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Efficacy of Partial ROM Squat in Maximal Strength Training

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Efficacy of Partial ROM Squat in Maximal Strength Training

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by
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ABSTRACT

Efficacy of Partial ROM Squat in Maximal Strength Training

by

Caleb D. Bazyler

Eighteen well trained males (1RM Squat: 150.57 ± 26.79 kg) were assigned to two groups: full ROM training (control) and full ROM with partial ROM training (CP) for the seven-week training intervention. There was a significant time effect ($p<0.05$) for 1RM squat, 1RM partial squat, IPFa 90°, IPFa 120°, and impulse at 90ms, 200ms, and 250ms at 90° and 120° of knee flexion. There was a significant interaction for RFD 200ms at 120° and a near significant interaction for 1RM squat scaled ($p=0.07$). There was a trend for CP to improve over control in 1RM squat (+2.3%), 1RM partial squat (+4.1%), IPFa 120° (+5.7%), and impulse scaled at all time points for 90° (+6.3-11.9%) and 120° (+3.4-16.8%). Our findings suggest that partial ROM squats in conjunction with full ROM squats may be an effective training modality for improving maximal strength and early force-time curve characteristics in well-trained males.

DEDICATION

This thesis is dedicated first and foremost to my Father in heaven, for in him we live, and move, and have our being (Acts 17:28). I would not have been able to complete any of this if it were not for God's abounding grace. The fact that I even have the privilege to write this is a testament to God's abundant provision. Lord, you must become greater and I must become less! Second, I am very blessed to have a wonderful wife who has been patient and understanding while I have been completing this thesis. I love you forever and look forward to glorifying the Lord through our marriage the rest of our lives together. "Glorify the Lord with me, let us exalt His name together!" (Psalm 34:3). I can't thank God enough for you! And of course I cannot end this dedication without acknowledging my father and mother, Simon and Laura, and my three brothers, Joshua, Benjamin, and Josiah. I did not realize until recently, and doubt I still have fully comprehended, how blessed I am to have grown up in a family established upon Christ. I only regret not expressing enough how much I love you and how very grateful I am for your love and support over the years.

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TABLE OF CONTENTS

Page

Chapter

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure

CHAPTER 1

INTRODUCTION

Strength training is believed to have originated in Ancient Greco-Roman times around the second century (Drees, 1968; Gardiner, 1930; Robinson, 1955). The training principle of overload has its origin in the classic legend of Milo of Croton. Milo lifted a calf every day and as the calf grew heavier, Milo was forced to lift more weight. Thus, the concept of progressive overload was born. Since Milo, varying volume and intensity over a training program has become one of the goals of strength training (Issurin, 2010).

In the 1920s Hans Seyle developed the General Adaptation Syndrome, which describes how an organism adapts to a stimulus. This theory laid the foundation for subsequent descriptions of the adaptation process such as the specific adaptation to imposed demands (SAID) principle, which suggests that strength will continue to increase as volume and intensity are appropriately manipulated due to muscular and nervous systems adaptations (Mann, Thyfault, Ivey, & Sayers, 2010) . In 1964 Leonid Matveyev designed what we now know as the traditional periodization model (Matveyev, 1964). Issurin in his 2010 review on periodization refers to Matveyev as the father of traditional periodization (Issurin, 2010).

Following Matveyev, in the 1970s and 1980s Verkoshansky (1985), Issurin (2010), and Stone, Stone and Sands (2007) developed models of periodization differing from the traditional model (conjugated-sequencing, block periodization, and phase potentiation, respectively). These models differed from the traditional model in that they did not involve a simultaneous increase in the fitness abilities (strength, speed, endurance) rather they emphasized a different ability in each phase. These phases are organized in such a way that one phase would potentiate the subsequent phase. These models are based on the long-term lag of the training effect (Verkoshansky, 1985).

That is that there is a lag time between the presentation of a stimulus and its realization in training.

Adaptation is the adjustment of an organism to its environment (Zatsiorsky, 1995). There are five features of the strength training adaptation process: overload, accommodation, variation, specificity, and individualization. In order to improve maximal strength there must be progressive overload of specific musculature. This overload must be sufficient as well as varied in order to avoid accommodation to the training stimulus. Finally, the strength training program needs to be catered to the individual's needs in order to maximize adaptation.

In addition, a common means by which strength coaches, athletes, and recreationally trained individuals provide variation and overload is by including partial lifts in their training programs. Partial lifts have been used commonly to improve strength at the terminal range of motion (ROM) of a movement, enhance metabolic adaptations, prevent injury, and enhance sport performance (Clark, Bryant, & Humphries, 2008; Clark, Humphries, Hohmann, & Bryant, 2011; Massey, Vincent, Maneval, Moore, & Johnson, 2004; Massey, Vincent, Maneval, & Johnson, 2005; Mookerjee & Ratamess, 1999; Pinto et al., 2012; Zatsiorsky, 1995) . The majority of studies including partial lifts have been training studies; however, very few of these studies (Graves, Pollock, Jones, Colvin, & Leggett, 1989; Graves et al., 1992; Massey et al., 2004; Mookerjee & Ratamess, 1999; Pinto et al., 2012) focused on partial lifts' efficacy.

Definitions

1. Allometric Scaling: A method of normalizing results of strength measures. The strength benefit derived from body mass is not linear, thus this scaling method uses a nonlinear

function. It is calculated with the formula $y = x \cdot (BdM^{2/3})^{-1}$ (Challis, 1999; Kraska et al., 2009).

  a. Where:
    1) y = allometrically scaled mass
    2) x = measured variable to be scaled
    3) BdM = body mass in kilograms

2. Core Lift: Multi-joint movements that involve one or more large muscle groups such as squat, bench press, and deadlift (NSCA 2000)
3. Isometric Force-Time Curve: The tracing that results from plotting force-time data obtained from force plate. This tracing, and the data used to create it, allow for a number of calculated variables.
4. Isometric Peak Force (IPF): The highest ground reaction force measured from a force plate during an isometric exercise. It is calculated from the force-time curve and generally measured in Newtons (N).
5. Overload: "The magnitude of a training stimulus that is above the habitual level" (Zatsiorsky 1995, p. 4).
6. Partial Lift: Movements that are a portion of a full range of motion (ROM) lift such as a quarter squat, rack pull, and bench lockout.
7. Rate of Force Development (RFD): The rate of rise of contractile force during muscle contraction. This is calculated from the force-time curve and can be analyzed at various times. RFD is expressed in Newtons per second ($N \cdot s^{-1}$) (Aagard et al., 2002).

8. Specificity: “The degree to which one movement is similar to another in kinetic, kinematic, and metabolic measures.” (Stone et al., 2007, p. 171).
9. Sticking Point: The point of minimum velocity in a continuous movement; is generally related to a changing mechanical advantage (Hales, Johnson, & Johnson, 2009; McGuigan & Wilson, 1996).

Significance of Study

In the strength and conditioning profession, partial lifts have commonly been incorporated into training programs (Clark et al., 2008, Clark et al., 2011; Harris, Stone, O’Bryant, Proulx, & Johnson, 2000; Stone, Potteiger, & Pierce, 2000). Some of the proposed benefits improved strength at the terminal ROM of a movement, improved weak portions of a movement, substituted for full ROM exercise during rehabilitation, injury prevention, enhanced metabolic adaptations, increased training volume, variation in training, and enhanced sport performance (Clark et al., 2008, Clark et al., 2011; Massey et al., 2004; Massey et al., 2005; Mookerjee & Ratamess, 1999; Pinto et al., 2012; Zatsiorsky, 1995). Few studies directly examine the efficacy of partial lifts in improving maximal strength (Bloomquist et al., 2013; Graves et al., 1989; Graves et al., 1992; Massey et al., 2004; Mookerjee & Ratamess, 1999; Pinto et al., 2012). The findings of these studies for maximal strength are conflicting.

