre adaptations of compensatory and stretch-induced hypertrophy are not necessarily similar to those of human strength training. The constant stimulus seen in these studies is quite different from intermittent strength training and therefore leads to different adaptations, namely larger increases in total muscle weight and CSA and a conversion of some fast twitch fibres to slow twitch fibres. However, all models seem to indicate that a higher intensity stimulus leads to greater increases in muscle hypertrophy and this can be valuable information when designing efficient strength training protocols.

Additional animal training studies have been performed in an attempt to examine physiological responses that occur with resistance training. Klitgaard (1988) trained rats to lift an external load with the use of their plantar flexors. Klitgaard found significant increases in muscle weight for the trained soleus and plantaris muscles. Gonyea and Ericson (1976) trained cats to move weights. They also found significant hypertrophy in the trained muscles. Wong and Booth (1988) electrostimulated the leg muscles of rats and found significant increases in the trained muscle's weight.

All of the above studies were able to directly examine the entire muscle after completion of the animals' training. These studies used training methods similar to human resistance training. That is, progressive overload with intense, low repetition intermittent resistance training. The specificity of this type of training should be more applicable to human strength training (Timson, 1990).

Other studies have used human participants to investigate which training protocols are the most effective for muscle hypertrophy. Higbie, Cureton, Warren, and Prior (1996) investigated human muscle CSA using MRI. They found smaller increases in quadricep CSA with ten weeks of concentric exercise compared to eccentric exercise. Similarly, Hortobagyi et al. (1996) found eccentric leg extension exercise to be more effective for increasing quadricep muscle hypertrophy compared to concentric training methods. Greater maximum force can be genereated with eccentric muscle actions compared to concentric muscle actions, therefore it has been suggested that eccentric training is more effective in increasing muscle mass.

To ensure that it was indeed the tension and not some other factor (i.e. neural) that was leading to the hypertrophy, studies have also looked at muscles with no nerve supply. A muscle that is denervated with no increased workload will atrophy. However, similar amounts of hypertrophy have been found in tenotomized and stretch induced animals that have been denervated, compared to those that have not had any nerves removed (Schiaffino and Hanzlikova, 1970). Sola, Christianson, and Martin (1973) observed similar amounts of stretch-induced hypertrophy in birds whether their wings were denervated or not. This suggests that neural activity is beneficial but not required for hypertrophy; thus tension is the most important factor.

While this may indicate that tension is the critical factor it should be noted that nerve supply and neural activity also appear to be beneficial. Markelonis and Hwan Oh (1979) added protein fractions from nerve cultures to embryonic skeletal muscle. The presence of this protein prevented the muscle cultures from degenerating. With the protein removed, the cultures experienced rapid atrophy and degenerated within two to three days.

1.2.4. Muscle Fibre Recruitment with Increasing Muscle Tension

As mentioned earlier, increasing muscle tension will lead to increases in muscle hypertrophy. A muscle can increase the tension it develops in two ways; by increasing the rate of firing of the muscle fibres and increasing the number of muscle fibres that are recruited or both (Sale, 1988).

When a muscle fibre contracts, it does so with full force. It cannot contract partially and therefore must contract all or none (Sherrington, 1906). In order to generate more force it must increase its frequency of contractions. Once it has reached its maximum firing frequency more muscle fibres will have to become active in order to achieve a higher level of force production.

A motor unit consists of a single motor neuron and all of the muscle fibres it innervates. Like a muscle fibre, a motor unit must contract all or none. Thus if the motor unit is activated, all the muscle fibres in that unit will contract maximally.

Henneman, Somjen, and Carpenter (1965) discovered that as the tension for a contraction increased, more motor units became active. They discovered that the smaller and weaker motor units were the first to be recruited. As the load increased larger and stronger motor units were recruited on top of the already active small motor units. This orderly recruitment of motor units is known as Henneman's Size Principle.

It was also noted that the smaller motor units consisted of tonic, slow twitch muscle fibres and the large motor units contained phasic, fast twitch muscle fibres. The slow twitch motor units contain only 10 to 180 fibres per unit while the fast twitch motor units can have up to 500 fibres per motor unit (Hole, 1978).

Recruitment of the smaller slow twitch motor units prior to the fast twitch units has several advantages. First of all, fine movements do not require large amounts of force but they must be very precise. With the smaller units, the increments of force generation are much smaller which allows for much greater control of movement. On the other hand, powerful, explosive movements do not require as much precision, so the larger motor units can be systematically recruited with larger gradients in force increases.

Slow twitch fibres are more efficient with respect to energy consumption and production. Slow twitch fibres have a smaller change in pH and Phosphocreatine (PCr) levels and quicker PCr replenishment after extended exercise (Mizuno, Secher, and

Quistorff, 1994). The length of time of a cross bridge cycle is much longer in the slow twitch fibres. This means less adenosine triphosphate (ATP) is used for each second a contraction is maintained. A large amount of energy is saved with these fibres being recruited first. Only when necessary do the energy expensive fast twitch fibres activate.

Muscles that have a high amount of tonic activity (i.e. postural muscles) tend to have a higher percentage of slow twitch fibres (Johnson, Polgar, Weightman, and Appleton, 1973). The slow twitch fibres have a large amount of mitochondria and therefore, a vast energy supply. The fast twitch fibres have limited energy supply due to fewer mitochondria and can fatigue very quickly. In a fatigued state the muscle fibres are unable to generate any force. Slow twitch fibres are resistant to fatigue and can be recruited for much longer periods without fatiguing.

From a performance perspective, a strength athlete will want to recruit all muscle fibres at maximal firing frequencies, especially the powerful fast twitch fibres. Since they are recruited last, it requires a high amount of tension for these motor units to be recruited. Training with very heavy loads (90 to 100% of 1RM) and few repetitions (Maximum Effort method) will recruit the majority of the muscle fibres but it will only fatigue some of the fast twitch fibres because of the short period of work. The slow twitch fibres have been recruited but they have not been fatigued and will not have received enough stimulation required for adaptation (Zatsiorsky, 1995). Use of the Repeated Effort method will lead to the fatigue of a greater number of muscle fibres. A heavy load (85% of 1RM) will recruit most of the fibres and it should also allow for more repetitions to be completed so more muscle fibres in total will be fatigued.

MacDougall (1992) points out that the majority of studies have found a greater level of hypertrophy in fast twitch fibres. This could be due to a greater relative involvement of these fibres since they are not used as much during normal daily activities. If these fibres are more capable of hypertrophy it would be important for those athletes who desire strength and power to recruit and fatigue these muscle fibres.

Henneman's Size Principle was based on isometric contractions and some investigations have found different responses for dynamic muscular contractions. Zehr and Sale (1994) state that ballistic actions reduce the threshold for motor unit recruitment. This could allow for slow and fast twitch fibres to be recruited closer together (i.e. simultaneously). The fast twitch fibres have a faster axonial conductive velocity (Fitts and Widrick, 1994) and thus it could appear that they are recruited first.

Some people insist that fast twitch fibres can be selectively recruited prior to slow twitch fibres by using fast and explosive movements. However, most studies that have compared recruitment patterns between slow building contractions and ballistic contractions have not shown reversals of recruitment order or selective recruitment of fast twitch units (Sale, 1988). For extremely fast (i.e. vibratory) movements, different muscles (i.e. flexors and extensors) must fire at very rapid rates. Fast twitch fibres may be recruited first to accommodate the very fast force generation that is required to quickly change directions (Komi, 1986).

The fast twitch fibres are associated with short and quick movements because these types of movements create greater tension on the muscles. The speed of the movement is dependent on the nervous system, which can be trained specifically to increase the speed of the movement (Wilmore and Costill, 1988).

A study with animals has led to the suggestion that there might be task-specific groups of motor units within multifunctional muscles. Hoffer et al. (1987) used EMG to study muscle activity in cats. The sartorius muscle has two main functions, to flex the hip and to extend the knee. It was originally believed that every muscle has one motor unit pool that contained all muscle fibres, but the investigators found the existence of three separate motor unit pools within sartorius. Each motor unit pool was specific for a certain aspect of locomotion: knee extension, hip flexion, and hip flexion with knee extension. Within each of these pools, the motor units were recruited by the size principle but this did not equate to orderly recruitment over the entire muscle. Because of technical limitations, large muscles involved in activities such as kicking, jumping, and throwing have not been investigated. Therefore, a definitive answer can not be made at present as to whether selective or preferential recruitment of fast twitch units in dynamic sport performance occurs.

If it is true that increasing the tension will lead to more muscle fibres being recruited for dynamic muscular contractions, then this should be the main goal for an athlete training to increase muscle size and strength.

1.2.5. Nervous System Adaptations and the Skill of Movement

Every movement can be broken down into two types of neuromuscular coordination: macro and micro-coordination. Macro-coordination refers to the coordination between different muscle groups, such as the shoulders, chest, and triceps in a shot put. Improvement of this type of coordination occurs when someone learns a motor pattern and is able to perform it more efficiently. Because this learning is skill specific, this development of strength will not be carried over to a different movement. Schmidtbleicher (1985) states that it is coordination training rather than strength training. The mechanisms of macro-coordination adaptation may include increased activation of the prime movers and changes in the activation of synergists and antagonistic muscles.

Co-contraction of antagonistic muscles may help provide joint stabilization and act as a braking mechanism near the end of the ROM. However, excessive co-contraction will lead to antagonistic muscle force generation that will reduce the net force generation of the prime movers. Additionally, co-contraction leads to reciprocal inhibition of the agonists which will also reduce their total force production (Sale, 1988). Intense training can help reduce the amount of co-contraction. Osternig, Robertson, Troxel, and Hansen (1990) found hamstring co-contraction during knee extension in running to be much higher in endurance athletes compared to high intensity athletes.

Micro-coordination refers to the neural coordination of motor units within a muscle group. This type of coordination is likely to carry over if the trained muscle is used in additional movements. The coordination of all the motor units can only be achieved when a majority of the muscle is contracting, such as during a maximal or near maximal contraction.

Longitudinal strength training studies have shown an increase in motor unit synchronization from weight training, while cross-sectional studies have found enhanced motor unit synchronization in weight lifters and others who regularly perform brief maximal contractions (Milner-Brown, Stein, and Lee, 1975).

There is a percentage of motor units that cannot be easily recruited voluntarily. Some of the motor units are only accessible in 'fight or flight' situations. Increased activation refers to an increase in the total number of motor units that can be voluntarily recruited. During a maximal voluntary contraction (MVC), a single supramaximal electrical stimulus can be applied directly to the nerve of the contracting muscle. A change in force production will indicate that the individual could not voluntarily recruit all muscle fibres. Cross-sectional studies have investigated weight lifters and elite sprinters and found they were able to voluntarily recruit a greater percentage of their total motor units than could control subjects (Upton and Radford, 1975).

Training also allows both slow and fast twitch motor units to maintain less variable firing intervals at lower rates than before training. This change might be interpreted as increasing the range of firing over which motor units can maintain tonic, long term firing. This adaptation may allow higher threshold units to fire continuously for a longer time before they start to fire intermittently or fatigue and cease to fire altogether (Kawakami, 1955).

Higher intensity training involves more motor units, which leads to greater micro-coordination. The higher intensity will also help reduce excessive co-contraction, and allow muscular contractions to be more efficient.

1.2.6. Strength Curves and Muscle Tension Limitations

The relative strength of a muscle (or group of muscles) across a single joint or series of joints depends on the joint angle. As the joint angle changes so does the ability of the muscles to move an external load. This is known as a joint's strength curve. As a joint moves from extension to flexion, the muscle's ability to generate force and move a load can increase, decrease, or increase to a certain angle and then decrease again (Komi, 1986). The torque generation of a muscle at a specific joint angle is dependent upon the muscle's length, and the muscle's lever arm. The speed of contraction also affects the force generation of the muscle. Increasing the speed of a concentric contraction will decrease the maximal force generation. This is thought to be due to an increase in internal resistance (friction) between the muscle fibres (Mayhew, Rothstein, Finucane, and Lamb, 1995).

Generally, a muscle is at optimal length for force generation when it is at resting length (Figure 1.2). This corresponds to a sarcomere length between 2.2 and 2.6 μm (Fitts and Widrick, 1994). At this length there is a maximum number of cross bridges formed between the actin and myosin filaments. Each cross bridge is able to generate a finite amount of force. At shorter lengths there is an overlap of actin from opposite ends of the muscle sarcomeres. This interrupts cross bridge formation, reducing the number of cross bridges that can generate tension. At longer lengths, there is reduced overlap between actin and myosin and less cross bridges are developed; hence less force can be produced. Fitts and Widrick (1994) state there is evidence that a muscle can change the number of sarcomeres in series to allow for an optimal sarcomere length at the location when the muscle encounters the greatest tension. Lynn and Morgan (1994) found an increase in the number of sarcomeres when they ran rabbits downhill on a treadmill, which put the muscles in a lengthened position.

The lever arm of the muscle also changes throughout the range of motion. Changes in the joint orientation and the muscle's length and line of pull will affect lever arm distance. It is at its longest when the line of pull is perpendicular to the bone. The longer the lever arm the more weight the muscle will be able to move.

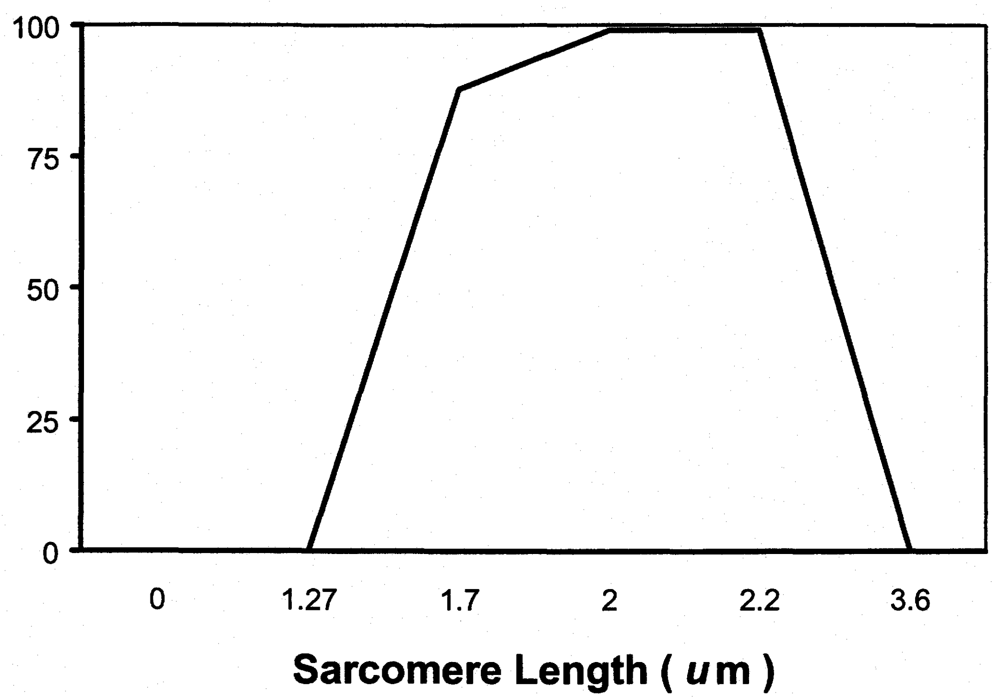


Figure 1.2 The theoretical force-length relationship curve for a muscle sarcomere.