Graves et al. (1989) had untrained males and females train leg extensions once per week for ten weeks and found groups that trained with a partial ROM had greater gains in isometric strength in the trained ROM than in the untrained. The group that trained through a full ROM improved isometric strength equally at all joint angles. Massey et al. (2004) compared full ROM with partial ROM and reported an improved 1RM bench press in both groups after training twice per week for ten weeks with no statistical difference observed between groups. In contrast, Pinto et al. (2012) compared full ROM vs. partial ROM and found that after 10 weeks of training twice per week the full ROM group significantly increased 1RM strength on preacher curls over the partial ROM group. Additionally, Pinto reported effect sizes for muscle thickness of 0.57 and 1.09 in the partial and full ROM group, respectively. Considering the lack of consistency in the design and results of the aforementioned studies, further research is warranted.

Purpose of the Study

The purpose of our study was to examine the effects of two different training modalities, full ROM training (control) and full ROM with partial ROM training (CP), on well-trained males during a seven-week training intervention. The study included measurements of 1RM squat, 1RM partial squat, and maximal isometric squat at 90° and 120° of knee flexion.

Hypothesis

Well-trained males training for 7 weeks (12 weeks total) in both conditions will improve dynamic maximal strength; however, CP will improve 1RM partial squat over control. Our rationale was based on previous research demonstrating that gains in strength are specific to the ROM trained (Graves et al., 1989; Massey et al., 2005; Pinto et al., 2012; Sale & MacDougall, 1981; Wilson, Murphy, & Walshe, 1996). These studies indicated that greater strength gains were made with the trained than the untrained joint angles. All joint angles were being trained in both groups, however, there were greater overloads through the terminal ROMs in the CP condition due to the supra-maximal loads being used during partial lifts. Thus, the CP condition trained with loads optimal for improving maximal strength at the end of the lift, whereas the control did not.

We hypothesized that both groups would improve for all isometric measures; however, CP would improve peak force at 120° over Control. Our rationale is based on the principles of specificity and overload (Zatsiorsky, 1995). CP would improve over Control at 120° because of the supra-maximal loads used at this joint angle during training.

Assumptions

1. All the equipment used for our study provided reliable and accurate results.
2. All participants adhered to the conditions provided in the Informed Consent Form.
3. All participants answered the health history questionnaire truthfully.
4. All participants performed to their utmost potential in each testing session.

Delimitations

The delimitations for this project were that each participant must have at least one year training experience in the back squat and squat with at least 1.3 x body weight (BW) resistance. Participants must have completed 80% of the programmed repetitions to be included in the data analysis. All participants were in the age range of college aged male students (18-24).

Limitations

1. Two participants dropped out of the study and a third was not included due to knee pain
2. Homogeneity of variance was not met for three variables (IPFa 90°, impulse 200ms, 250ms at 90°).

CHAPTER 2

REVIEW OF THE LITERATURE

Genetic and Molecular Responses to Resistance Training

Mechanical stress modulates muscle tissue form and function and is specific to the type of mechanical load. Kumar et al. (2002) found that axial versus transverse mechanical stress resulted in activation of distinct intracellular signaling pathways. This is strong evidence for mechanotransduction specificity. Thus, the type of mechanical load (i.e. velocity and force of contraction) will contribute to the specific adaptations derived from training.

Resistance exercise results in a large efflux of Ca^{2+} from the sarcoplasmic reticulum resulting in an increase in intracellular [Ca^{2+}]. After a single bout of anaerobic exercise Ca^{2+} release and uptake are significantly impaired and do not return to baseline until 60 minutes of recovery (Matsunaga et al., 2002). There is an adaptive response to resistance exercise resulting in a smaller disturbance in Ca^{2+} release and uptake. Cytosolic [Ca^{2+}] will affect downstream events such as gene expression and protein synthesis. The magnitude and duration of Ca^{2+} flux is dependent on the mode, intensity, and volume of exercise (Coffey & Hawley, 2007). For example, endurance exercise will result in smaller perturbations in Ca^{2+} release and uptake as compared to anaerobic exercise (Baar, Blough, Dineen, & Esser, 1999).

The redox potential of a muscle cell is dependent on how rapidly NAD can be reduced to NADH. Resistance exercise is capable of producing large increases in reactive oxygen species (ROS) due to an increased demand for oxygen and the activity of metabolic pathways. As the rate of intracellular catabolic reactions increase, there is a concomitant increase in free radical synthesis. The oxidative stress resulting in free radical synthesis may modulate signaling pathways by effecting transcriptional regulation and decreasing myofilament Ca^{2+} binding sensitivity (Smith & Reid, 2006). These ROS are buffered by antioxidant systems such as catalase and glutathione peroxidase.

Resynthesis of adenosine tri-phosphate is dependent on both oxidative and non-oxidative pathways. ATP production and consumption are regulated by concentrations of substrates such as AMP, Pi, CP, and ADP. There is inverse relationship between metabolite concentrations and contractile intensity and duration during exercise (Ferguson et al., 2001; Ivy et al., 1987; Krustrup, Ferguson, Kjaer, & Bangsbo, 2003). In particular, AMP is a potent stimulator of ATP production via enhanced activation of phosphofructokinase (PFK), the rate-limiting enzyme in glycolysis (Stone et al., 2007). Phosphorylation state is a primary messenger of adaptive responses and exerts its effects primarily through five adenosine monophosphate (AMPK). AMPK regulates multiple signaling cascades, such as fatty acid oxidation, glucose uptake, and inhibition of protein synthesis. AMPK is up-regulated to conserve and generate ATP, thus it is involved in enhancing glucose uptake to the muscle cell and increasing mitochondrial fatty acid oxidation. AMPK has been linked to down-regulating components of the mTOR pathway, thus inhibiting protein synthesis. AMPK phosphorylation seems to be greatest when there is an extensive and rapid reduction of ATP (Chen et al., 2000). AMPK activation occurs in endurance activities due to its ability to regenerate ATP via fat oxidation (Chen et al., 2003; Rasmussen & Winder, 1997; Wadley et al., 2006). Durante and colleagues' (2002) findings support the notion that AMPK activation is greater in slow oxidative fibers than fast glycolytic fibers (Durante, Mustard, Park, Winder, & Hardie, 2002). However, caution is advised in interpreting findings that suggest this fiber type specific AMPK activity because many studies have incorporated exercise protocols that are more aerobic in nature (Ferguson et al., 2001, Ivy et al., 1987, Wadley et al., 2006).

Research on AMPK responses to resistance exercise is limited. Changes in AMPK phosphorylation may be linked to the enhanced glucose uptake by increased GLUT 4 receptor translocation in response to exercise. Coffey et al. (2005) found that trained cyclists and powerlifters experienced a blunted response in AMPK after an exercise bout in their discipline; however, when athletes performed a bout of unfamiliar exercise AMPK activity increased (Coffey & Hawley, 2007). The authors suggested that the AMPK response may be related to the athlete's phenotype and stimulus applied rather than the mode of exercise. AMPK has also been found to inhibit mammalian target of rapamycin (mTOR) hypertrophic effects via phosphorylation of tuberous sclerosis complex 2 (TSC 2).

IGF-1 may enhance gene expression and satellite cell activation. IGF-1 has been associated with greater strength gains following resistance training for 10 weeks (Kostek et al., 2005). When muscle contractile structure is damaged, satellite cells are activated, the cells proliferate and differentiate to repair damaged tissue and add myonuclei. A few transcription factors that play a role in satellite cell activation, increased myonuclei and size of the myofiber are myogenic differentiation (MyoD) and myogenin transcription factor (MyoG). Both are believed to contribute to the compensatory hypertrophy seen with resistance training (Kosek, Kim, Petrella, Cross, & Bamman, 2006).

Calcium calmodulin-dependent kinases (CaMK) are a group of single and multifunctional kinases that respond to [Ca^{2+}]. Conclusive data on the effect of CaMK activation on adaptive mechanisms are lacking. CaMKII and IV are isoforms of the CaMK family that have been linked to gene expression of contractile and mitochondrial proteins, respectively (Wu et al., 2002). CaMKII appears to be the primary CaMK activated in response to endurance exercise (Rose & Hargreaves, 2003). Calcineurin also seems to have an important role in gene expression.

Calcineurin appears to augment muscle fiber hypertrophy along with IGF in combination with proliferation and differentiation of satellite cells during regeneration of muscle fibers (Sakuma et al., 2003). Calcineurin is also involved in fast-to-slow fiber type transformation (Michel, Dunn, & Chin, 2004). These opposing responses may represent adaptations specific to the velocity, force, and duration of contraction. More extensive research on the role of calmodulin-calcineuron dependent pathways in response to exercise in humans is needed.

Akt, also known as protein kinase b, is a serine-threonine protein kinase that has been associated with enhancing muscle protein synthesis as well as inhibiting degradation. Akt 1 and Akt 2, isoforms of Akt, are responsible for muscle hypertrophy and glucose transport signaling, respectively (Taniguchi, Emanuelli, & Kahn, 2006). Akt mediates its effects of muscle hypertrophy through activation of MTOR. Akt suppresses TSC2, which inhibits protein synthesis. Akt has been shown to prevent transcription of atrophy genes by translocating forkhead box O (Fox O), a regulator of protein degradation, from the nucleus to the cytosol (Latres et al., 2005; Rena et al., 2002). Akt response has varied depending on the exercise mode; however, both resistance and endurance exercise have resulted in increases in Akt phosphorylation. Akt is expected due to its role in both protein synthesis and glucose transport.

mTOR is capable of binding with a rapamycin raptor or rictor protein, which are responsible for cell growth and Akt activation respectively. Downstream targets of mTOR are p70 ribosomal protein S6kinase (p70 S6K) and eIF4E binding protein (4E-BP1), which increase protein synthesis and cell size. Dreyer et al. observed an increase in mTOR phosphorylation following eight weeks of resistance exercise providing evidence for the role of mTOR in muscle anabolism (Dreyer et al., 2006). Downstream of mTOR, p70 S6K has been shown by Bodine and colleagues to be a primary regulator of muscle fiber hypertrophy (Bodine et al., 2001). Further research has shown that endurance exercise does not increase p70 S6K activity (Atherton et al., 2005; Lee et al., 2006). Additionally, endurance stimuli decrease 4E-BP1 phosphorylation resulting in a negative effect on protein synthesis (Atherton et al., 2005).

Cytokines are released in response to inflammation resulting from damage to the muscle fiber. Cytokines initiate protein degradation and suppress synthesis. In particular tumor necrosis factor alpha (TNFalpha) has been linked to decreased protein synthesis through suppression of IGF-1 (Lang, Krawiec, Huber, McCoy, & Frost, 2006). IGF-1 elevates muscle proteolysis via increased ubiquitin gene expression (Garcia-Martinez, Agell, Llovera, Lopez-Soriano, & Argiles, 1993). Hamada et al., (1999) observed an increase in TNFalpha three days after a 45-minute exercise bout consisting of downhill running showing that inflammation persisted for days after the induced muscle damage (Hamada, Vannier, Sacheck, Witsell, & Roubenoff, 2005). Increased circulation of TNFalpha occurs following heavy eccentric resistance training (Ostrowski, Rohde, Asp, Schjerling, & Pedersen, 1999). However, training seems to decrease the local inflammatory response (Coffey & Hawley, 2007).

Adaptations to Resistance Training

The principle adaptations to heavy resistance training exercise are altered neural recruitment patterns and an increase in muscle cross-sectional area (Baechle & Earle, 2000). Neural changes include an increase in rate coding, firing synchronicity, and total number of motor units recruited. The increase in cross-sectional area is due to a positive nitrogen balance where protein synthesis exceeds degradation. Resistance training may also down-regulate pathways associated with muscle atrophy allowing for a greater net protein synthesis.

Neural

Increasing neural drive is crucial for optimizing strength and power performance. The ability to recruit higher threshold motor units begins in the motor cortex and the action potential is propagated down the descending corticospinal tracts towards the targeted muscle fibers. Increasing neural drive is achieved via increases in motor unit recruitment, rate coding, agonist synchronization, and the timing and pattern of discharge (Baechle & Earle, 2000). All have been reported as adaptations to resistance training.

Activation of the motor cortex is enhanced when the amount of force developed increases and when learning of new movements (Dettmers, Lemon, Stephan, Fink, & Frackowiak, 1996). The majority of neural adaptations to resistance training take place in the descending corticospinal tracts. Adams et al. (2000) found that untrained individuals only activated about 71% of their muscle tissue (Adams, Harris, & Woodard, 2000). Furthermore, strength training can enhance the activation of higher threshold motor units leading to improved force production (Stone et al., 2007).

The order of motor unit activation is governed by the size principle, which is based on the relationship between motor unit size and activation threshold. Larger motor units have higher activation thresholds (Henneman, Wuerker, & McPhedran, 1965). Thus, in mixed muscle, large motor units innervating fast twitch fibers would be activated last. However, once a motor unit is recruited it requires less activation to be recruited again. Resistance training may allow for higher threshold motor units to be recruited more readily by lowering their activation threshold (Baechle & Earle, 2000).

Rate coding is the frequency at which motor units are activated (Stone et al., 2007). Motor units innervating fast twitch fibers are activated at a greater neural discharge frequency. There is a positive relationship between firing frequency and RFD. Viitasalo and Komi (1981) showed that a rise in EMG activation is associated with a rise in RFD. Improving the nervous system's ability to activate muscle tissue will enhance RFD. The firing frequency and RFD are also related to the amount of force produced. Therefore, resistance training that improves maximal strength may also increase firing frequency and RFD (Andersen & Aagaard, 2006).

Resistance training increases agonist activation and synchronization upon initiation of contraction rather than the typical asynchronous activation pattern (Felici et al., 2001; Milner-Brown, Stein, & Lee, 1975; Semmler, Kornatz, & Enoka, 2003). As force output increases greater synchronization occurs. Resistance training enhances both number of motor units synchronized and synchronization at lower force outputs (Stone et al., 2007). Increased agonist synchronization is more critical to the timing of force production rather than the amount of force produced (Semmler & Nordstrom, 1998).

Additionally, other neurological adaptations to resistance training include morphological changes to the neuromuscular junction, increased reflex potentiation, and decreased antagonist cocontraction. Deschenes et al. (2000) showed that seven weeks of resistance training increased motor end plate perimeter and area as well as greater dispersion of acetylcholine receptors over this region. Enhancing the efficiency of the stretch reflex via resistance training may lead to improvements in RFD and maximal force production. The reduced inhibition may be due to decreased antagonist cocontraction following resistance training as well as reduced receptor sensitivity (reduced golgi tendon organ reflex activity) (Carolan & Cafarelli, 1992). The reduced inhibition may allow for greater forces to be achieved (Aagaard et al., 2000). More recent findings suggest there are differential adaptations when comparing nonballistic with semiballistic movements.

How do the findings discussed above relate to the effectiveness of partial lifts? Wilson (1994) proposed that partial lifts involving supramaximal loads may result in reduced inhibition lending to an increase in maximal force production. The increase in maximal force production with training may also result in increases in RFD (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Hakkinen, Komi, & Alen, 1985); however, these are likely through different processes (Holtermann, Roeleveld, Vereijken, & Ettema, 2007). Training the terminal ROM of a lift may improve peak force, RFD, and impulse to a greater extent than full ROM training alone (Zatsiorsky, 1995). This is because the terminal range of motion is loaded more optimally in the partial than in the full ROM lift. The full ROM is limited by the sticking point.