The lever arm of the external load also affects the strength curve. As the horizontal distance between the load and the joint centre increases, the lever arm of the external load will increase. This will result in the muscle having to produce a greater torque to move the external load.

The joint centre (or axis or rotation) can change during the movement. This would affect the distance between the muscle's insertion and the axis of rotation, making it closer or farther away, which in turn would affect the leverage of the muscle.

Performing traditional weightlifting with free weights creates a problem when trying to maintain maximal muscle tension throughout the entire lift or ROM. There is one location in the trained ROM where the muscle (or muscle group) has the poorest ability to move an external load. This location is commonly referred to as the sticking point. If an athlete trains to failure, it is this one spot that will prevent the athlete from lifting after muscle fatigue has occurred. This means that this one joint angle position limits how much weight an individual can lift for the entire ROM, yet the muscle is capable of moving more weight. More importantly, it is only around this point that the muscle will be generating maximal or near maximal tension. This type of training does not appear to be very efficient since the muscle is only working at its maximum tension in a very small region of its entire ROM. This will reduce the overall intensity of the exercise.

Variable resistance training attempts to keep muscle tension near maximum levels throughout the FROM by adjusting the external load to match the joint's strength curve (Atha, 1981). This can be accomplished by the use of a cam wheel that changes the lever arm of the load as it is being lifted. This adjusts the torque required to move a constant external load and can be matched to amount of torque the muscles can maximally produce throughout the entire ROM. In theory this looks very promising but in practice it has numerous limitations.

Every individual has a somewhat different strength curve for a joint, so an exercise machine will not be effective for everybody. Herzog, Hasler, and Abrahamse (1991) measured the knee joint strength curves of several individuals. Although the curves had a somewhat similar look, the differences between individuals was significant. This individual difference makes it impossible to develop a mass market variable resistance exercise machine that can work for everybody. The individual differences in strength curves could be due to anatomical differences or training differences between the subjects. Tsunoda, O'Hagan, Sale, and MacDougall (1993) found that individuals with greater muscle mass had a greater decrease in maximum voluntary force production with their elbow flexors when the joint angle and muscle length decreased. They suggested that this could be due to either a greater change in the muscle fibre's line of pull with respect to the tendon or to impaired electrical conduct through the muscle fibres since the muscle fibres' diameter increased when the muscle length decreased.

An even greater problem arises with respect to athletic movements, such as jumping, which generally involve more than one joint. Developing a variable resistance machine to accommodate more than one joint at a time does not seem possible considering how many different ways the joints could orientate to achieve the end movement (Andrews and Hay, 1989).

1.2.7. Full ROM and Limited ROM Strength Training

Many coaches and trainers have advocated training in a FROM to properly develop strength (Little and Sisco, 1993). However, FROM can be considered an arbitrary term since it will change, depending on the exercise and type of equipment being used. For example, when a person uses a barbell for a benchpress, the ROM is limited by the barbell coming into contact with their chest. Using dumbbells instead allows the individual to go through a greater ROM.

There are also conflicting opinions as to what is actually the FROM. In powerlifting, a squat is considered successful only if the top of the thigh is parallel to the ground, yet one can go down further than that. Olympic weightlifters squat with their buttocks almost touching the ground. While the barbell benchpress and parallel squat are not true FROM exercises they are used by the majority of lifters and they lead to functional strength gains.

Little and Sisco (1993) state that training in a FROM is not required to develop strength over the entire ROM. A muscle fibre extends the entire length of a muscle. Therefore, it will not matter at what joint angle or ROM the muscle is recruited to generate tension. A muscle fibre 'pulls' towards it centre so the distal or proximal end of a muscle fibre cannot be activated separately. Magnetic resonance imaging (MRI) studies have shown that a muscle is activated over its entire length regardless of whether the tension is maximal or minimal (Little and Sisco, 1993). Therefore, it is the intensity, not the ROM that determines the number of motor units recruited. If the muscle fibres receive sufficient stimulation they will hypertrophy, regardless of the ROM.

Restricting movement to a LROM may permit more intense training by reducing the fluctuation in the muscle's ability to move an external load. Less range variation allows an individual to invoke greater intensity and tax the muscles to a greater extent (i.e. closer to maximal tension) for a longer relative time than training in a FROM. While variable resistance training attempts to maximize intensity by adjusting tension to match what the body can produce, LROM training tries to reduce the differences in force production of the muscles by restricting the range in which they contract and thus maximizing intensity (Figure 1.3).

Unlike variable resistance, LROM can be performed for multi-joint movements that are more sport specific and thus stimulate greater muscle mass. Since a sport may not require the macro-coordination identical to their weight training movement there is no need to train in a FROM to develop the skill of the weight training exercise.

An athlete does want to develop micro-coordination however, since that can be used in any movement that requires the muscle to contract. An example would be a football lineman who performs a benchpress. He does not have to perform a benchpress in a game but he can use the strength developed to help in blocking. Sale (1988) suggests that the specificity of the movement pattern is not crucial for advanced training because any training exercise that induces hypertrophy and macro-coordination of the desired muscles will be effective. Unless the sport movement is exactly like the training movement, as in Olympic weightlifting and Powerlifting, it is not essential to develop the motor pattern by training in a FROM.

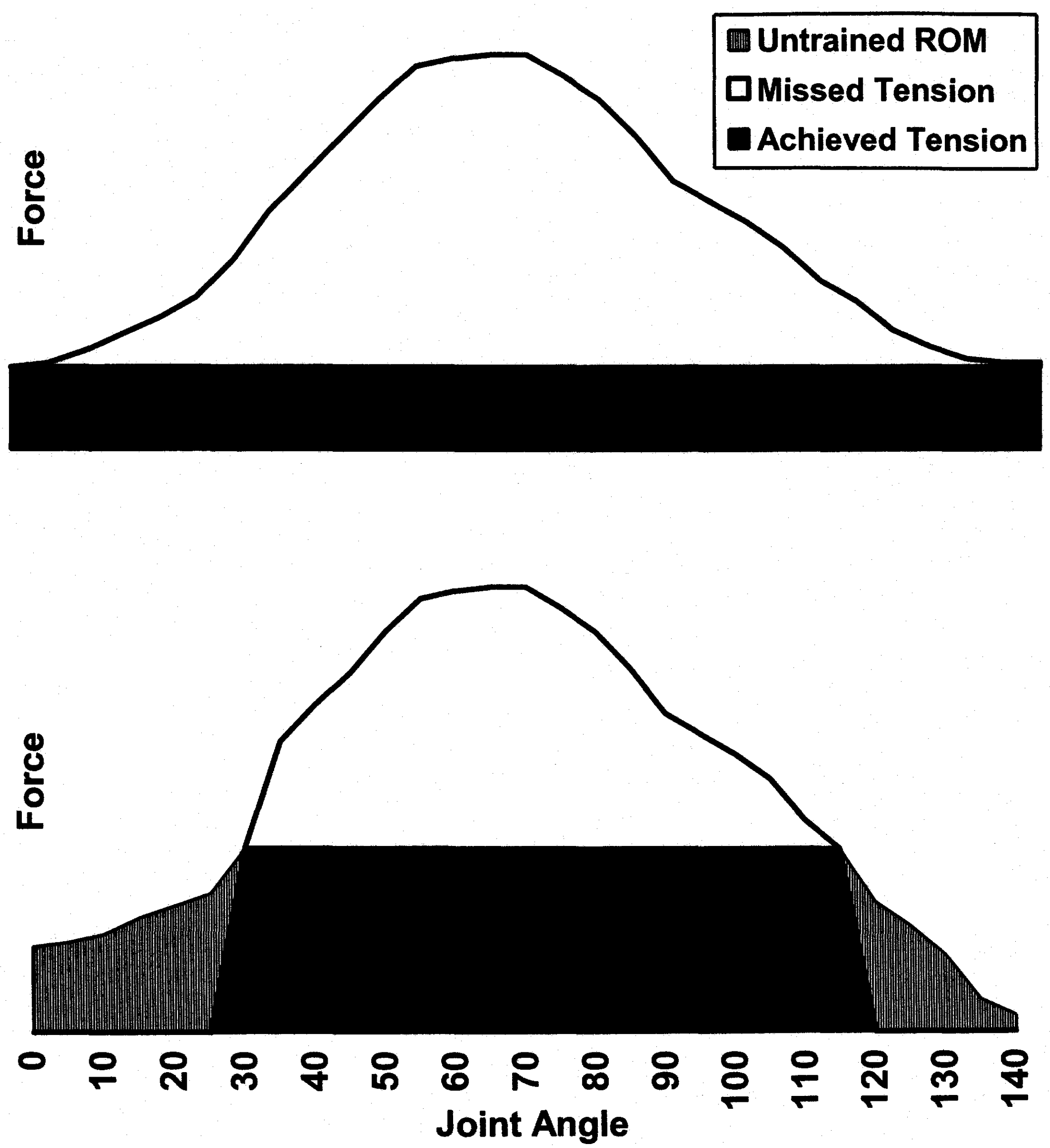


Figure 1.3 A strength curve, using a full ROM (above) and a LROM (below). With a constant external load, the areas of least force development (horizontal shaded) determine the external load that can be lifted for the entire ROM. The LROM movement occurs only between 30 and 120°. This reduces the amount of 'missed tension' by allowing a greater external load to be used, and subsequently increasing the force production and exercise intensity.

LROM training can have other benefits as well. Psychologically it can be very hard for an athlete to keep continually increasing the training resistance when they are already near maximum. It may seem that the resistance is too great before they even try to lift it. However, if they subject their bodies to supramaximal loads with LROM training, the load they then attempt for a FROM may actually seem light, and not as intimidating (Little and Sisco, 1993).

Novelty of the stimulus is another point to consider. Regardless of how effective the training is, the body will become accustomed to it and training improvements will start to plateau. By changing the type of training (i.e. periodizaton) the body will not be as able to get accustomed to the training and therefore must keep adapting.

When a motor unit is recruited, all of its fibres will be activated regardless of the posture or joint angle of the muscle. This can lead to increases in strength at joint angles different from those trained. It therefore seems that the most effective method of recruiting muscle fibres will involve the greatest tension regardless of where this tension is encountered in terms of joint ROM. A maximal amount of fibres will be stimulated if the greatest tension is encountered. Maximal tension can be generated for a longer time if an individual works in a LROM.

It becomes apparent from the above discussion that LROM strength training focuses on the most important aspects of strength training with respect to athletes who are training to develop strength for their specific sport. It is possible that LROM strength training leads to greater hypertrophy and increases motor unit micro-coordination to a greater degree than FROM strength training and thus can lead to more efficient increases in functional strength.

1.2.8. Previous Studies

Past studies have investigated LROM training using different training and testing protocols, and have come up with various results. Gardner (1963) investigated knee flexion. Participants trained with isometric MVCs at one of three angles of knee flexion: 115, 135, and 155°. Pre and post isometric tests revealed that the only significant increases in strength occurred at the trained angles. Lindh (1979) also investigated knee flexion. Subjects trained at either 15 or 60° of knee flexion. They performed repeated six second MVCs for three times a week for an average of five weeks. Lindh found greater increases in strength at the trained joint angle compared to the untrained joint angle. The results of these studies suggest angular specific training results. That is, strength increases occur only at the trained ROM or joint angle.

Other studies have not supported angle specific training effects. Rasch and Pierson (1964) had one group of subjects perform isometric work only at 90° of elbow flexion while another group trained at 60, 90 and 120°. Each group performed three isometric contractions (15 second MVC) a day for five days a week. Five weeks of training produced no significant differences between the groups with respect to arm girth or strength increases at any angle. Knapik, Mawdsley, and Ramos (1983) had participants perform 10 weeks of isometric contractions (80% MVC) at 90° of elbow extension. Pre and post strength tests were performed at 70, 90, and 110°; they found that increases in strength were significant and similar for all joint angles. These results suggest a global training effect, strength increases occurred throughout the entire ROM. Significant strength increases were found at all tested angles.

Thepaut-Mathieu, Van Hoecke, and Maton (1989a) performed a study where their subjects performed five weeks of isometric training (80% MVC) at one of the following angles of elbow flexion: 25, 80, or 120°. They found the greatest increases in MVC at the training angle for all subjects. However, strength increases were also found at other joint positions. The shorter the muscle training length, the more the strength gain was limited to the training angle. Raitsin (1974) also performed a study on the elbow joint. Participants trained elbow flexors isometrically (70% MVC) for 10 weeks at either 70 or 150°. Pre and post-tests revealed that the individuals who trained at 70° had significantly greater strength increases at their training angle compared to those who trained at 150°. Participants who trained at 150° had more uniform strength increases at joint angles further away from the training angle.

Graves, Pollock, Jones, Colvin, and Leggett (1989) looked at the effect of LROM and FROM variable resistance strength training on knee extension. The participants engaged in a ten week training program in which they exercised up to three times a week. There were four participant groups; a FROM group, a LROM group that trained from 0 to 60° of knee flexion, a LROM group that trained from 60 to 120° of knee flexion, and a control group. The participants did pre and post-tests that consisted of isometric testing at various angles throughout the entire range of motion. The researchers found that the participants had significantly greater increases in isometric strength within the ROM that they trained compared to the untrained ROM. However, they also found significant increases in isometric strength at some joint angles outside the trained ROM. The isometric strength increases for the FROM group were similar throughout the entire ROM. The participants who trained in the shortest muscle position (60 to 120°) had the greatest increase in isometric strength at any one angle. The results of the above three studies suggest a position dependent global training effect. In a longer muscle position global training effects are more dominant, while in a shorter muscle position angular specific training effects occur.

Logan (1960) investigated knee extension. One group of participants trained with resistance equipment that led to the greatest amount of resistance at 155° of knee extension. The other group trained with a spring resistance that produced the greatest resistance at 115°. When isometric strength was tested at five angles: 95, 115, 135, 155, and 175°, Logan found that the greatest increases in isometric strength for each group was at the angle were the training was the most demanding. However, he also found that both groups had significant increases at all other joint angles. Graves et al. (1992) did a limited range study on lumbar extension. Participants were split into four groups, similar to their study mentioned above. The participants trained only once a week. The researchers again found the greatest increases in isometric strength at the angles within the trained ROM but significant isometric strength increases were found at all joint angles for all training groups. These two studies suggest a greater angular specificity, however, global training effects were still present.