Muscular

It is well reported that gains in strength during the first 6-10 weeks of a resistance training program are primarily due to neural adaptations (Sale, 1987; Sale, 1992). As training progresses (e.g. more than ten weeks) hypertrophy takes over as the primary adaptation contributing to strength gains. Muscular adaptations resulting from resistance training are increased hypertrophy, altered biochemical response, enhanced muscle architecture, and fiber type transitions (Stone et al., 2007).

Resistance training results in myofibrillar hypertrophy, which involves the net accretion of muscle proteins, actin and myosin, accompanied by a concomitant increase in myofibrils within a muscle fiber (MacDougall et al., 1979). The addition of myofilaments along with the increase in pennation angle from chronic resistance training lends to an increase in physiological cross-sectional area (PSCA). There is a strong relationship between cross-sectional area and maximal strength, which is a function of sarcomeres being added in parallel. The more sarcomeres aligned in parallel the greater the strength of a muscle (Stone et al., 2007).

The primary stimulus for muscular hypertrophy is additional mechanical strain and tension produced resulting in muscle damage (Goldspink, 1998). Following an acute bout of resistance exercise there is an inflammatory response resulting in cytokine release and satellite cell proliferation and differentiation (Stauber & Smith, 1998). Satellite cells donate their nuclei to existing muscle fibers in order to enhance muscle protein synthesis in accordance with the myonuclear domain theory. Muscle damage also leads to the upregulation of growth factors involved in myogenesis (such as IGF-1 and mechano growth factor) and down-regulation of inhibitory growth factors (such as myostatin) (Baechle & Earle, 2000; Stone et al., 2007).

There have been few alterations found in enzyme activity as the result of heavy resistance training; however, high volume training may produce anaerobic and aerobic enzyme alterations (Stone et al., 2007). An under-studied area is change in isozyme content. Strength and sprint training alter the lactate dehydrogenase profile such that LD5, which converts pyruvate to lactate, is favored over LD1, which is responsible for the reverse reaction (Karlsson, Diamant, & Saltin, 1968). Higher volume resistance training increases fat oxidation postexercise, which suggests that high training volumes may be used to alter body composition (McMillan et al., 1993). In order to enhance acid-base balance during resistance exercise, another adaptation to high volume training is an increased buffering capacity. Increased buffering capacity enables the individual to maintain force output at a lower blood pH (Costill, Barnett, Sharp, Fink, & Katz, 1983). Repeated high intensity contractions in an interval fashion may increase ATP and creatine phosphate stores within the muscle via supercompensation (MacDougall et al., 1979).

Additionally, heavy resistance training for five months increases glycogen stores (MacDougall, Ward, Sale, & Sutton, 1977).

Muscle fibers properties are found on a continuum ranging from least to most oxidative. The least oxidative in humans, Type IIx, and the most oxidative Type I. The proportion of Type I to Type II fibers is genetically predetermined; however, alterations may be made within the subtypes as a result of training (Stone et al., 2007). As the volume of training increases there is a noticeable shift towards more oxidative fibers, and when training volume is reduced (Kadi & Thornell, 1999). The transition of Type IIx to the more oxidative Type IIa is driven by the increased demand to resist fatigue during training. This is reversed during a taper theoretically allowing for slightly greater power outputs (Ross & Leveritt, 2001). The transitions in fiber types, and corresponding myosin heavy chain (MHC) content, occur early in the training program. Over an eight-week resistance training program, Staron and colleagues (1994) found decreases in the Type IIx percentage in both men and women with a concomitant transition in MHC IIx to MHC IIa. There is insufficient evidence to say whether or not there is a transition from Type I to Type II or vice-versa (Baechle & Earle, 2000).

How do these findings relate to partial ROM training? One of the proposed benefits of partial lifts is increased volume-load. In a longitudinal study the additional work from partial lifts may result in a greater hypertrophic response; however, it is questionable whether this would be greater than the hypertrophic response elicited performing an equivalent amount of work through a full ROM. In one of only two studies directly examining muscle thickness with partial lift training, Pinto (2012) found that muscle thickness effect size for the full ROM condition was twice that of the Partial ROM condition following ten weeks of resistance training (1.09 vs 0.57). Even though the average load for the Partial ROM condition was 36% greater than the full ROM condition. Caution is needed in interpreting these findings because there was no attempt to equalize volume-load. Additionally, the full ROM condition improved 1RM over the partial ROM. Bloomquist et al. (2013) found similar results when comparing a full ROM to partial ROM training group. They reported that full ROM training resulted in significantly greater increases in 1RM squat, front thigh muscle CSA, LBM of the legs, and isometric knee extensor strength at 75° and 105°. These findings (Massey et al., 2005; Sale & MacDougall, 1981; Wilson et al., 1996) suggest that partial lift training alone may result in weakness in the untrained angles, which would not be an effective means of improving 1RM in a full ROM.

Strength Training Specificity

Training specificity involves both metabolic and mechanical factors. This discussion focuses on mechanical specificity and its relation to strength performance. Transfer of training is the degree to which a training exercise induces performance adaptations (Stone et al., 2007). The more similar the training exercise is to the performance measure the greater the probabilities of transfer (McDonagh & Davies, 1984). The kinetic and kinematic parameters influencing greater transfer include movement pattern, contraction velocity, contraction type, and contraction force (Kumar, Chaudhry, Reid, & Boriek, 2002).

Movement Pattern Specificity

Research has well documented that the degree to which strength improves depends on the similarity between the strength test and the training exercise used (Fry, Powell, & Kraemer, 1992; Sale, 1988). For example, Harris et al. (2000) reported a 10% increase in 1RM squat following nine weeks of squatting and pulling movements. However, the high power group, which did not perform back squats, did not improve 1RM squat. Wilson et al. (1996) reported a

12.4% increase in 1RM bench press and 20.9% increase in 1RM squat after eight weeks of training squat and bench press two times per week. This study also found that the increase in 1RM squat and bench press were poorly correlated with isokinetic knee extension and horizontal arm abduction, respectively. The authors concluded that activities, which were performed in a position similar to that of weight training, tend to improve the most compared to those performed in dissimilar positions.

The degree to which a training exercise transfers to the primary movement is related to intermuscular movement pattern specificity (Stone et al., 2007). This means that training exercises that include similar joints, velocities, and positions have a greater degree of transfer to the primary movement. For example, there is a strong correlation between performance in the snatch and clean and jerk and vertical jump height (VJ) (Stone et al., 2007). The mechanical factors affecting transfer from the Olympic lifts to VJ include high power outputs, high RFDs, and movement pattern (i.e., triple-extension of the hips, knees, and ankle joints). Thorstensson (1977) trained physical education students on the half squat for eight weeks. Following the eight weeks, the students improved half squat by approximately 75%; however, isometric leg press improved only about 40% and there was no improvement in knee extension. This study shows that differences in movement pattern altered the strength gains on each exercise even though the half squat activated similar muscle groups.

Specificity of Contraction Force, Velocity, and Type

In addition to movement pattern specificity, the degree of transfer of the training exercise to the performance measure is affected by contraction force, velocity, and type. Harris et al. (2000) studied 42 well trained football players for nine weeks. Athletes were placed in either a high force (>80% 1RM), speed-strength, (30-40% 1RM) or combination training (speed-strength and high force training) group. After nine weeks, the high force and combination group improved on maximum strength measures, whereas the speed-strength group did not. Additionally, the combination group and speed strength group improved on measures of power and explosiveness, whereas the high force group did not. This is strong evidence for the specificity of contraction force and velocity. Groups that trained with heavy loads improved maximal strength and groups that trained at higher velocities with lighter loads improved in power measurements. This study also demonstrated that combination training produced performance gains across a wide spectrum of performance variables.

To date there is little evidence on intentionally slow training. There is evidence to suggest that some hypertrophy may occur; however, it is not as extensive as that incurred by heavy weight training (Keeler, Finkelstein, Miller, & Fernhall, 2001). Stone and colleagues (2007) also suggest that for trained individuals intentionally slow training may diminish RFD, power, and maximal strength.

Alterations in the performance measure are also dependent on the contraction type (isometric, isokinetic, dynamic constant external resistance). Isometric tension has not been shown to produce extensive hypertrophy; however, maximum strength when measured isometrically can be improved by isometric training. Isometric training improvement is angle specific, smaller gains in isometric strength are observed when the strength measurement moves further from the angle trained (Atha, 1981). Dynamic exercises are recommended over isometric exercises because they cover a larger range of motion and have greater transfer to dynamic performance measures. Isokinetic training holds angular velocity constant by applying accommodating resistance via a machine. However, the external validity and reliability of isokinetic devices is questionable. In fact research has shown that gains from free-weight training are not always apparent when measured on isokinetic devices (Stone et al., 2007). As mentioned earlier, Wilson et al. (1996) found that a 20.9% increase in 1RM squat did not significantly improve isokinetic knee extension at 60 or 270° per second in recreationally trained males after eight weeks of training the squat twice per week. Dynamic constant external resistance training that involves a stretch-shortening cycle seems to have the greatest transfer to dynamic strength measures such as 1RM bench press and squat (Campos et al., 2002; Coffey & Hawley, 2007; Stone et al., 2000). Fry et al. (2000) demonstrated that 4 weeks of training squats and leg curls twice per week resulted in a significant increase in 1RM back squat in recreationally trained males. These studies support the specificity of contraction force, velocity and type in strength training.

Optimizing Strength Training

The more important question to ask when it comes to performance enhancement is not “does the intervention work?” but “is the intervention optimal?” An untrained individual may benefit from a nonperiodized training routine when the individual first begins, but this does not mean it is optimal to do so when periodized routines produce equal or greater strength gains in trained and untrained individuals (Herrick & Stone, 1996; Kraemer et al., 2000; Kraemer et al., 2003). There is a multiplicity of factors involved in optimizing strength training. A few of these include periodization of training variables (i.e., frequency, intensity, volume, and duration), exercise selection, individualization (e.g., training status), and the use of cluster sets and assistance exercises. Arguably, the most important factors are the transfer of training exercises to the performance measure and the appropriate manipulation of training volume and intensity.

It is first important to distinguish between programming and periodization. Periodization refers to the purposeful sequencing of different training units (e.g., macrocycle, mesocycle, microcycle) so that athletes can attain a desired state and achieve planned results (Issurin, 2010). Programming refers to the numerical models (sets per repetitions) that compose the training cycles (Stone et al., 2007). The vast majority of research has focused on programming a microcycle rather than the principles and strategies involved in creating an annual plan (Graves et al., 1989; Massey et al., 2005; Pinto et al., 2012; Sale & MacDougall, 1981; Wilson et al., 1996). This is due to the scarcity of longitudinal studies on training periodization. More research in needed in this area.

Periodized Versus Nonperiodized Models

There has been extensive research done showing that in untrained and trained males and females periodized training routines produce superior gains in strength measures as compared to nonperiodized routines (Fleck, 1999; Fleck & Kraemer, 1997; Willardson, 2006). A study by Willoughby et al. (1993) showed that periodized training elicited greater increases 1RM bench press and squat when compared to nonperiodized training over a 16-week training program in a large sample of 92 previously weight-trained college aged males. Schiotz et al. (1998) studied 14 male ROTC cadets over 10 weeks and demonstrated that 1RM bench press significantly increased in the periodized group as compared to the nonperiodized group. Kraemer et al. (2003) tracked female tennis players over 9 months, with testing strength and power at months 3, 6, and 9. The periodized group showed significant increases over the nonperiodized group at each time. These studies show that among untrained and trained individuals, periodized routines produce superior gains in strength and power.

Periodization Models

The General Adaptation Syndrome (GAS) was a concept developed by Hans Seyle in the 1920s to explain physiological responses to stress. GAS was later applied to training adaptations and early models of periodization are believed to have stemmed from GAS (Zatsiorsky, 1995). There are three phases of the GAS: alarm phase, resistance phase, and exhaustion phase. The alarm phase is when the training stimulus is recognized and the individual may experience soreness and/or a temporary drop in performance. The alarm phase gives rise to the resistance phase where the individual either returns to baseline or supercompensates as a result of positive training adaptations. If the stress persists for an extended period, symptoms of the alarm phase may reappear (e.g., fatigue, soreness, decreased performance) resulting in an overtrained state. The GAS lays the foundation for training variation suggesting that planned decreases in training volume or intensity may reduce the likelihood of being overtrained (Baechle & Earle, 2000; Stone et al., 2007). There are also external variables (e.g., insufficient sleep, poor diet, and work issues) that can contribute to overall stress and hamper positive adaptations.

An individual’s preparedness (readiness to perform) is primarily dependent on the aftereffects of two training responses: fitness and fatigue. The fitness and fatigue model proposes that fitness and fatigue have opposing effects; fatigue falls off faster than fitness creating a window of increased preparedness. Therefore, strength training to enhance performance is a balance between maximizing fitness benefits while minimizing fatigue. Fitness and fatigue likely have different aftereffects based on the different fitness abilities (strength-endurance, agility, speed) incorporated into training and can also be influenced by external factors and individual differences (e.g. sleep quality and quantity, age, maturation). For example, a strength endurance phase may result in diminished 1RM strength and lower T:C ratios; however, after a de-load (microcycle of reduced volume-loads) supercompensation may result in enhanced preparedness manifesting as increased cross-sectional area and a greater potential to improve strength in the subsequent training phase (Stone & Fry, 1997). Thus, a strength endurance phase may be used to potentiate a subsequent strength phase due to the long-term lag of the training effect proposed by Verkhoshansky (1985).

Involution rate (decline of training effects) is another important consideration in program design (Zatsiorsky, 1995). The rate of decline is thought to be related to the half-life of various glycolytic and oxidative enzymes (Stone et al., 2007). Fitness abilities such as power and speed have greater rates of involution than strength (Fry, Webber, Weiss, Frye, & Li, 2000). Thus, involution is modulated by the specific fitness ability and the time spent training that ability. The greater the training duration of the fitness ability the more stable the residual effect. As a result of this stability, adaptations gained during a strength-endurance phase can be maintained during the subsequent strength phase with less emphasis on strength-endurance. This is the basis for sequenced training, where successive training blocks of different emphasis are superimposed against a background of adaptation responses (Zatsiorsky, 1995).

The fluctuation in volume and intensity and the conflicting demands of specificity and variation are fundamental in the structuring of a training program (macrocycle or annual plan). In resistance training volume-load is the accepted estimate of work performed during training (Stone & O' Bryant, 1987). The traditional periodization model includes general preparation, special preparation, competition (with peaking), and active rest over a mesocycle or macro-cycle. During the general preparation phase high volume loads are used to increase work capacity and readiness for the intensive efforts to follow. This phase does not emphasize technique training in order to avoid the compounding effects of fatigue on motor skill development (Chargina et al., 1987). During the special preparation phase technique is emphasized while volume is lowered and intensity is elevated (Stone et al., 2007). The competition period involves maintenance of adaptations gained during the previous phases and peaking for performance. During this period volume continues to fall as intensity and technique rise towards a peak. The competition period is followed by an active rest period focused on nonsport specific recreational activities with low intensities and volumes (Baechle & Earle, 2000).