No clear evidence is present from the previous studies investigating LROM training. The majority of studies indicate strength gains are not isolated to the ROM trained and that strength can be developed outside of the trained joint angle or ROM.

1.2.9. Isometric Testing and Training; Mode Specificity

Numerous studies have compared methods of strength training and how they affect performance but very few have looked at LROM strength training. The few studies that have examined LROM strength training have used questionable measuring techniques, mainly isometric testing, which has been criticized with respect to its applicability to dynamic movements that dominate most athletic performances (Wilson and Murphy, 1996).

It was initially thought that insight into dynamic strength qualities could be gained by measuring isometric qualities (Baker, Wilson, and Carlyon, 1994). If strength has just a general quality then any test could discriminate between good and bad performers and show improvements from training. A correlation of .71 or greater would suggest a minimum of 50 % of common variance (Clarke and Clarke, 1970). This would support the concept of generality. Only if strength was a truly general quality should isometric tests be used to relate any information about dynamic muscle actions; and only if strength was a general quality should isometric testing be used to measure adaptations from dynamic training.

The concept of specificity suggests that specific training will result in specific results (Bompa, 1993). Low relationships between dynamic and isometric tests of strength would indicate that muscle function measures are specific to the test modality, rather than to general qualities. Wilson and Murphy (1996) suggest that isometric tests lack external validity in terms of assessing changes in dynamic performance as well as their actual relationship to dynamic performance.

Numerous investigators have examined whether isometric testing is a valid predictor of athletic performance or ability. Sale, Martin, and Moroz (1992) trained subjects using dynamic resistance exercise, namely a leg press. After 19 weeks of training the subjects demonstrated significant increases in leg press strength but their maximal isometric knee extensor strength was virtually unchanged.

Studies by Viitasalo, Hakkinen, and Komi (1981), Jaric, Ristanovic, and Corcos (1989), and Murphy, Wilson, Pryor, and Newton (1994) looked at various dynamic performances and their relationship to isometric strength. They found low correlations between isometric tests and counter movement jumps (CMJ) ($r = .35$), static jumps ($r = .16$), and seated shot put ($r = .38$), respectively.

Strass (1991), however, found a small but significant relationship ($r = .51$) between max isometric strength and swimming speed. The test Strass used was very position specific and may explain why a significant relationship was found. Secher (1975) investigated isometric strength in a position that was very specific to the sport of rowing. He found that in this position isometric strength was able to distinguish between international, national, and club level rowers.

In general, isometric tests will tend to have a better relationship with a dynamic performance if the test is sport specific (i.e. specific position) or if the movement itself is slow and of maximal effort, like the isometric test itself. If the movement is explosive and not a maximal effort, it is unlikely that the isometric test will be a good predictor of performance (Wilson and Murphy, 1996). In sport, movement and muscular work is almost always dynamic and thus tests should measure dynamic strength.

Since an isometric test investigates only one angle, which is only a small portion of the ROM, the angle must be chosen carefully. Sale (1991) suggested that isometric testing should be performed at an angle that corresponds to the peak force of the joint's strength curve. Since this angle gives the highest value it might be a good indicator of the strength for the muscles around that joint. Murphy, Wilson, Pryor, and Newton (1995) suggest a different approach. They found that using the joint angle at which the greatest peak force is developed for a specific movement led to a higher correlation of isometric tests to that specific movement.

Thepaut-Mathieu, Van Hoecke, and Maton (1989b) state that the specificity of strength is due to neural factors. Specificity refers to adaptations that will only be established in certain situations, such as: certain velocities, joint angles, or a certain type of muscle contraction. To get these specific adaptations it is necessary to train in a specific way. This is known as the specificity of training. For example, training with minimal or no weight increases maximum movement velocity but not isometric strength, while training with maximal weights increases isometric strength but not maximum velocity of movement (Kaneko, Fuchimoto, Toji, and Suei, 1983). Mueller and Schmidtbleicher (1989) found differences in activation rates between isometric and concentric contractions. This suggests that dynamic performance can elicit different neural responses than static performance.

Any general characteristics of strength are probably due to muscular adaptations (hypertrophy). The changes in the muscle fibres themselves are useable during any type of contraction (and joint angle) and so may lead to noticeable general strength adaptations.

There are also mechanical differences between isometric and dynamic contractions. Many sport movements involve a muscle stretch-shorten cycle that takes advantage of already activated motor units and optimal cross-bridge alignment to increase muscular output. It might also allow for the use of stored elastic energy to be released to increase force production (Cavagna, 1977). This source of force production is not available in isometric contractions.

Therefore, in testing of muscle function, adherence to the principle of specificity should apply, as strength appears to be specific and not general in nature. Consequently, testing should involve conditions similar to those experienced by the individual, in terms of the structure of the test, the mode of the contraction, the velocity of contraction, and the load or resistance. Therefore, using isometrics to assess dynamic training does not seem a valid protocol.

1.2.10 Summary

Development of strength from a LROM could affect athletic performance. It could make strength training more efficient and reduce the time and energy spent developing strength. Studies have found isometric strength can transfer from trained to untrained joint angles. However, a pure isometric contraction is uncommon in most sports and the mechanisms for isometric contractions are different from dynamic movement. Therefore these findings should not be generalized onto other types of muscular contractions. Only a few studies have looked at the transfer of strength from dynamic strength training and they agree that significant strength increases occur outside of the ROM trained. However, these studies use isometric testing, which as mentioned earlier reduces the validity of the findings in terms of dynamic performance.

From the few studies on LROM strength training and angular specificity, it seems apparent that it is not required to train in a FROM in order to achieve strength increases in the FROM. However, many questions remain as to how far the transfer of strength occurs and if the strength increases can lead to increases in athletic performance. It is not apparent what is the optimal LROM to train.

It is also not known if increasing strength just in a LROM will lead to increases in a dynamic performance that uses the same muscle groups. Wilson, Murphy, and Walshe (1996) found that training with half squats led to significant increases in vertical jump. However, training using different ROMs has not been investigated to see whether their effect on vertical jump performance are similar.

1.3 STATEMENT OF PROBLEM AND HYPOTHESES

1.3.1 Problem:

Are there any differences in strength gains when training with FROM versus LROM?

1.3.2 Hypotheses:

1. Due to a greater intensity, LROM strength training will produce superior results to that of FROM training when evaluated using FROM parallel squat strength and vertical jump take-off velocity.
2. LROM strength training will produce strength gains over the FROM, not just the trained ROM.

1.3.3 Assumptions and Limitations

1. Nutrition for the participants was not controlled; it was assumed that all participants would have similar diets. Differences in macro and micronutrient ingestion may have an effect (positive or negative) on training results.
2. Participants were asked to perform every set to failure. Fear of injury or lack of motivation may limit the ability to train every set to failure.
3. Small sample size. In order to keep the training procedure constant, all training sessions were attended by the investigator. This limited the number of participants that could participate in the study.

1.3.4 Delimitations

1. The results are delimited to untrained male subjects who range in age from 19 to 25.
2. Participants who fit the criteria had to be available to train twice a week on non-concurrent days.

CHAPTER TWO
METHODS

2.1 EXPERIMENTAL DESIGN AND STATISTICAL PROCEDURES

The changes in strength and dynamic performance from a seven week training program were examined using a two by three pre-post study design. Analyses of pre and post 1RM parallel squat strength and vertical jump take-off velocity were performed using analysis of covariance (ANCOVA) tests, with the subject's mass entered as a covariate.

A comparison was also made between the two training groups with respect to the orientation of joints (ankle, knee, hip, and absolute trunk angle) during their respective training. This was performed to see if the participants used a different movement pattern during their training. The LROM group was examined at the bottom of their LROM squat and the FROM group was examined at the midway and bottom of their parallel squat. An analysis of variance (ANOVA) was performed to compare the means from the three different squat conditions (Appendix H). An ANOVA was also performed to compare the recorded activity levels outside of weight training for the three groups (Appendix I). All statistical tests were set to $p < .05$. Standard descriptive statistics, including mean, standard deviation, and range were also recorded.

2.2 PARTICIPANTS

The participants were 31 male volunteers aged 19 to 25 years from the University of Saskatchewan. They were all undergraduate or graduate students, primarily from the College of Kinesiology. Their descriptive statistics (height and mass) are listed in Table 3.1 in Chapter Three. All participants had minimal weight training experience, which was defined as less than one year of serious training (three times a week), or a layoff of at least six months if they had previously been involved in weight training.

2.3 MEASURES AND PROTOCOLS

2.3.1. Study Protocol

All pre-tests were performed over a period of two weeks following the University midterm break in February. The one repetition maximum (1RM) parallel squat test and the vertical take-off velocity test were conducted on the same day for all subjects. The participants were instructed not to perform any vigorous activity two days prior to their test day. The vertical jumps were performed first, followed by the 1RM parallel squat. The post-tests were performed over a period of two weeks at the end of April and the start of May. Academic conflicts required the test dates of some of the participants to be rescheduled, however, all post-tests were completed within 6 to 10 days of the participant's final training session.

All participants signed a consent form that informed them they could withdrawal from the study at any time without penalty. The study was approved by the Human Ethics Committee at the University of Saskatchewan (Appendix A).

2.3.2 Participant Screening and Activity Log

All participants were screened prior to the study with respect to their weight training experience. As well, all participants were required to fill out an activity log for each week of the study (Appendix J). They were instructed to record all of their physical activities for the week including their type of exercise, duration of exercise, and intensity of exercise. The evaluation of exercise intensity was subjective. All subjects were instructed before the start of the study to avoid other intense lower body resistance activities that may reasonably contribute to strength gains. The levels of exercise were examined to see if exercise activities were similar for the three groups. Every thirty minutes of activity was considered one exercise session. Activity times that primarily stressed the upper body (i.e. upper body weight training) were excluded from the activity analysis.

2.3.3 Training Groups

The participants were randomly assigned into one of three groups: a control group, a FROM group, or a LROM group. The control group participated in only the pre and post-tests while the other groups trained twice a week using their respective method of training.

The FROM strength training movement used by the FROM group was the parallel squat. The LROM group performed a half squat. Each participant in the LROM group had the vertical distance that the barbell moved during the FROM squat measured. This distance was then used to set the appropriate distance required to move the barbell during the LROM training sessions. The LROM participants trained only in the upper half of the FROM. The metal spotters of the squat rack were used as guides to limit the training range (Figure 2.1).

The participants trained for seven weeks. This was the time period between the midterm break and the end of school that allowed for the longest uninterrupted training period for the participants. Squatting technique was reviewed and the weight loading procedures for the training sessions was explained to the participants.

To ensure that each training group worked maximally, all participants were instructed to train as close as possible to failure. The training weights were selected to produce muscular failure at about ten repetitions. However, if the participant felt that they could do more, they were encouraged to perform as many repetitions as possible during each set. This ensured maximum stimulation to the muscles (Zatsiorsky, 1995). The spotters and safety bars were there to assist when the participants reached failure. The participants were also instructed to move the weights with maximum velocity while staying in control (Fleck and Krammer, 1987).

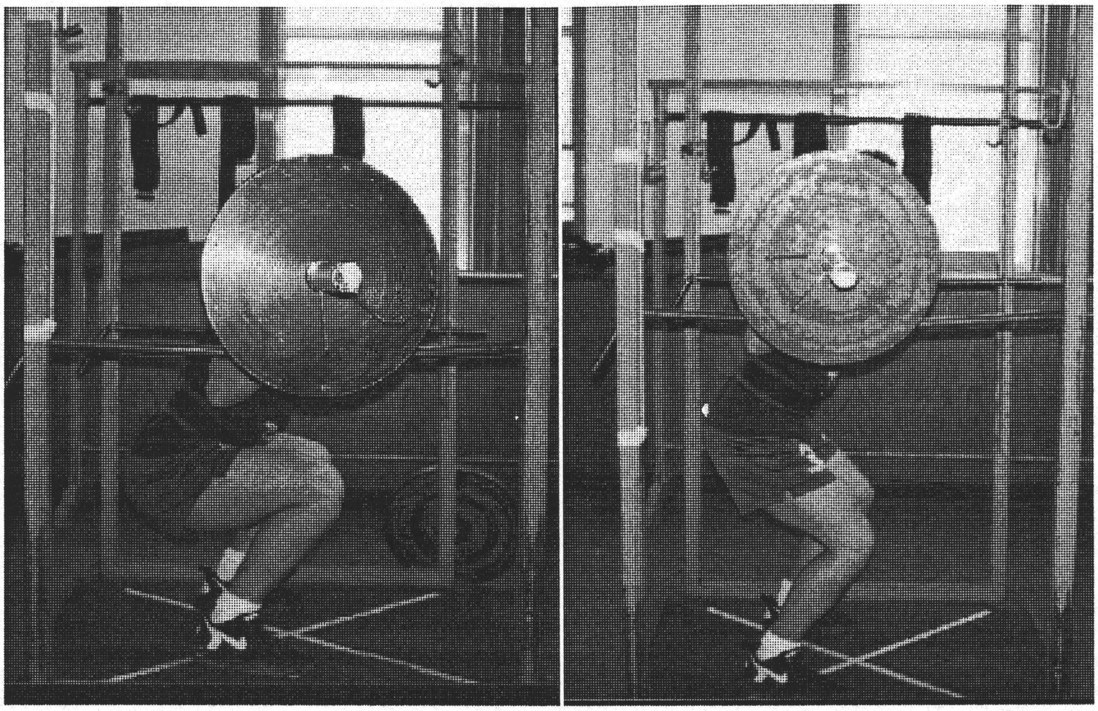


Figure 2.1 The picture on the left shows the depth of a parallel squat. The picture on the right shows a LROM squat. The metal spotter bars were adjusted for each participant to restrict their movement to the desired ROM.

Individuals are able to perform only about ten repetitions when using 80% of their 1RM (Bompa, 1993). This guideline was used to set the training weight the FROM group initially used. There is no literature on LROM training and the percentages of 1RM used for training. The LROM group was able to lift a heavier load with the LROM squat. Therefore, it was decided to start training the LROM group with 100 % of their 1RM parallel squat. As the participants' strength increased, their training weights were increased accordingly.

Three sets of repetitions to failure were performed for each exercise session.

This is the usual number of sets performed for resistance training (O'Shea, 1966). To allow for recuperation between sets, participants took a minimum five minute break after each set (Wescott, 1983). The participants were allowed as many warm-up sets as they felt necessary to get ready for the training. Most participants took two or three warm-up sets with light (10 to 50% 1RM) loads.

The participants trained twice a week. It was assumed that this gave them enough recovery time between the high intensity exercise sessions (Hay et al. 1985). Training sessions were scheduled to give the participants two to three days of rest between sessions. To reduce the possibility of overtraining, the fifth week of training consisted of two recovery workouts. These workouts were lower in intensity (65 % of 1RM) than the previous workouts.

The training sessions took place in the R.J. Williams Building (College of Kinesiology) and were supervised by the investigator to ensure that the proper technique and procedure was followed. All workouts were recorded with respect to the loads and repetitions completed by the participants (Appendix K).

Any participants who missed more than four total training sessions or more than two consecutive training sessions were excluded from the data analyses. These cutoffs followed the guidelines of Gregor (1988) who performed a similar weight training study for ten weeks. Participants were permitted to make up their missed training sessions whenever possible as long as they did not train two days in a row and no more than three times a week.

2.3.4 One Repetition Maximum (1RM) Parallel Squat

This test was performed at the College of Kinesiology in the Athletic Therapy Centre. The term 1RM refers to the maximum amount of weight lifted one time during the execution of a standard weightlifting exercise. This strength measurement does not require elaborate measurement equipment and is easy to administer (McArdle, Katch, and Katch, 1986).

Before the test began, each participant was instructed on the requirements of the lift and its basic execution. Weightlifting belts were mandatory for the participants to wear while performing the squat lift. A lifting belt can help reduce excessive back flexion during squatting by increasing intra-abdominal pressure and thus reduce the chance of injury to the low back region (Lander, Simonton, and Giacobbe, 1990).

The squats were performed in a squat rack that allowed for adjustment of the height of the barbell so the participant could step under the barbell to put it on their shoulders. The height of the spotter bars, which were used to stop the barbell descent on any failed attempts, was adjustable as well (Figure 2.1). The barbell and weights used were standard Olympic equipment. In addition, the centre of the bar supporting the weights was securely wrapped with a cotton towel to provide additional cushioning on the participant's neck and shoulders.

The participants were allowed to warm-up within the squat rack for as long as they felt necessary. With their warm-up squats, the height of the bar at the top of the squat and at the bottom (parallel) was measured; this was recorded as the participant's FROM. For their warm-up sets, the participants selected a weight that they felt comfortable they could squat for several repetitions. During these sets the participants were given additional technical instruction and were informed when they achieved proper squat depth. A slow, controlled descent was always emphasized.

When the participant was ready to begin the test, a weight was selected that both he and the investigator felt confident he could squat for one repetition. A minimum of two spotters were used for all of the 1RM attempts. They stationed themselves on either end of the barbell to help the participants if they failed an attempt, and with the racking of the bar upon the completion of a lift. If a third spotter was present, he was stationed directly behind the lifter. One of the spotters was the investigator who informed the participants when they reached proper depth of the squat and also determined if the lift was successful.

For a lift to be considered successful, it had to meet the criteria set out by the Canadian Drug Free Powerlifting Federation (C.D.F.P.F.). These rules, listed below, were explained to the participants prior to their first 1RM attempt.

1. The barbell could be placed anywhere on the back as long as it was no lower than three centimetres (cm) below the rear deltoid.
2. The lifters could use any foot placement they desired, but once they were set and began their descent, their foot could not move. The heel must stay in contact with the floor at all times.
3. The lifters had to achieve a depth on the squat where the top of their thigh was parallel to or lower than where the thigh meets the hip (roughly, the anterior superior illiac spine).
4. Once depth was reached the lifters had to ascend in one motion. They could not descend by any amount after they started moving upward (known as 'hitching').
5. Only when the lifters were completely erect with no hip or knee flexion was the lift considered successful.

The 1RM was determined by increasing the weight after each successful lift until the participant failed two successive attempts or the participant failed an attempt and did not want to try again (Appendix C). The minimum load increase was 2.3 kg and the final successful attempt was recorded in kilograms as the subject's 1RM. A minimum of three minutes between lifts was allowed in which to recover. Wescott (1983) stated this was the minimum time needed to recover most (90 to 100 %) of one's strength after a maximal effort.

2.3.5 Counter Movement Jump (CMJ) Vertical Take-off Velocity

The vertical take-off velocity test was performed on a AMTI force platform in the College of Kinesiology (Figure 2.2). The force platform was set to record data at a sampling rate of 200 Hz. The participant's vertical component of ground reaction force (GRF) during a vertical jump was saved to a data file on a PC computer using the Peak Force software. The file was then processed by a program written specifically to calculate vertical take-off velocity (in metres/second) of the jump by computing the integral of the resultant force time curve of the jump. Prior to their jumps, the body mass of the participants was recorded to the nearest half kilogram. The body mass was required to calculate vertical take-off velocity (Appendix D).

The jump task involved a modified counter movement jump (CMJ) in which the participant eliminated arm swing by holding a broom handle across their shoulders. This was done because arm movement can increase force production and add variability to performance. Harmen, Rosenstein, Frykman, and Rosenstein (1990) state that an effective arm swing can increase the duration of force production as well as peak force, which can lead to contributions of up to 10 % of the total vertical impulse.

For each jump, the participants stepped onto the force platform with their hands on the broom handle across their shoulders. Once on the platform, they remained motionless for two seconds. This allowed the platform to record the vertical GRF that was equal to the participant's bodyweight in newtons. When they were ready, the participants initiated a counter movement with hip and knee flexion, and ankle dorsiflexion. This was followed by rapid hip and knee extension, and ankle plantarflexion as the participants attempted to jump as high as possible. There were no guidelines set with respect to rate or depth of descent of the counter movement; all participants were simply instructed to try to jump as high as possible. All participants were given as many practice trials as they felt necessary to be comfortable with the technique. Five jump trials were recorded for each subject with 30 seconds of rest between each trial. The best trial (highest vertical take-off velocity) for each subject was used for the statistical analysis.

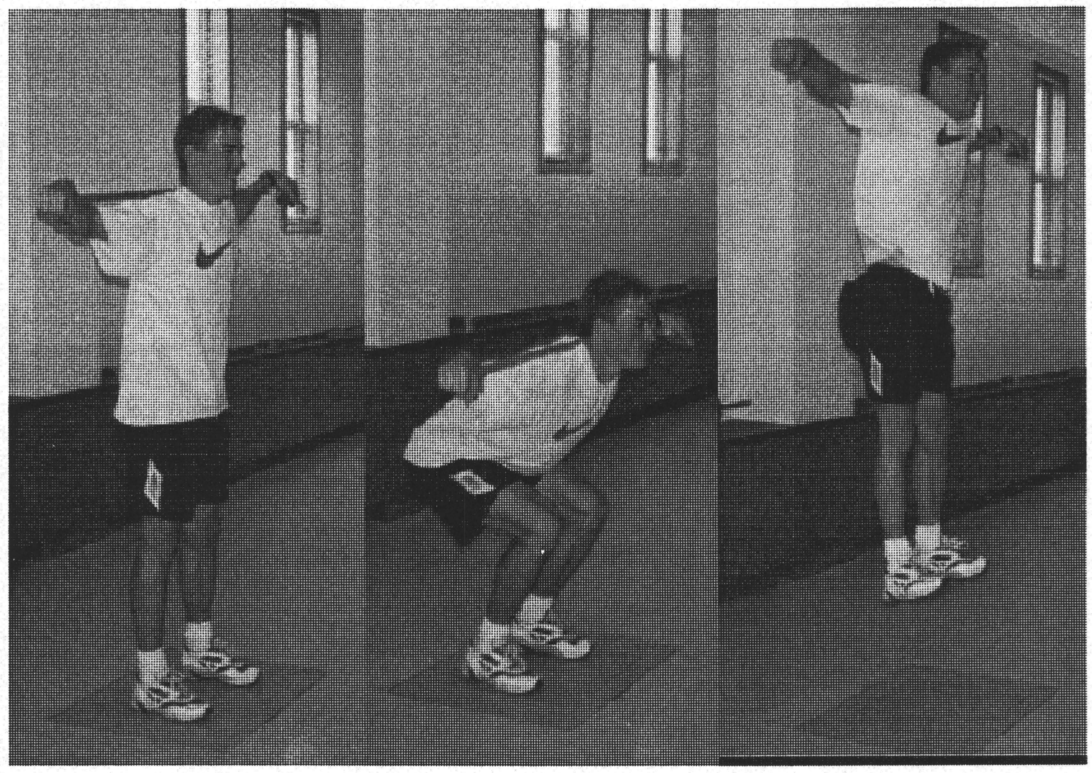


Figure 2.2 A participant performing the modified CMJ on a force platform. The pictures from left to right show; starting position, depth at countermovement, and height of vertical jump.

2.3.6 Video Analysis

Six participants from each group were videotaped for one training session during the fifth week of the study. It was assumed that by this time both training groups had developed a consistent technique for their respective training movements. The participants were selected at random and all trained on the same day. The collected video data from the random selection of participants was assumed to be representative of each training group.

The first two training sets were recorded for each of the six participants. The middle four repetitions of each training set were used for the analysis. It was assumed that these repetitions would be the most representative of the participant's typical training movement. Earlier repetitions in the set might not be performed with the same movement pattern since the subject could still be adjusting to the weight, and fatigue might affect the latter repetitions. This gave a total of eight repetitions that were analyzed for each participant (Appendix E).

A Panasonic (800 series) video camera was used to videotape the participants' movements in the sagittal plane. Anthropometric markers were placed on the participants to identify various landmarks: base of the fifth metatarsal, lateral malleolus, proximal end of the fibula, greater trocanter, and the location of the barbell on the back. These landmarks were used to invesigate the following joint angles: ankle, knee, hip, and absolute trunk angle (Figure 2.3). The ankle joint angle was measured as the angle between the fifth metatarsal and one cm above the proximal end of the fibula. The lateral malleolus was considered the axis of rotation. The knee angle was measured as the angle between the lateral malleolus and the greater trochanter, with the spot 1 cm above the proximal end of the fibula used as the axis of rotation. For the hip joint, the angle measured was taken between the proximal end of the fibula (one cm above) and the location of the barbell on the subject's back, with the greater trochanter as the axis of rotation. The absolute trunk angle was defined as the angle between the horizontal and the location of the barbell on the subject's back, with the greater trocanter as the axis of rotation. It should be noted that any lumbar or thoracic flexion or extension above the hip joint would affect the interpretation of the last two angles.

The FROM participants were analyzed at both the mid-range and the parallel depth for their squats, while the LROM participants were analyzed only at the LROM position which was close to the mid-range position of the FROM group.

The video tape was analysed on the Peak System. The images were captured digitally at 30 Hz. The Peak software allowed the anatomical landmarks to be digitized. With these landmarks identified, the joint angles could then be determined.

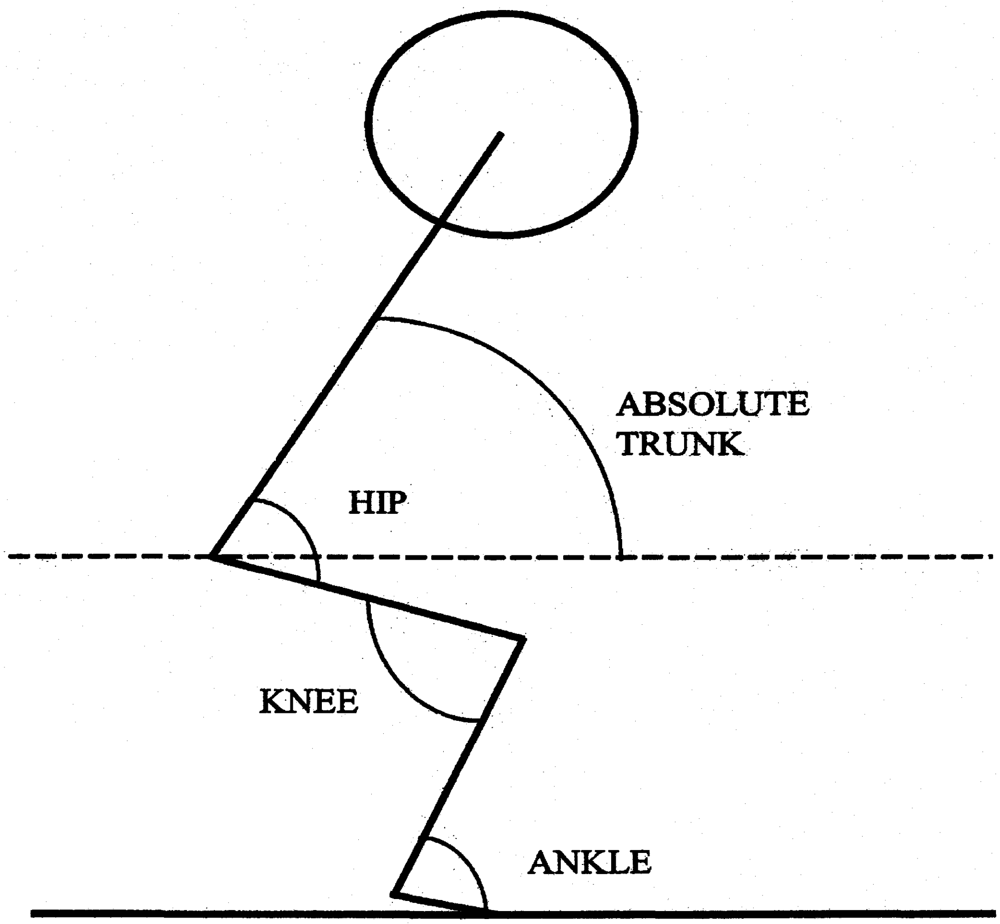


Figure 2.3 The Joint angles measured from the video analysis (sagittal view). The lines represent body segments and the circle represents the external load. The arcs represent the measured joint angles. The dashed line represents the horizon, which was used to measure the absolute trunk angle.

The measurement error for this procedure was calculated by repeatedly measuring a known angle. In the sagittal view, the bottom and side of the squat rack formed a right angle. Thirty repeated measurements of this angle using the Peak System gave an average angle of 90.02 ° and a standard error of 0.097 °

CHAPTER THREE
RESULTS AND DISCUSSION

3.1 RESULTS

The purpose of this study was to identify changes in leg strength and dynamic performance that resulted from seven weeks of resistance squat training using either the FROM or LROM training protocol. It was hypothesized that LROM strength training would produce superior increases in both 1RM parallel squat strength and vertical jump take-off velocity when compared to FROM strength training. It was also hypothesized that LROM strength training would produce strength increases throughout the parallel squat ROM.