A few limitations of the traditional model are the reduced potential for sport-specific fitness to be maintained over the competition period and the inability to maintain a peak for more than three weeks. The inability to maintain a peak for longer than 3 weeks may be detrimental to team sports with a long competition period or many important competitions close together. This model may be appropriate for novices. However, for trained individuals, nontraditional models such as the conjugate sequencing system, developed by Verkhoshansky, could provide more variation and specificity in training (Stone et al., 2007). The conjugate sequence system (similar to block periodization) is based on the premise that the delayed effects of certain training stimuli (fitness abilities) can alter the responses to others (Harland & Steele, 1997; Verkhoshansky, 1999). The system is composed of a series of microcycles (generally 4-week blocks) involving periods of accumulation followed by restitution where recovery adaptation takes place and gains are achieved (Stone et al., 2007). As mentioned above, if the training goal is to improve 1RM strength an accumulation phase may involve primarily strength-endurance work while de-emphasizing strength training, followed by a restitution block where strength training is emphasized and strength-endurance is de-emphasized.

Manipulating Volume and Intensity

There is evidence demonstrating that appropriate manipulation of volume and intensity is essential for improving 1RM (Fry et al., 2000; Rena et al., 2002; Stone et al., 2000; Zourdos & Kim, 2012). Studies incorporating additional exercises into the training program include the exercises in both the experimental and the control condition. This is due to the vast amount of research examining various periodization models, which need to maintain internal validity by matching the exercises performed while manipulating other training variables. Fry et al. (2000) trained recreational level males twice per week for seven weeks. The exercises were the back squat and leg curl. After the first four weeks, participants improved 1RM back squat. For the next three weeks participants trained at ≥90% 1RM with the same exercises; however, there was a plateau in 1RM. Miranda (2011) divided 20 recreationally trained males into two different training groups. Both groups trained 4 days per week for 12 weeks with various assistance exercises (leg extension, leg curl, tricep extension, upright rows). They found that both the ‘linear periodized group’ and the ‘daily undulating group’ produced similar gains in 1RM and 8RM in bench press and leg press; however, the daily undulating group exhibited superior effect sizes. These studies show that the appropriate manipulation of training volume and intensity are paramount to improving 1RM.

Stone et al. (2000) divided 21 college aged males (1RM squat >1.3 x BW) into three groups. The control group (Group 1) performed 5x6RM on the core lifts and 3x8RM on assistance lifts throughout the entire 12-week study. A step-wise periodized model (Group 2) decreased repetitions per set every four weeks and trained at RM values every day. An overreaching periodized group (Group 3) trained with heavy and light days and microcycles of increased volume were inserted on weeks one and nine. All groups trained three days per week using the same exercises. Squats were performed on Monday and Friday and clean pulls and power shrugs on Wednesday. The additional exercises consisted of incline press and lat pull-downs. Group 1 (non-periodized) performed the same assistance exercises but did not improve the 1RM squat. No significant differences were found between the periodized groups (two and three) in the 1RM squat. The results of this study indicate that periodized models increase the 1RM squat to a greater extent than a constant repetition scheme (number of repetitions does not change during program), even when the repetitions were equalized (Group 1 vs. Group 2) or when the repetitions were substantially fewer (Group 1 vs. Group 3). Therefore, the efficacy of partial lifts may be determined by the timing of inclusion in the training program and how partial lifts are used to manipulate volume and intensity.

Training studies including additional exercises to the core lifts have consistently produced increases in strength (Apel, Lacey, & Kell, 2011; Hakkinen, Pakarinen, & Alen, 1987; Stone et al., 2000; Willougby, 1993). However, it is not possible to determine if the strength gains were related to the additional exercises used because these exercises were held constant while other variables were manipulated (load, volume, rest period, etc.). In contrast, Wilson (1996) found that maximal strength improved after eight weeks of training squat and bench press twice per week without addition of assistance exercises. Zourdos and Kim (2012) found that highly trained powerlifters training squat and bench 3 days per week were able to improve 1RM squat and bench without additional exercises. These findings imply that additional exercises are unnecessary to induce gains in 1RM strength in recreationally and highly trained males. Harris et al. (2000), who varied the assistance work for each group based on the mode (strength-speed, high force, or a combination), found that the training adaptation that took place corresponded to the training mode. This shows that additional exercises should vary depending on the training mode. For example, a jerk would be an appropriate exercise for a speed-strength phase, whereas a strict overhead press would be an appropriate exercise for a strength phase.

Effect of Training Status on Strength Gains

It is well established that during the initial phases of a resistance-training program, untrained individuals markedly improve strength measures primarily from neurological adaptations (Sale, 1988). The reason hypertrophy may lag behind neural factors is that learning to reach maximal exertion must be achieved before a sufficient intensity can be produced. The neural adaptations are followed by gains in hypertrophy that continue so long as training volume and intensity are appropriately manipulated (Stone et al., 2007). The alterations in strength are dependent upon individual training status as well as their previous and current training blocks.

The vast majority of training studies include partial lifts in the training program (Campos et al., 2002; Harris et al., 2000; Kraemer et al., 2000; Kraemer et al., 2003); however, there is a paucity of research examining the efficacy of partial lifts in maximal strength training. Partial lifts provide variation to training programs avoiding accommodation and stagnation among experienced lifters (Mookerjee & Ratamess, 1999). Partial lifts may also be incorporated to increase the volume-load of a training phase and to provide a novel stimuli. However, it is unknown whether it is best to increase the volume of the core exercise or incorporate additional exercises if the goal is to improve 1RM on a particular lift. One-repetition maximums may depend heavily on the training status of the individual (Campos et al., 2002; M. H. Stone, Potteiger, & Pierce, 2000). Untrained individuals may benefit more from increasing the volume of the core exercise to allow for more practice, whereas highly trained individuals may benefit from the additional volume-load and variation provided by partial lifts.

As discussed previously, untrained individuals are likely to improve strength regardless of the strength training program used (Campos et al., 2002). Thus, to examine the efficacy of partial lifts it would be necessary that the participants involved have prior training experience on the core lifts. However, that is not to say experienced lifters would not benefit from higher volumes on the core lifts. Zourdos and Kim (2012) found that highly trained powerlifters improved the 1RM on bench press, and squat by 9.3% and 5.5%, respectively. These improvements occurred after training both lifts 3 days per week for 6 weeks without any additional lifts.

Campos et al. (2002) divided 32 untrained males into four groups: control (no training), low repetitions (3-5RM), intermediate repetitions (9-11RM) and high repetitions (20-28RM). After 8 weeks of training 2 to 3 days per week, all three groups significantly improved 1RM squat and leg press over the control condition; however, within group analysis revealed that the low rep group improved more. This study demonstrates that regardless of RM range selected untrained individuals will improve lower body strength; however, heavier loading in the low rep group produced superior results. As mentioned previously, Harris et al. (2000) divided 42 collegiate football players into three groups. The speed-strength group was the only group that did not improve 1RM squat. The lack of improvement may have been due to the relatively low training load (30% to 40% 1RM) used during the training intervention. This study showed that individuals with more training experience require more variation to produce further adaptations. Therefore, a sequenced approach to training including strength-endurance, strength, and speed-strength can optimize strength measures as well as measures of agility and power for trained individuals (Stone et al., 2007). In contrast, untrained individuals do not require as much variation to incur strength adaptations. Thus, less trained individuals will yield larger physiological gains after shorter periods of training (Apel, Lacey, & Kell, 2011).

Strength Training Recommendations and Strategies

One-RM strength heavy loads (≥85% 1RM) must be lifted for two to six sets of ≤six repetitions per set for core exercises (i.e., squat, bench, deadlift) to foster improvements (Baechle & Earle, 2000). This recommendation may be over simplified because increases in strength are a function of neurological as well as muscular adaptations. The most important mechanisms related to maximal strength are physiological CSA of a muscle and total CSA of type II fibers (Thorstensson, 1977). Higher training volumes are associated with significantly increased CSA (Hather, Tesch, Buchanan, & Dudley, 1991; McDonagh & Davies, 1984). Therefore, in order to improve maximal strength, phases including higher volume-loads are pertinent.