Due to large differences in the initial measurement values of the participant groups, the original method of analysis lacked statistical power. An ANCOVA using both the subject's mass and pre-test values as covariates was then performed. This model, using both mass and pre-test performance as covariates, provided greater statistical power than the repeated measures ANCOVA where only mass was entered as a covariate (Appendix F and G). Entering the pretest values as a covariate reduced the standard error on the marginal means of the dependent variables by over 50% on the vertical jumps (0.024 m/s from 0.058 m/s) and about 80% for the parallel squats (1.9 kg from 7.9 kg). This model produces a single value (post-test value) that can be used to compare the different participant groups regardless of their initial (pre-test) value. Table 3.1 lists the post-test values of the participants (adjusted on both mass and pre-test performance) as well as their height and mass.

Table 3.1 Subject Physical Characteristics and Non-Adjusted Post-test Values

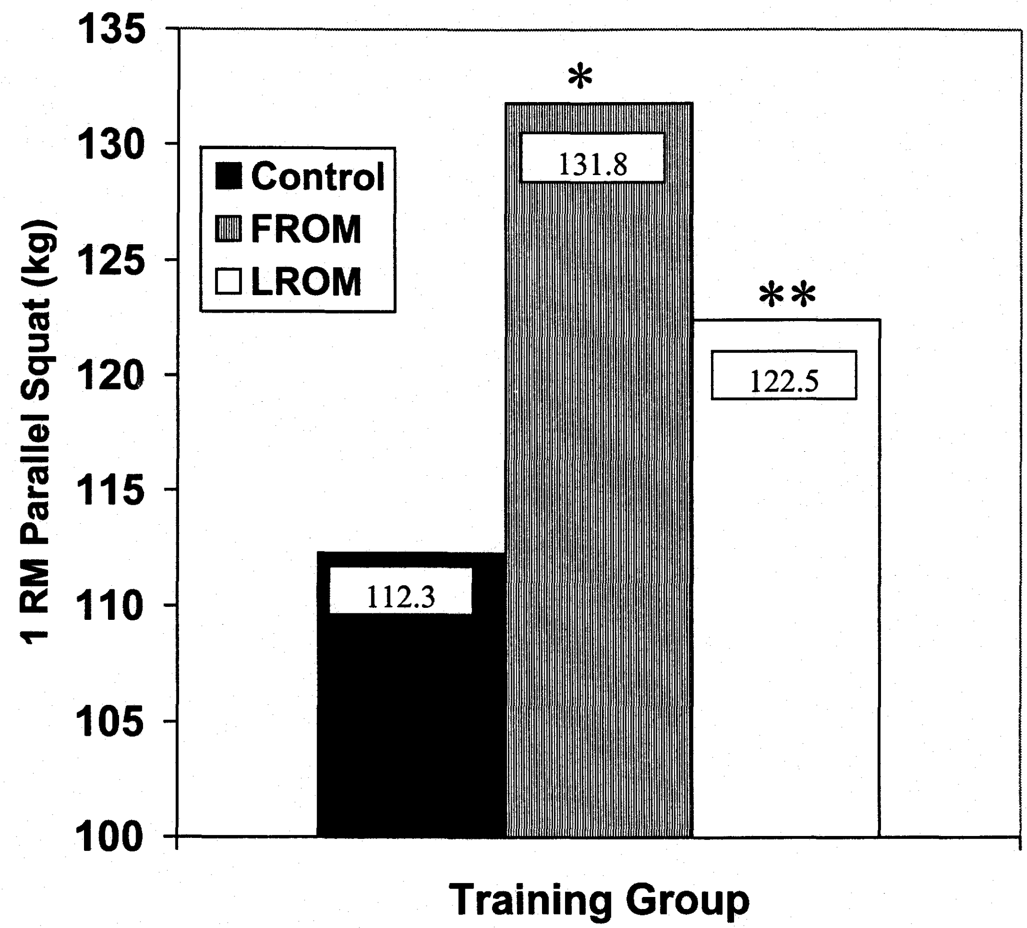
	Control [a]		FROM [a]		LROM [a]	
	M SD	Range	M SD	Range	M SD	Range
Height (cm)	179.1	168.5	178.8	165.5	176.6	165.0
	5.5	191.0	4.9	187.0	3.7	186.5
Bodymass (kg)	79.4	67.5	76.6	63.0	80.6	64.5
	8.8	91.0	7.9	88.5	16.3	104.5
1 RM Parallel	107.1	79.2	132.3	83.7	126.3	67.9
Squat (kg)	16.3	133.5	22.7	165.2	25.8	165.2
Vertical Take-off	2.669	2.380	2.893	2.493	2.540	1.915
Velocity (m/s)	0.17	2.926	0.21	3.220	0.18	2.788

Note. [a] n = 9 for control group, n =11 for FROM and LROM groups.

Besides some minor aches and muscle soreness, no serious injuries occurred during the training sessions. All participants were able to complete the required number of workouts in the required time frame.

3.1.1 1RM Parallel Squat

For the 1RM parallel squat, the two covariates, body mass ($p = .000$) and the pre-test values ($p = .000$) were found to be statistically significant (Appendix F). The mean post-test value of the 1RM for the FROM group (131.8 kg) was significantly greater than the mean 1RM for both the LROM (122.5 kg) ($p = .001$) and control (112.3 kg) ($p = .000$) groups (Figure 3.1). The mean of the LROM group was significantly greater than the control group ($p = .000$).



Note. n = 9 for control group, n = 11 for FROM and LROM groups.

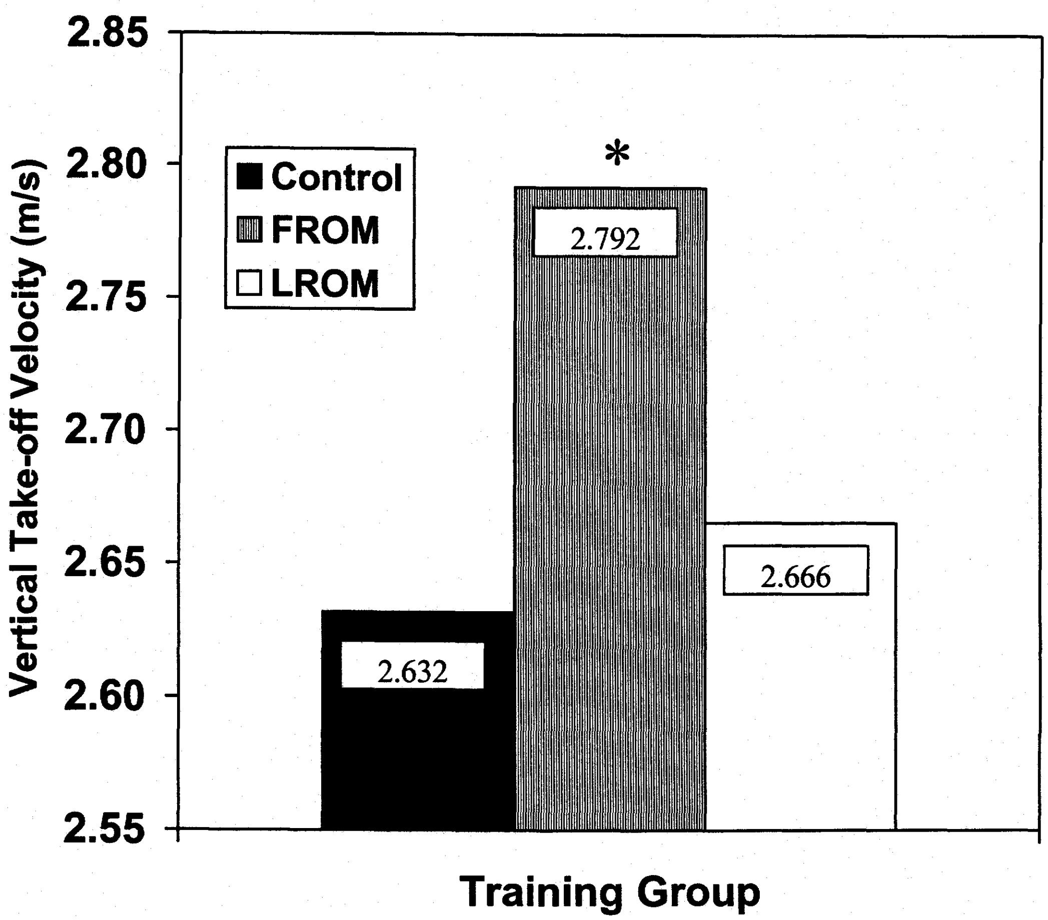
* significantly greater than both LROM and control ($p < .05$)

** significantly greater than control ($p < .05$)

Figure 3.1 Post-Training 1RM Squat Performance Adjusted for Covariates (body mass and pre-test value)

3.1.2 CMJ Vertical Take-Off Velocity

Three separate variables from the vertical jump were initially analyzed; vertical take-off velocity, peak power, and total power. All three variables are highly correlated and they yielded near identical statistical results, therefore, only vertical take-off velocity was further examined and reported (Figure 3.2).



Note. n = 9 for control group, n =11 for FROM and LROM groups.

* significantly greater than both LROM and control ($p < .05$)

Figure 3.2 Post-Training Vertical Take-Off Velocity Adjusted for Covariates (body mass and pre-test value)

In the statistical analysis of the vertical take-off velocity both body mass and pre-test values were entered as covariates (Appendix G). Both body mass ($p = .047$) and the pre-test values ($p = .000$) were found to be statistically significant. The FROM group adjusted mean for the vertical jump (2.792 m/s) was significantly greater than both the LROM (2.666 m/s) ($p = .018$) and the control (2.632 m/s) ($p = .000$) groups. The LROM and control group marginal means were not significantly different from each other ($p = .152$).

3.1.3 Joint Angle Orientation

An ANOVA was performed to test whether there was a significant difference in joint angles: ankle, knee, hip, and absolute trunk angle between the two training groups when performing their respective squat training. The FROM group was examined at full and half depth of their parallel squat and compared to the half squat of the LROM group (Table 3.2).

Table 3.2 Joint Angles for FROM and LROM Video Analysis

	FROM (parallel)		FROM (half)		LROM	
	M SD	Range	M SD	Range	M SD	Range
Ankle Plantarflexion	85.3 *	76.2	91.2 *	77.3	74.1 *	66.8
	4.9	92.8	6.4	102.1	4.9	86.0
Knee Extension	75.4 *	61.8	108.0 *	96.4	111.5 *	103.5
	8.8	94.3	5.0	117.0	4.8	124.1
Hip Extension	65.9 *	46.4	108.6 *	91.2	125.6 *	110.8
	10.2	86.1	9.0	123.4	8.6	142.4
Absolute Trunk	50.1 *	38.4	65.7 *	48.5	73.6 *	61.0
Angle	5.9	62.4	7.1	79.4	5.6	83.0

Note. * significantly different than other training groups ($p < .05$)

All three conditions were significantly different from each other for each of the four angles (p = .000 for all comparisons, except LROM and FROM half squat knee angle, p = .005). (Appendix J). The LROM position had greater ankle dorsiflexion, less knee and hip flexion, and a larger absolute trunk angle than the other two positions. The FROM (half) position had the least amount of dorsiflexion. The FROM (parallel) position had the greatest amount of knee and hip flexion, and the smallest absolute trunk angle.

It is not surprising that the FROM parallel squat position has a different joint orientation than the other two positions which have the lifter only at half of the depth of the parallel squat. However, the differences in joint orientation between the FROM half squat position and the LROM squat position suggest a different movement pattern is being used by the two training groups (Figure 3.3).

3.1.5 Activity Levels

An ANOVA was used to compare the activity levels for each of the grades of exercise (light, moderate, and hard) as well as the total amount of activity (Table 3.3). The control group averaged significantly higher levels of light activity (p = .011), as well as overall recorded activity (p = .004), than either of the training groups. The control group also averaged significantly higher levels of moderate activity (p = .024) than the FROM group. None of the groups was found to be significantly different (p = .557) with respect to levels of hard activity (Appendix K).

Table 3.3 Number of 30 Minute Activity Sessions for the Training Period

	Control		FROM		LROM	
	M SD	Range	M SD	Range	M SD	Range
Light Activity	12.4 *	6.0	6.2	0.0	7.4	0.0
	4.0	21.0	4.6	16.0	4.6	14.0
Medium Activity	22.2 **	3.0	14.1	1.0	17.0	2.0
	7.8	31.0	8.8	27.0	5.9	28.0
Hard Activity	7.0	2.0	6.7	0.0	8.2	1.0
	3.1	17.0	3.4	12.0	3.3	14.0
Total Activity	41.7 *	19.0	26.8	6.0	32.5	17.0
	9.6	68.0	10.4	39.0	6.4	42.0

Note.

* significantly greater than other FROM and LROM groups ($p < .05$)

** significantly greater than FROM group ($p < .05$)

3.2 DISCUSSION

The purpose of this study was to investigate possible changes in dynamic strength and performance induced by FROM and LROM lower body strength training. The training period for this study lasted seven weeks and was comparable in duration to other strength training studies discussed in the literature review.

The studies mentioned in the literature review, that investigated LROM strength training, all used isometric training or testing (or both). Using isometric tests provided for a more controlled situation but compromised the external validity of the results when trying to draw conclusions on athletic performance, which consist primarily of dynamic movements (Wilson and Murphy, 1996). Training with one type of modality (i.e. isometrics) and testing with another could lead to an inability to detect performance changes due to the specificity of training (Wilson and Murphy, 1996). This study used both dynamic training and dynamic testing. By using the same modality for testing and training, any training effect should be detected by measuring the post-test performances. As well, results from this study should be readily applicable to similar athletic movements.

Intensity of training is the most important factor for increasing strength. Greater development of micro-coordination will also help increase in strength. It was predicted that decreasing the range of movement to that where the muscle's force output is the greatest would allow for more intensive training sessions and greater micro-coordination. It was therefore hypothesized that using LROM strength training would lead to greater increases in strength and dynamic performance than that produced with FROM training. However, this investigation found that the FROM group had significantly greater increases in the 1RM parallel squat and CMJ vertical take-off velocity than both the LROM and control group, while the LROM group was significantly greater than the control group with respect to the 1RM parallel squat. This is in contradiction to the first hypothesis. Thus, it would appear that other variables besides intensity affected the post-test results.

From the studies on LROM strength training it seems apparent that one is not required to train in a FROM in order to achieve strength increases in the FROM. Most studies found some evidence of a global training effect. It was also hypothesized that intense training in a LROM would lead to measurable strength increases in the FROM. This study did find that LROM training did lead to significant increases in FROM strength. This agrees with the second hypothesis.