Consistent training too long with heavy loads (>80% 1RM) may cause stagnation or a decrease in the 1RM (Fry et al., 2000; Hakkinen, Pakarinen, & Alen, 1987). There is some conflicting evidence showing that gains in strength can be made while consistently training with heavy loads three times per week as long as volume-load is carefully manipulated during the training program (Zourdos & Kim, 2012). These findings were observed with well-trained lifters who adapted to higher training frequencies. Theoretically, if an individual is able to train at higher intensities with greater frequency, the individual may increase motor unit recruitment, increase rate coding, and thereby increase maximal strength (Plisk & Stone, 2003).

An important strategy to avoid staleness resulting from training an exercise for long periods is deletion and re-presentation. This involves removing an exercise from the program and reinserting it several weeks later (Stone et al., 2007). Deleting an exercise from a training program for too long may cause the loss of intramuscular coordination and detraining of the musculature involved in the lift. Thus, it is advised that the exercise supplemented involve a similar movement pattern to satisfy specificity demands. Another option is offset loading where the volume load of one exercise is decreased across a block while the other is increased. This is important in the sport of powerlifting where both the squat and deadlift are performed in competitions (Stone et al., 2007). There is muscle group cross-over in these lifts, therefore decreasing volume-load in the deadlift while simultaneously increasing volume-load in the squat will allow for more optimal gains in both lifts over the training cycle. This will allow for an appropriate distribution of work while avoiding excessive fatigue.

Another strength training strategy is the use of cluster sets, which are sets with small rest periods between repetitions (Haff et al., 1997). This may be more relevant with pulling exercises because the weight rests on the ground rather than the lifter (such as in the squat or bench). The advantages of this method include short rest periods that can allow heavier loads to be used, and greater force, power, and velocity can be maintained throughout a set. This method may be particularly advantageous for intermediate and advanced lifters (Roll & Omer, 1987).

An often forgotten but important psychological strategy is manipulation of arousal levels. The inverted-U theory proposed by Yerkes and Dodson states that arousal facilitates performance up to an optimal level beyond which further increases in arousal reduce performance (Yerkes & Dodson, 1908). Arousal varies from person to person and from task to task. As an individual becomes more familiar with a skill the better the individual can perform at less or greater than optimal arousal. Extroverts require heightened stimulation because of their tendency to dampen arousal, while introverts require lower levels of stimulation because of their tendency to increase arousal (Eysenck, 1967). Regardless of personality type, in order for an individual to properly control his or her arousal the individual needs to be in a nonanxious state (Baechle & Earle, 2000). Simple skills can tolerate a higher degree of arousal because they have few task-relevant cues to monitor (Oxendine, 1970). For example, performing a machine bicep curl may tolerate higher levels of arousal as compared to a clean and jerk due to the lower degree of motor control required.

Efficacy of Partial Lifts in Strength Training

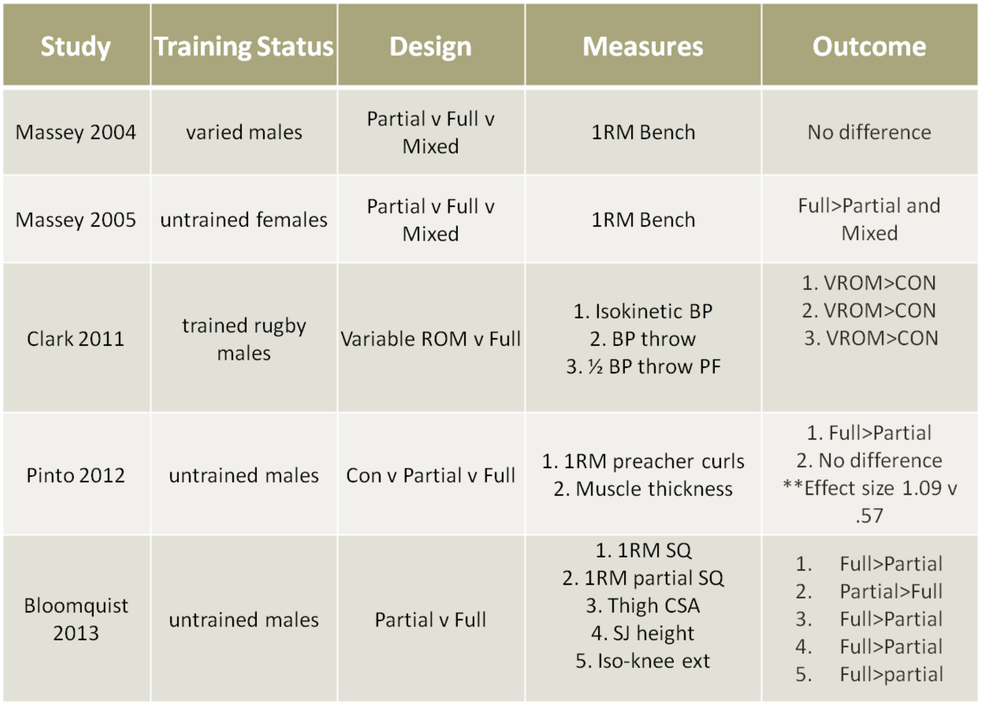
The inclusion of partial lifts in training programs has been prevalent for decades as a means to optimize training. Some examples are a bench lockout, rack pulls, and quarter squats. There is currently no formal definition for partial lifts. Massey et al. (2004) describes a bench lockout as the final 5.1 to 12.7 cm of a lift. However, lifters often perform lockouts from different positions, some lower than 12.7 cm depending on the location of one’s sticking point. Pinto et al. (2012) had participants perform preacher curls in their optimal elbow flexion strength curve. Clark et al. (2011) had lifters perform bench press at ¼, ½, and ¾ ROM. Bloomquist et al. (2013) had the partial ROM group perform squats to 60° of knee flexion (with full extension being 0°). While assistance exercises (such as dumbbell flys or tricep extensions) are generally performed to increase work capacity; partial lifts have a more skill-oriented role and are often performed to improve weak portions of a lift (e.g., bench lockouts to improve strength through the terminal ROM of the bench press). Partial lifts are commonly incorporated into training programs to increase maximal strength, impulse, RFD, and volume of training; however, research on the topic is lacking and past studies show conflicting results (Clark et al., 2011; Massey et al., 2004; Pinto et al., 2012).

In the first peer-reviewed study on partial lifts, Graves et al. (1989) randomly assigned 28 males and 31 females to three conditions and a control condition that did not train. All three groups trained bilateral knee extensions 2 to 3 days per week for 10 weeks. Group A trained in a ROM limited to 120-60°, Group B trained in 60-0°, Group AB trained through a full ROM. Isometric strength gains for Group AB were similar throughout the entire ROM, whereas strength gains for Groups A and B were greater in the trained than in the untrained ROM. In addition; there was no statistical difference between control and Group A at 9° and 20°, and no difference between control and Group B at 95°. These findings along with other corroborative data (Massey et al., 2004; Pinto et al., 2012; Sale & MacDougall, 1981; Wilson et al., 1996) suggest that strength gains are specific to the ROM trained. Graves et al. (1992) follow-up study tested lumbar extension isometric strength pre- and posttraining. In contrast to their previous findings, Graves reported no statistical difference in isometric strength between full ROM and limited ROM groups at any angle. It is important to note that in this study, participants only trained one day per week. Training 1 day per week may not have provided a large enough training stimulus to elicit differences between groups as was observed in their previous study where participants trained 2 to 3 days per week.

Few training studies on partial lifts have analyzed changes in 1RM (Bloomquist et al., 2013; Massey et al., 2004; Pinto et al., 2012). In these studies training status, study design, exercise performed, and outcome all varied (Table 2.1). Massey et al. (2004) divided untrained and recreationally trained males into three groups, full ROM, partial ROM and mixed ROM. All groups trained twice per week for 10 weeks. The full ROM group performed three sets of 15 full ROM bench presses, partial performed three sets of 15 partial ROM bench presses (5.1 to 12.7 cm from lockout), and mixed ROM group performed both full and partial repetitions. All three groups improved 1RM bench; however, there was a significant difference in 1RM between groups at the beginning of the study with the mixed ROM group being stronger than the others. This may explain why the mean increased by 11.4 kg in the full ROM and partial ROM groups and only 7.5 kg in the mixed ROM group. These findings suggest that partial lifts can positively influence the development of maximal strength in untrained and recreationally trained males. The results may have been confounded by the broad range of training experience and strength levels and the ambiguity of partial lifts (5.1 to 12.7 cm from lockout). There was also no attempt to equate work between groups and the partial bench 1RM was not tested.