The video tape analysis revealed that the LROM group used less trunk, hip, and knee flexion and more ankle dorsiflexion than the FROM group at the same squat depth (Figure 3.3). The macro-coordination of the training compared to the testing must be considered when examining the results of any study. The FROM group performed their training with the same movement pattern that was used for the 1RM parallel squat. The repetition of this movement pattern should equate to a greater skill development of the squat. Therefore, it is likely that the FROM group increased their 1RM parallel squat strength not only from muscle hypertrophy and micro-coordination, but from skill development (macro-coordination) as well.

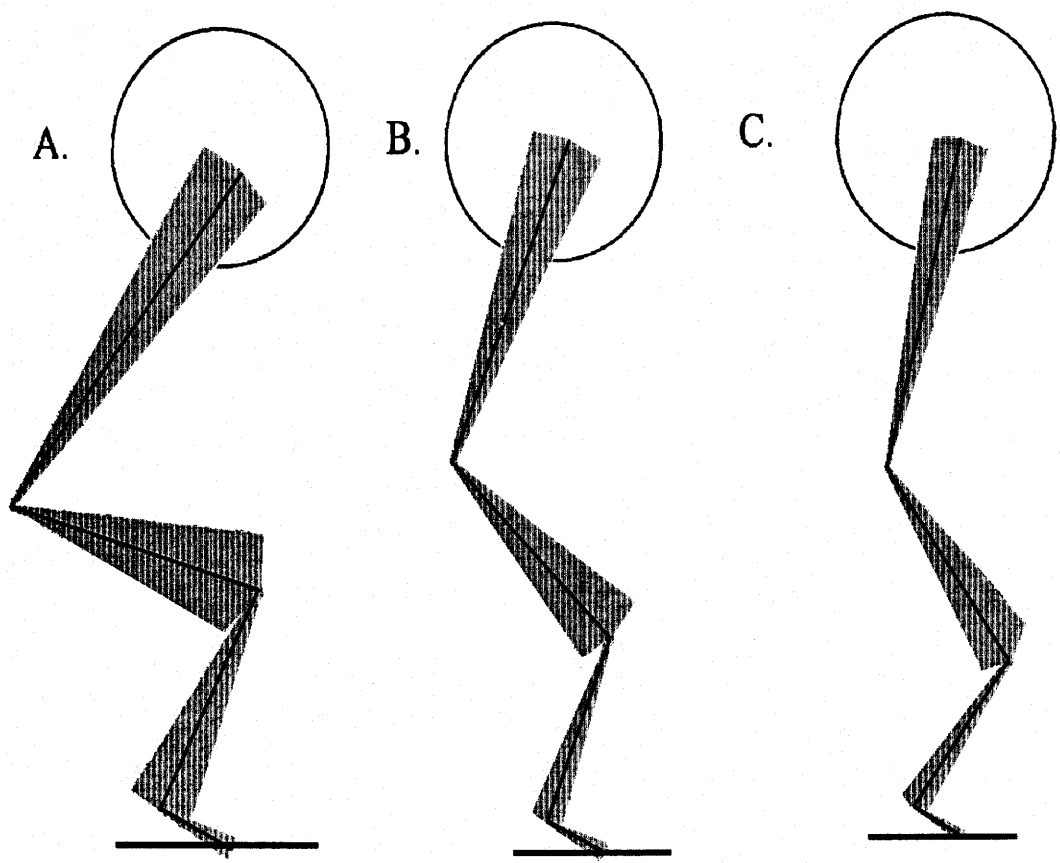


Figure 3.3 A Comparison of body segment orientation during FROM and LROM squat training. A) FROM at Parallel Squat B) FROM at Half Squat C) LROM Squat. The circle represents the barbell and weights while the lines represent the trunk, thigh, leg, and foot. The shaded region represents one standard deviation for each measured joint angle. The LROM squat shows a more upright stance (less trunk flexion) and less knee flexion than the FROM half squat. This is most likely due to the heavier training weight the LROM participants used (see discussion).

Bompa (1993) points outs that for novice lifters, skill development (macro-coordination) provides the largest part of strength gains. The interplay of neural adaptations and muscular adaptations during strength training is illustrated in Figure 3.4. Moritani and Devries (1979) calculated that almost all strength increases during the first two weeks of strength training are due to neural adaptations. The neural contributions decreases to 60% after four weeks and drops to only 5% after eight weeks when hypertrophy contributes the most to strength increases. Schmidtbleicher (1985) also places most macro-coordination to be completed at two weeks while micro-coordination is essentially completed at six to eight weeks.

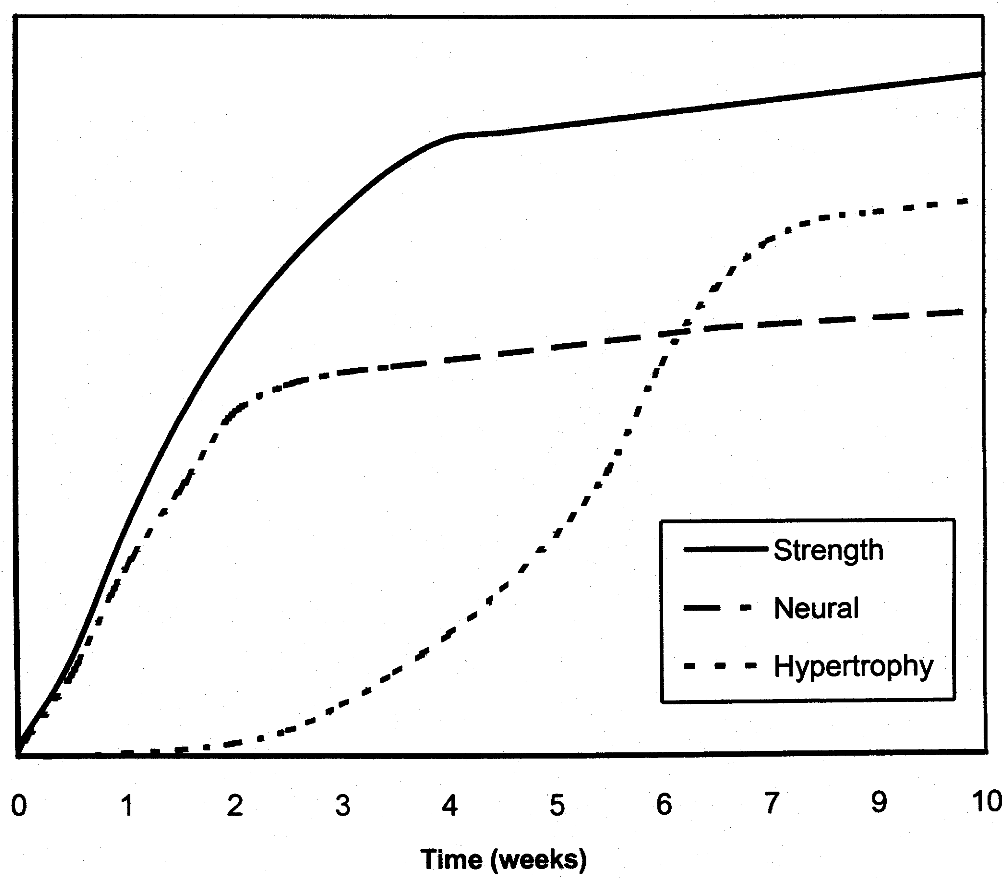


Figure 3.4 An illustration of the gains in strength due to neural and muscular adaptations. (Adapted from Bompa (1993), p. 45)

During training the LROM group used a different movement pattern from that used during testing, therefore, they did not develop macro-coordination to the same degree as the FROM group. In retrospect, even if the LROM group performed more intense training and developed greater hypertrophy and micro-coordination than the FROM group, it would be expected that they would not benefit from any of the large strength increases associated with macro-coordination development. Conceivably, the specificity of the testing protocol of the 1RM parallel squat gave the FROM group an advantage. This might explain the smaller increase in the 1RM parallel squat of the LROM group.

There is also the possibility that two slightly different motor patterns might interfere with one another. Negative transfer occurs when training with a slightly different movement affects the execution of the original movement (Magill, 1989). Conceivably, the movement of the LROM squat might adversely affect the performance of the 1RM parallel squat.

Proper squatting starts by initiating simultaneous hip, trunk and knee flexion. This keeps the Centre of Mass (CM) over the base of support and optimizes the external torque at both the hip (trunk flexion) and knee (knee flexion). A limiting factor for squats is the strength of the lower back (trunk extensor) muscles and how much weight they can resist in an attempt to counterbalance trunk flexion torque. Hatfield (1985) reported that when squatting, the trunk flexion torque created by an external load was always higher than knee flexion torque. Therefore, it is usually this value that determines the success or failure of the lift.

Elite powerlifters have been found to have a more erect posture (less absolute trunk flexion) than novice powerlifters when performing a parallel squat (McLaughlin, 1975). This minimizes the maximum trunk flexion torque produced by the external load, and places the lifter in a better position to use the powerful hip extensors to begin the ascension phase of the lift. The greater the amount of absolute trunk flexion, the longer the lever arm of the external load (training weight and upper body) and thus the greater the trunk extension torque needed to stabilize the load.

During the training sessions the LROM participants were constantly reminded to try to start their movement with hip and knee flexion, not just knee flexion (Figure 3.3c). As the training weight increased, their lifting technique departed from the ideal. They were able to use primarily knee flexion because they only had to get partial depth compared to a parallel squat. By using less hip and trunk flexion, the LROM participants were able minimize the torque on the back extensors, and thus lift a heavier weight. If the participants attempted a parallel squat with this movement pattern, they would require excessive trunk flexion in the last part of the movement in order to move their hips back so as to keep their CM over their base of support. With a heavy weight, this would create a very large trunk flexion torque and most lifters would not have enough strength in the low back extensors to complete the squat.

As mentioned above, proper squat technique involves greater initial hip flexion. This is consistent with the position of the FROM group (Figure 3.3b) which had a smaller absolute trunk angle (greater trunk flexion) than the LROM group at the half squat position. Compared to the LROM movement, which consisted of primarily knee flexion, the FROM movement reduces shear strain on the knee joint and keeps the centre of mass (CM) closer to the rear of the base of support, which makes it easier to achieve parallel depth (Hatfield, 1985).

The LROM training did not lead to significant increases in CMJ performance. This result does not support the conclusion reached by Wilson, Murphy, and Walshe (1996) who found training with half squats led to significant increases in vertical jump height. However, unlike the present study, they did not have participants train using different variations of the squat to see if the vertical jump performance was affected by the ROM that was trained.

Macro-coordination could also affect the performance increases of the vertical take-off velocity. The depth of the CMJ performance was not controlled in this study. Therefore, it is hard to say whether the FROM or LROM training groups used a similar depth to the CMJ. The joint orientation of the descent and ascent motion of the parallel squat is very similar to the descent and takeoff of the modified CMJ used in this study. In contrast, the LROM group trained with a different movement pattern, one that used greater dorsiflexion, less knee and hip flexion, and had a greater absolute trunk angle. As was the case with the 1RM parallel squat mentioned previously, the similar macro-coordination of the FROM training may have benefitted the vertical jump performance. The slightly different pattern of LROM training may have led to a smaller increase in performance efficiency.

The major difference in the movement patterns between the parallel squat and vertical jump was the ankle plantarflexion at the completion of the take off for the vertical jump. The plantarflexors helped generate ground reaction force (GRF) near the end of the take off phase of the jump. The greater GRF the participants generated, the greater their vertical take-off velocity.

Although not a benefit from a macro-coordination perspective, the tibia forward position of the LROM group (Figure 3.4c) created a larger dorsiflexion torque at the ankle joint than the FROM parallel squat. To counterbalance this torque, the plantar flexors had to generate an equal and opposite plantarflexion torque. This higher intensity work might be expected to increase plantarflexor strength to a greater degree, which could improve vertical jump performance. The higher intensity isometric work of the plantarflexors for the LROM group might not lead to any noticeable changes to an explosive movement like the CMJ due to the specificity of training speed.

In the squat, the plantar flexors are used primarily for stabilization and not for movement, while in the vertical jump they are used explosively to quickly generate GRF to propel the jumper upward. Training at a velocity of contraction that is different than what is tested has been shown to be ineffective. Kaneko, Fuchimoto, Toji, and Suei (1983) placed subjects in training groups that trained with a 0, 30, 60, or 100% MVC load for 12 weeks. The groups with the lighter loads were able to perform the exercises at a much higher velocity while the groups using heavier loads exercised at a slower velocity. The group that trained with no external load (0%) had the greatest increases in maximum velocity of contraction, but they had the smallest increases in MVC strength. Conversely, the 100% training load group produced the greatest increases in MVC strength but showed no change in maximum velocity of contraction with any load.

The LROM group was observed by the investigator to have trained with a higher velocity than the FROM group. Relatively speaking, the training speed of the LROM group was still considerably less than the speed at which a CMJ is performed. Therefore, it is doubtful this helped with the post-test jump performance.

Unless one performs a movement where the weight/implement is accelerated until the end of the ROM (i.e. shot put or vertical jump), there must be a phase of deceleration for the external load and the body or body part. When force generation is below that of the force of gravity, the load will decelerate. If relatively light loads are used and accelerated as quickly as possible, the load must be decelerated at a higher rate or for a longer period of time to stop at the end of the ROM.

If less force is applied when a load is decelerated against gravity, high muscle tension levels will only be achieved through the acceleration ROM at the beginning of the movement. The faster an external load is moved the greater the deceleration phase. Only when heavy weights are used and acceleration is minimal will this deceleration phase become negligible. That is why it is critical to train with heavy weights to help maintain maximal tension.

It is possible that any increases in tension created by using the LROM movement might be offset by the larger relative deceleration required due to the faster training movement. Adding additional weight to the LROM lifters to decrease the speed of movement could increase the chance of an injury, and possibily change the movement pattern even more.

In talking with the subjects during testing and training an interesting comment kept surfacing with all of the LROM subjects. They found it awkward to get back down to the proper depth for a parallel squat for testing after training with LROM squats. As well, almost all LROM subjects, when performing the parallel squat, mentioned a tightness and strain in their hip region when approaching parallel depth and ascending from this position. The additional strain was felt in the location of the anterior superior illiac spine of the hip. This is the location of the insertion point of the rectus femoris and sartorius muscles, which both function as hip flexors and knee extensors.

The squat is a multijoint movement and numerous muscle groups cross the joints involved. The change in movement pattern with the LROM group and the decrease in ROM could have changed the tension emphasis to different muscle groups. This lends support to speculation that the parallel squat is more demanding in terms of the muscle torques that are required to withstand the applied load. If the muscles required to generate tension at the bottom of the parallel squat were not stimulated to the same level by the LROM squatting style, then this could conceivably explain the smaller increase in 1RM parallel squat strength.

Another possible explanation for this discomfort is an adjustment of the number of muscle sarcomeres within a muscle fibre. Thepaut-Mathieu (1989b) stated that if a muscle repeatedly generates maximum force at a certain length it will attempt to adapt by increasing or decreasing the number of sarcomeres in series so that each individual sarcomere will be at the optimal length were the greatest amount of muscular force is required. Holly et al, (1980) found an increase in sarcomere numbers when a muscle was continually stretched. A change in the number of sarcomeres in series would affect the muscle's entire strength curve and could lead to detrimental effects at other positions.

Because *in vivo* force-length properties are not know for most muscles, it would be impossible to say with certainty how the sarcomere lengths of the various muscles were adjusted due to the different methods of training. However, if the sarcomere number of the knee extensor muscles in the LROM group was decreased, it could explain the sensations the LROM group felt. It could also mean a decreased ability to generate peak knee extensor torque at the bottom position of the parallel squat.

The LROM group in this study trained most of the major muscles for the squat in a shortened position: the quadriceps, sartorius, bicep femoris, and gluteal muscles. The two multi-joint hamstring muscles (semimebranous, and semitendonous) were trained in a midrange due to their dual function as both a knee flexor and hip extensor. Thepaut-Mathieu (1989b) did a review of angle specific strength training studies. He found that, in general, isometric strength increases were greater when the muscle was trained in a shortened position. He also reported that the strength increases were more restricted to the training position when the muscle was exercised in a shortened position. Conversely, strength increases were smaller when a muscle was trained in a longer position but the amplitude of the transfer of strength increases to adjacent angles was greater. Graves et al. (1989, 1992) found the group that trained in the shortest muscle position exhibited the greatest increase in training weight for the knee extensors (65.1%) and the lumbar extensors (42.1%). The LROM groups that trained with a longer muscle position had smaller increases in training weight, 38.9 and 36.6 % respectively.

In summary, it appears that changes to the muscle (i.e. hypertrophy) should lead to increases in strength for the entire ROM while neural and mechanical changes in response to where the muscle was trained should lead to more location specific increases in strength. While the theory of LROM strength training suggested that more intense training would result in greater strength and performance increases, this study does not support this hypothesis. LROM squat training appears to alter the normal parallel squat movement pattern due to the heavier loads required. It also appears that the specificity of the training movement outweighs any increased training effects that might have occured from LROM training. However, this study did find that strength increases outside of the trained

ROM are possible, which has implications for injury rehabilitation.

CHAPTER FOUR
SUMMARY AND CONCLUSIONS

4.1 SUMMARY

This study examined 31 university aged male participants for changes in strength and dynamic performance over seven weeks of resistance training. It was hypothesized that the participants in the LROM group would show greater increases in strength (1RM parallel squat) and dynamic performance (CMJ takeoff velocity) than the FROM and control groups due to an increase in training intensity. The results of this study indicate that contrary to the first hypothesis, the FROM group showed the greatest improvement in both the 1RM parallel squat and CMJ vertical takeoff velocity. The LROM group significantly improved their 1RM parallel squat compared to the control group. This supports the second hypothesis, which stated that LROM training would lead to an increase in FROM strength.

Videotape analysis revealed that the LROM group trained with a movement pattern that was significantly different from the FROM group. To accommodate the heavier training weights, the LROM group used a movement pattern that created a smaller external trunk flexion torque. Although only speculation, the altered movement pattern may have diminished macro-coordination effects for the LROM group. This lack of specificity of the training movement may have affected the performance results of the post-tests. Other possible explanations for the less effectual LROM training include: less activation to muscles that would not be as heavily recruited in the LROM, and changes in sarcomere length for certain muscles, which could affect the ability to generate force at other positions not trained, namely the sticking point for the 1RM parallel squat.

While this study did not find the LROM training method to be advantageous to increasing the maximum strength for the 1RM parallel squat or CMJ vertical take-off velocity, it did find increases in strength outside of the trained ROM, which supports the second hypothesis. Increased strength outside the trained ROM has applications for sport training or injury rehabilitation. People with joint or muscle injuries may not be able to train in the complete or desired ROM but they can still receive benefits from LROM training.

4.2 CONCLUSIONS

1. For the 1RM parallel squat, FROM weight training produced significantly greater increases than either LROM training or no training (control group). For the 1RM parallel squat, LROM weight training produced significantly greater increases than no training (control group). This does not support the first hypothesis.
2. For CMJ vertical take-off velocity, FROM weight training produced significantly greater increases than either LROM training or no training (control group). This does not support the first hypothesis.
3. LROM weight training produces strength increases outside of the trained ROM. This does support the second hypothesis.

4.3 RECOMMENDATIONS FOR FURTHER RESEARCH

1. The theory behind increasing muscle tension with LROM training is to decrease the range of movement to where the muscle's output is the greatest. In this study, the upper half ROM of a parallel squat was used. LROM training could also have been performed using the lower half ROM. This would eliminate the stronger positions of the ROM and reduce the changes in force generation in the trained ROM. The LROM subjects all had to select heavier weights than when

training in a FROM in order to achieve failure within the required repetitions. However, the heavier weight produced changes in the movement. If the subjects trained in the lower half ROM, lighter weights could be used and perhaps the movement pattern would have been unaltered. This might also eliminate the possibility of muscular remodelling with respect to the number of sarcomeres in series because the original sticking point of the full ROM is still being encountered in this LROM.

2. One way to reduce or eliminate increases in strength due to macro-coordination is to use experienced lifters who have already developed their motor pattern of the specific movement. With a population of advanced weight lifters, any neural improvements would most likely be from micro-coordination. Advanced lifters need high intensity training in order to develop additional strength. LROM training might be more beneficial to them compared to novice lifters who still have to develop proper movement patterns.

3. Testing and training with a LROM involving only a single joint would eliminate a lot of variables that are present when using a multi-joint movement. Fewer muscle groups would be involved and their length could be investigated more easily. If the surrounding joints are controlled, only one movement pattern is possible. Restricting a study to a single muscle such as in an animal study where muscle groups can be removed would allow for an even more controlled situation.

4. It is unknown if LROM training would lead to greater injury rates compared to traditional forms of resistance training.

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APPENDIX A
ETHICS COMMITTIEE APPROVAL

UNIVERSITY ADVISORY COMMITTEE ON ETHICS IN HUMAN EXPERIMENTATION

(Behavioral Sciences)

NAME: Dr. E. Sprigings (J. Crocker) **EC #:** 98-26
Department of Physical Education

DATE: March 9, 1998

The University Advisory Committee on Ethics in Human Experimentation (Behavioral Sciences) has reviewed the revisions to your study, "A Comparison of Full and Limited Range of Motion Strength Training on Strength and Dynamic Performance" (98-26).

1. Your study has been APPROVED.

2. Any significant changes to your protocol should be reported to the Chair for Committee consideration in advance of its implementation.

3. The term of this approval is for 3 years.

David Hay, Chair
University Advisory Committee
on Ethics in Human Experimentation
Behavioral Sciences

Please direct all correspondence to:

Bonnie Korthuis, Secretary
UACEHE, Behavioral Science
Office of Research Services
University of Saskatchewan
Room 210 Kirk Hall, 117 Science Place
Saskatoon, SK S7N 5C8

APPENDIX B
COVER LETTER AND CONSENT FORM

Cover Letter

Dear Interested Participant,

A study is being conducted to examine the effectiveness of limited range of motion strength training on full range of motion strength and dynamic performance. We would like you to participate in this study. The participants will be placed into one of three groups; a full range of motion group, a limited range of motion group, and a control group. It involves an initial test of parallel squat strength and vertical jump. After this there is a seven week training period with two training sessions a week. The training involves either a parallel squat or a half squat and will be performed in a squat rack with a lifting belt and a minimum of two spotters. After the training period the parallel squat and vertical jump will be tested again. As with any resistance training program there is a risk of injury however with spotters, lifting belt, and the squat rack this risk will be minimized.

All of your results will remain confidential. That is, no person outside of the research team will be able to acquire your data. The findings of this study will be made available to you at your request upon the completion of the study.

Yours Respectfully,

John E. Crocker. B.S.P.E.

Dr. Eric Sprigings

Consent Form

My signature on this sheet indicates that I, ________________________, will participate in a study by John Crocker and Dr. Eric Sprigings involving full and limited range of motion strength training.

I understand the following:

1. I am a volunteer and am free to withdraw at any time from the study without fear of penalty.
2. I have received explanations about the nature of the study, its purpose, procedures, and risks.
3. There is minimal risk of harm.
4. My individual data will remain confidential from sources outside of the study.
5. I will receive a summary of the project, upon request, following the completion of the project.
6. Any questions or comments can be directed towards;

   John E. Crocker

   Dr. Eric Sprigings

Signature____________________________

Date________________________________

Researcher's Signature_________________

APPENDIX C
PRE-SQUAT AND POST-SQUAT VALUES
(RAW DATA)

		INITIAL LOAD (kg)	
Participant #	CONTROL	FROM	LROM
1	92.8	101.8	140.3
2	106.3	76.9	129.0
3	119.9	101.8	142.5
4	79.2	65.6	124.4
5	92.8	153.8	58.8
6	113.1	147.1	101.8
7	140.3	101.8	92.8
8	126.7	124.4	135.7
9	104.0	135.7	92.8
10		90.5	113.1
11		119.9	106.3
M	103.3	110.9	112.5
SD	14.1	26.8	24.19

		FINAL LOAD (kg)	
Participant #	CONTROL	FROM	LROM
1	101.8	131.2	156.1
2	115.4	104.0	138.0
3	133.5	131.2	156.1
4	79.2	83.7	124.4
5	92.8	156.1	67.9
6	115.4	165.2	110.9
7	95.0	131.2	113.1
8	126.7	142.5	165.2
9	104.1	151.6	113.1
10		115.4	129.0
11		142.5	115.4
M	107.1	132.3	126.3
SD	16.3	22.7	25.8

APPENDIX D

PRE-JUMP AND POST-JUMP VALUES

(RAW DATA)

Participant #	INITIAL VELOCITY (m/s)		
	CONTROL	FROM	LROM
1	3.004	2.778	2.891
2	2.768	2.430	2.575
3	2.669	2.979	2.612
4	2.691	2.736	2.351
5	2.633	2.901	2.396
6	2.345	2.908	2.662
7	2.783	2.659	2.676
8	2.561	2.980	2.165
9	2.699	2.711	2.617
10		2.535	1.869
11		2.814	2.723
M	2.684	2.766	2.494
SD	0.17	0.17	0.19

Participant #	FINAL VELOCITY (m/s)		
	CONTROL	FROM	LROM
1	2.915	2.838	2.784
2	2.926	2.493	2.705
3	2.633	3.220	2.787
4	2.692	2.784	2.416
5	2.508	2.923	2.311
6	2.380	2.969	2.715
7	2.791	2.829	2.686
8	2.632	3.066	2.290
9	2.547	2.873	2.543
10		2.623	1.915
11		3.210	2.788
M	2.669	2.893	2.540
SD	0.17	0.21	0.18

APPENDIX E
JOINT ANGLE VIDEO ANALYSIS
(RAW DATA)

	FROM Half-Squat Positon			
TRIAL #	Ankle	Knee	Hip	Trunk
1	78.2	100.3	99.8	56.2
2	77.3	97.0	98.4	60.5
3	79.4	98.2	95.8	58.0
4	78.7	96.5	92.5	57.8
5	82.2	96.4	94.9	57.2
6	83.3	100.5	99.4	60.1
7	80.4	100.8	98.8	58.9
8	96.7	117.0	91.3	48.5
9	92.3	100.8	93.7	54.2
10	92.7	111.9	95.3	51.1
11	88.1	106.7	96.4	55.3
12	92.2	103.5	91.2	53.3
13	92.6	103.2	94.6	56.7
14	89.8	106.2	95.0	54.5
15	98.6	106.4	115.1	74.8
16	94.0	112.5	118.3	74.1
17	91.5	110.5	114.1	72.2
18	96.5	114.0	112.7	75.3
19	94.0	102.0	118.0	78.7
20	98.8	110.8	123.4	79.4
21	97.8	111.8	110	67.6
22	92.4	111.3	114.9	69.4
23	97.8	104.4	108.5	72.2
24	94.0	108.2	111.0	66.5
25	82.6	110.5	121.1	70.1
26	97.7	109.8	119.9	74.4
27	87.6	107.4	121.3	75.7
28	89.5	106.2	113.9	68.4
29	99.0	111.4	112.1	65.4

30	92.3	110.3	110.1	65.5
31	102.1	111.7	112.6	68.0
32	89.6	104.9	104.8	64.2
33	94.0	111.5	115.1	71.1
34	89.5	110.3	110.9	69.7
35	93.4	110.3	108.7	71.6
36	92.2	110.8	107.0	68.7
37	97.6	114.5	109.3	64.7
38	97.0	115.6	113.7	71.4
39	92.3	108.9	110.4	68.9
40	88.8	108.1	107.7	67.8
41	90.6	105.7	106.8	66.8
42	95.9	110.8	108.3	66.8
43	85.8	109.5	104.4	66.7
44	87.2	111.3	109.4	66.3
45	97.0	110.7	119.4	69.6
46	97.2	111.1	112.7	63.8
47	90.4	109.0	112.2	65.5
48	81.4	108.7	112.1	65.0
M	91.2	108.0	108.6	65.7
SD	6.4	5.0	9.0	7.1

		FROM Parallel Squat Position		
TRIAL #	Ankle	Knee	Hip	Trunk
1	79.9	71.5	68.2	55.8
2	77.5	75.9	70.6	53.7
3	81.1	80.5	73.3	56.0
4	85.3	88.0	80.7	51.5
5	84.8	90.2	85.4	53.4
6	87.8	94.3	81.4	48.9
7	83.9	90.8	81.2	50.0
8	82.0	80.7	65.9	51.7
9	77.4	79.8	63.2	47.2

10	79.6	71.9	63.6	51.0
11	85.3	66.3	55.7	47.4
12	81.6	66.6	56.2	45.5
13	76.2	66.9	55.4	45.0
14	79.8	61.8	52.2	42.9
15	79.5	62.3	57.2	46.1
16	85.2	69.4	61.9	49.0
17	81.3	67.2	56.8	46.3
18	84.0	66.4	61.6	48.9
19	76.2	63.8	53.8	42.7
20	86.2	69.5	59.5	46.5
21	80.1	65.2	57.7	48.5
22	80.7	75.8	55.9	39.9
23	81.7	72.8	58.6	44.1
24	88.7	71.4	55.9	43.3
25	91.1	77.8	54.6	37.9
26	90.0	69.9	46.4	38.4
27	83.8	64.6	46.0	39.5
28	83.5	66.1	51.5	42.3
29	91.3	74.2	71.4	56.7
30	83.3	68.2	72.3	57.7
31	85.0	72.8	70.4	54.2
32	91.5	73.8	71.8	57.2
33	92.6	67.9	72.1	57.6
34	90.7	71.2	63.9	49.7
35	90.4	69.5	68.7	56.0
36	90.1	90.3	79.5	55.6
37	88.3	81.8	69.5	51.8
38	85.2	81.5	69.7	54.8
39	91.4	82.9	70.8	55.5
40	91.1	85.6	69.2	51.7
41	89.4	84.4	86.1	62.4

42	92.8	76.2	71.7	56.0
43	90.8	86.2	79.4	59.0
44	87.6	88.0	73.8	52.8
45	91.3	81.1	68.8	49.2
46	88.4	85.6	73.3	53.0
47	76.2	66.9	55.4	45.0
48	83.5	66.1	51.5	42.3
M	85.3	75.4	65.9	50.1
SD	4.9	8.8	10.2	5.9

		LROM Squat Position		
TRIAL #	Ankle	Knee	Hip	Trunk
1	66.8	107.7	114.8	66.9
2	73.5	108.4	117.9	68.0
3	78.8	113.4	120.9	70.1
4	68.1	111.5	128.1	76.1
5	71.7	112.3	128.7	74.1
6	73.6	110.8	128.0	73.8
7	69.8	115.9	133.6	75.2
8	75.7	120.3	132.4	73.7
9	70.9	115.0	127.6	73.7
10	67.7	111.9	126.6	70.7
11	67.6	113.2	128.9	73.2
12	72.7	114.4	126.3	68.4
13	75.8	117.8	126.7	72.9
14	68.8	113.0	127.4	73.3
15	70.9	112.0	129.2	76.2
16	69.1	114.3	125.6	71.3
17	68.4	107.5	125.4	73.5
18	75.6	119.3	131.5	74.2
19	72.6	114.9	133.5	77.2
20	71.7	113.8	135.2	79.1
21	77.7	118.4	130.6	73.7

22	71.8	110.4	111.2	63.4
23	73.9	114.0	110.8	61.0
24	73.8	110.2	119.9	68.9
25	70.8	111.5	120.5	70.6
26	71.4	106.7	116.1	66.7
27	70.8	109.1	120.5	69.3
28	67.8	105.6	121.0	69.2
29	68.3	107.9	117.5	65.6
30	70.2	115.2	131.5	79.2
31	72.4	105.3	127.0	81.2
32	72.0	106.9	123.9	80.9
33	69.4	106.8	125.5	80.0
34	79.8	108.6	130.6	80.2
35	76.2	103.5	131.8	83.0
36	81.5	111.6	130.8	78.3
37	81.2	109.3	126.8	77.1
38	76.9	111.5	127.5	-78.1
39	77.5	106.6	127.9	78.3
40	83.3	112.1	129.4	78.2
41	75.9	114.8	135.6	78.2
42	81.9	116.2	138.4	80.9
43	80.1	117.0	142.4	82.0
44	77.1	113.1	137.0	81.4
45	74.7	114.8	138.6	79.1
46	79.2	119.4	136.6	77.8
47	78.2	115.4	135.3	79.7
48	86.0	124.1	138.2	79.1
M	74.1	111.5	125.6	73.6
SD	4.9	4.8	8.6	5.6

APPENDIX F
STATISTICAL DATA FOR 1RM PARALLEL SQUAT

ANCOVA
(mass and pretest covariates)

Variable	Df	Mean Square	F Value	Significance
Mass	1	5524.0	36.7	**.000**
Pretest	1	47747.7	317.2	**.000**
Treatment	2	4495.6	29.9	**.000**

Treatment	Adjusted Mean	Standard Error	95 % Confidence Interval	
Control	112.3	1.9	108.5	116.2
FROM	131.8	1.7	128.3	135.3
LROM	122.5	1.7	119.0	126.0

Pairwise Comparison		Mean Difference	Standard Error	Signficance
Control	FROM	- 19.5	2.5	**.000**
	LROM	- 10.1	2.5	**.000**
FROM	LROM	9.3	2.4	**.001**

Repeated Measures ANCOVA
(pretest and posttest, mass covariate)

Variable	Df	Mean Square	F Value	Signficance
Mass	1	26090.8	5.568	**.026**
Treatment	2	7738.0	1.651	.211
Time	1	342.5	3.1	.089
Time * Mass	1	1630.7	14.8	**.001**
Time * Treatment	2	2037.4	18.5	**.000**

Treatment By Time	Adjusted Mean	Standard Error	95 % Confidence Interval	
Control – Pre	104.0	7.9	87.8	120.2
Control – Post	108.2	6.9	94.1	122.3
FROM – Pre	112.7	7.2	97.9	127.5
FROM – Post	135.4	6.3	122.4	148.2
LROM – Pre	108.0	7.3	93.1	123.0
LROM - Post	121.9	6.3	108.9	134.9

Pairwise Comparison		Mean Difference	Standard Error	Signficance
Control – Pre	FROM - Pre	- 8.7	10.6	.420
	LROM - Pre	- 4.0	10.8	.710
FROM – Pre	LROM - Pre	4.66	10.4	.658
Control –Post	FROM - Post	-27.1	9.3	**.007**
	LROM - Post	- 13.6	9.4	.158
FROM – Post	LROM – Post	13.4	9.0	.149

APPENDIX G

STATISTICAL DATA FOR VERTICAL TAKE-OFF VELOCITY

ANCOVA
(mass and pretest covariates)

Variable	df	Mean Square	F Value	Signficance
Mass	1	0.022	4.4	**.047**
Pretest	1	1.074	213.9	**.000**
Treatment	2	0.045	8.9	**.001**

Treatment	Adjusted Mean	Standard Error	95 % Confidence Interval	
Control	2.670	0.024	2.621	2.719
FROM	2.808	0.023	2.761	2.856
LROM	2.720	0.023	2.672	2.767

Pairwise Comparison		Mean Difference	Standard Error	Significance
Control	FROM	- 0.138	0.033	**.000**
	LROM	- 0.049	0.033	.152
FROM	LROM	0.089	0.033	**.018**

Repeated Measures ANCOVA
(pretest and posttest, mass covariate)

Variable	Df	Mean Square	F Value	Signficance
Mass	1	1.313	13.7	**.001**
Treatment	2	0.339	3.5	**.043**
Time	1	0.081	11.5	**.002**
Time * Mass	1	0.114	16.3	**.000**
Time * Treatment	2	0.027	3.9	**.033**

Treatment By Time	Adjusted Mean	Standard Error	95 % Confidence Interval	
Control - Pre	2.717	0.059	2.596	2.838
Control – Post	2.682	0.064	2.551	2.814
FROM – Pre	2.837	0.053	2.728	2.947
FROM – Post	2.946	0.058	2.827	3.065
LROM – Pre	2.623	0.056	2.508	2.738
LROM - Post	2.637	0.061	2.512	2.762

Pairwise Comparison		Mean Difference	Standard Error	Signficance
Control - Pre	FROM - Pre	- 0.120	0.079	.141
	LROM - Pre	0.094	0.081	.259
FROM - Pre	LROM - Pre	0.214	0.078	**.010**
Control - Post	FROM - Post	- 0.264	0.086	**.005**
	LROM - Post	- 0.045	0.088	.611
FROM - Post	LROM – Post	- 0.309	0.084	**.001**

APPENDIX H

STATISTICAL DATA FOR JOINT ANGLE ANALYSIS

ANOVA

Ankle Joint

Variable	df	Mean Square	F Value	Signficance
Between Groups	2	3796.8	127.2	**.000**
Within Groups	141	29.9		

Multiple Comparisons		Mean Difference	Standard Error	Signficance
LROM	FROM	- 16.5	1.0	**.000**
	FROM-par	- 10.6	1.0	**.000**
FROM	FROM-par	5.9	1.1	**.000**

Knee Joint

Variable	df	Mean Square	F Value	Signficance
Between Groups	2	19350.2	484.5	**.000**
Within Groups	141	39.9		

Multiple Comparisons		Mean Difference	Standard Error	Signficance
LROM	FROM	3.5	1.2	**.005**
	FROM-par	36.1	1.3	**.000**
FROM	FROM-par	32.7	1.3	**.000**

Hip Joint

Variable	df	Mean Square	F Value	Signficance
Between Groups	2	46651.4	546.0	**.000**
Within Groups	141	85.4		

Multiple Comparisons		Mean Difference	Standard Error	Signficance
LROM	FROM	17.0	1.8	**.000**
	FROM-par	59.7	1.8	**.000**
FROM	FROM-par	42.7	1.9	**.000**

Absolute Trunk

Variable	Df	Mean Square	F Value	Signficance
Between Groups	2	7088.1	182.0	**.000**
Within Groups	141	38.9		

Multiple Comparisons		Mean Difference	Standard Error	Signficance
LROM	FROM	7.8	1.2	**.000**
	FROM-par	23.5	1.2	**.000**
FROM	FROM-par	15.7	1.3	**.000**

APPENDIX I

STATISTICAL DATA FOR ACTIVITY LEVELS

ANOVA

Activity		df	Mean Square	F Value	Significance
LIGHT	Between Groups	2	106.6	5.3	**.011**
	Within Groups	28	19.9		
MODERATE	Between Groups	2	165.6	2.9	.073
	Within Groups	28	57.5		
HARD	Between Groups	2	6.5	0.6	.557
	Within Groups	28	10.9		
TOTAL	Between Groups	2	548.9	6.9	**.004**
	Within Groups	28	80.1		

Multiple Comparisons			Mean Difference	Standard Error	Significance
Light	Control	FROM	6.3	2.0	**.004**
	Control	LROM	5.1	2.0	**.017**
	FROM	LROM	- 1.2	1.9	.540
Moderate	Control	FROM	8.1	3.4	**.024**
	Control	LROM	5.2	3.4	.137
	FROM	LROM	- 2.9	3.2	.376
Hard	Control	FROM	0.3	1.5	.855
	Control	LROM	- 1.2	1.5	.431
	FROM	LROM	- 1.5	1.4	.309
Total	Control	FROM	14.8	4.0	**.001**
	Control	LROM	9.1	4.0	**.031**
	FROM	LROM	- 5.7	3.8	.145

APPENDIX J

SAMPLE ACTIVITY LOG

NAME: WEEK: 1

			INTENSITY		
DATE	ACTIVITY	DURATION	Light	Moderate	Hard
Monday	Hockey			60 min.	
Tuesday					
Wednesday	Hockey			60 min.	
Thursday					
Friday	Hockey			60 min.	
Saturday					
Sunday					

WEEK: 2

			INTENSITY		
DATE	ACTIVITY	DURATION	Light	Moderate	Hard
Monday	Hockey			60 min.	
Tuesday					
Wednesday	Hockey			60 min.	
Thursday					
Friday	Treadmill				30 min.
Saturday					
Sunday					

NAME: WEEK: 3

			INTENSITY		
DATE	**ACTIVITY**	**DURATION**	**Light**	**Moderate**	**Hard**
Monday	Hockey			60 min.	
Tuesday					
Wednesday	Hockey			60 min.	
Thursday					
Friday	Hockey			60 min.	
Saturday					
Sunday	Curling	90 min.			

WEEK: 4

			INTENSITY		
DATE	**ACTIVITY**	**DURATION**	**Light**	**Moderate**	**Hard**
Monday	Hockey			60 min.	
Tuesday					
Wednesday	Treadmill				30 min.
Thursday					
Friday	Treadmill				30 min.
Saturday					
Sunday					

NAME: WEEK: 5

			INTENSITY		
DATE	**ACTIVITY**	**DURATION**	**Light**	**Moderate**	**Hard**
Monday	Soccer			60 min.	
Tuesday					
Wednesday	Treadmill				30 min.
Thursday					
Friday					
Saturday	Bowling		90 min.		
Sunday					

WEEK: 6

			INTENSITY		
DATE	**ACTIVITY**	**DURATION**	**Light**	**Moderate**	**Hard**
Monday					
Tuesday					
Wednesday	Soccer			60 min.	
Thursday					
Friday	Treadmill				30 min.
Saturday	Rollerblade			30 min.	
Sunday					

NAME: WEEK: 7

			INTENSITY		
DATE	**ACTIVITY**	**DURATION**	**Light**	**Moderate**	**Hard**
Monday	Rollerblade			30 min.	
Tuesday					
Wednesday	Hockey				30 min.
Thursday	Soccer		60 min		
Friday					
Saturday	Rollerblade			30 min.	
Sunday					

APPENDIX K

SAMPLE WORKOUT LOG

NAME: TRAINING GROUP: Full ROM: 71-21 PINS: 10-4

DATE	Workout Number	Warmup	Set1	Set 2	Set 3	Comments
March 4 W-1:30	1	Bar x 10 95 x 10	65% 145 x 10	69% 155 x 10	76% 170 x 10	
March 6 F-10:30	2	Bar x 10 95 x 10	69% 155 x 10	76% 170 x 10	80% 180 x 10	
March 10 T-3:30	3	Bar x 10 115 x 10	75% 170 x 10	80% 180 x 10	84% 190 x 10	leans too much?
March 14 S-10:30	4	Bar x 10 125 x 10	80% 180 x 10	84% 190 x 10	89% 200 x 10	
March 18 W-2:30	5	Bar x 10 135 x 10	84% 190 x 10	89% 200 x 10	84% 190 x 10	out of town to Calgary
March 23 M-3:00	6	Bar x 10 135 x 10	87% 195 x 10	89% 200 x 10	89% 200 x 10	
March 27 F-10:30	7	Bar x 10 135 x 10	89% 200 x 10	91% 205 x 10	91% 205 x 10	slightly high
March 30 M-3:00	8	Bar x 10 135 x 10	91% 205 x 10	93% 210 x 10	93% 210 x 10	High on third set
April 3 F-10:30	9	Recovery Bar x 10	65% 145 x 10	65% 145 x 10	65% 145 x 10	
April 6 M-1:30	10	Recovery Bar x 10	65% 145 x 10	65% 145 x 10	65% 145 x 10	
April 10 F-9:30	11	Bar x 10 135 x 10	96% 215 x 13	100% 225 x 9	96% 215 x 8	
April 13 M-1:30	12	Bar x 10 155 x 10	98% 220 x 13	100% 225 x 11	100% 225 x 10	High on third set
April 16 Th-11:30	13	Bar x 10 155 x 10	100% 225 x 12	102 % 230 x 11	102% 230 x 11	
April 20 M-2:00	14	Bar x 10 155 x 10	105% 235 x 11	105% 235 x 10	100% 225 x 10	

1 RM Max - 225

<u>Note:</u> All load values are in pounds. % value refers to percentage of initial 1RM.