Table 2.1

Previous Research



Study	Training Status	Design	Measures	Outcome
Massey 2004	varied males	Partial v Full v Mixed	1RM Bench	No difference
Massey 2005	untrained females	Partial v Full v Mixed	1RM Bench	Full>Partial and Mixed
Clark 2011	trained rugby males	Variable ROM v Full	1. Isokinetic BP 2. BP throw 3. ½ BP throw PF	1. VROM>CON 2. VROM>CON 3. VROM>CON
Pinto 2012	untrained males	Con v Partial v Full	1. 1RM preacher curls 2. Muscle thickness	1. Full>Partial 2. No difference **Effect size 1.09 v .57
Bloomquist 2013	untrained males	Partial v Full	1. 1RM SQ 2. 1RM partial SQ 3. Thigh CSA 4. SJ height 5. Iso-knee ext	1. Full>Partial 2. Partial>Full 3. Full>Partial 4. Full>Partial 5. Full>partial

Furthermore, Massey et al. (2005) performed a follow-up study with untrained females using the same protocol and found the full ROM group increased 1RM bench over the partial

ROM and the mixed ROM groups (25.4lb vs. 16.9lb vs. 16.3lb, respectively). These findings are in agreement with Pinto et al. (2012) who found the full ROM group improved over the partial ROM group after training preacher curls twice per week for 10 weeks. The partial ROM group performed preacher curls through the ROM near the optimal angle of the elbow flexion strength curve while the full ROM group performed preacher curls through a full ROM. They also reported magnitude of the treatment effect for muscle thickness was twice as large in the full ROM group compared to the partial ROM group (1.09 vs. 0.57), while the p-value was near significance (p=0.07). In regards to work performed, the partial ROM group lifted 36% heavier loads than the full ROM group; however, there was no attempt to equate mechanical work between groups.

It is clear from the findings of Sullivan et al. (1996), Pinto et al (2012), and Clark et al. (2011) that greater torque is produced during partial lifts compared to full ROM. This is because the load used for full ROM training is limited by the sticking point. Thus, Zatsiorksy (1995) and Clark et al. (2012) reasoned that partial lifts train different segments of a lift allowing for greater control of external loads at different countermovement positions. Clark and colleagues stated that the improved control of external loading coupled with greater force production at different countermovement positions may result in enhanced sport performance and decrease injury risks (Clark et al., 2012).

In order to determine if training with partial lifts results in longitudinal performance gains, Clark et al. (2012) divided 22 rugby players into a variable ROM (VROM) and full ROM group. Both groups trained bench press twice per week during a 5-week training intervention. VROM performed sets in the following order: 1- full ROM, 1- ¾ ROM, 1- ½ ROM, 1- ¼ ROM, 1- full ROM (second day order was reversed to cross-over) while the full ROM group performed four sets through a full ROM. They found no statistical difference between groups in iso-bench at ¼ ROM. VROM improved over the full ROM group in iso-kinetic bench at 45° per second (particularly in the terminal portion of the movement), ½ ROM bench press throw peak force and full ROM bench press throw bar displacement. There was no significant change in any of these measures for the full ROM group except for a significant improvement in iso-bench at ¼ ROM (the authors suggested this was possibly because of familiarization). These findings suggest that VROM training improves force production during the terminal ROM of a lift as evidenced by the isokinetic data. The increase in peak force with the ½ ROM bench press throw also suggests enhanced mid-ROM reactive strength (Clark 2012). This study provides novel insights into the effectiveness of partial lifts in an athletic population. Further research is needed in order to elucidate the underlying mechanisms lending to the performance gains and whether gains will transfer to other sport-specific tasks (e.g., running, jumping, throwing).

In a more recent study by Bloomquist et al. (2013), researchers compared full ROM training to partial ROM training in 17 untrained males. They found a 20% increase in 1RM squat and 1RM partial squat in the full ROM group (0-120° knee flexion), and a 9% and 36% increase in 1RM squat and partial squat, respectively, in the partial ROM group (0-60° knee flexion). The full ROM group significantly increased 1RM squat over the partial ROM group, and the partial ROM group significantly improved partial 1RM squat over the full ROM group. Additionally, they found full ROM training resulted in superior increases in front thigh muscle cross-sectional area, squat jump (SJ) performance, LBM of the legs, and isometric strength at 75° and 105° of knee extension. Interesting to note, the partial ROM group only improved front thigh muscle cross-sectional area at the two most proximal sites. No significant differences between groups were observed for muscle thickness, pennation angle, collagen cross sectional area or synthesis, and countermovement jump height. These results strongly support the specificity of ROM in training adaptations. The authors suggest that the larger muscle–tendon forces over the knee joint, greater internal work produced, and longer muscle length of the knee extensors are the primary explanations for the superior adaptations in the full ROM compared to the partial ROM training group. It is important to note, however, that although groups performed a similar training program (matched repetitions and %1RM), no attempt was made to calculate or equate work between the two groups. It was assumed that because the external moment arm is about twice as long when the femur is parallel to the ground compared to the 60° of knee flexion performed by the partial ROM group (also load used was twice as large as the full ROM group), that the force on muscle-tendon system was similar between groups. Nevertheless, this has been the only known training study that measured 1RM partial squat, muscle CSA, pennation angle, collagen cross sectional area and synthesis, and jump performance. The results suggest that partial ROM training alone results in inferior adaptations as compared to full ROM training in untrained males. This, however, does not rule out the efficacy of partial ROM in conjunction with full ROM training in more well trained populations.

Examining the findings from the aforementioned studies makes it unclear whether partial lifts augment full ROM 1RM strength. Studies by Massey et al. (2004, 2005) show conflicting results for untrained participants showing no significant difference between partial ROM and full ROM training, and full ROM greater than partial ROM training. Pinto et al. (2012) and Bloomquist et al. (2013) found greater improvements in 1RM for full ROM training; however, work was not equated between groups and the partial ROM groups did not perform full ROM training. In order to fulfill specificity requirements the partial ROM group should continue with full ROM training if the training goal is to improve 1RM in a full ROM. Additionally, these studies only researched untrained participants while multiple studies state that partial lifts, if effective, would benefit lifters with previous training experience (Clark et al., 2011; Massey et al., 2004; Mookerjee & Ratamess, 1999). The question remains are partial lifts effective in improving 1RM in a full ROM?

Maximal Strength Testing

Isometric Tests of Maximal Strength

As established previously, in order for an isometric test to transfer to a dynamic movement there must be a high degree of task specificity (movement pattern, velocity, and magnitude of contraction) (Kawamori et al., 2006). Without intermuscular task specificity it is not probable that the test will be valid. Isometric testing may provide a sufficient alternative to dynamic maximal strength tests because the protocol results in less fatigue and can be performed in a shorter time.

A few studies have been done to ascertain the joint angles the isometric tests should be performed in order to see correspondence with dynamic movement. Smidt (1973) reported that the knee extensors produce peak isometric torque at 120° of knee extension. Therefore, in order to use an isometric test that correlates strongly with a dynamic movement, joint angles of the isometric test must correspond to the joint angles in the dynamic movement in which force output is the highest.

Another important consideration is the position in the lift when mechanical advantage is the lowest (sticking points). Blazevich et al. (2002) found that isometric squats performed at 90° of knee flexion are highly correlated ($r=0.77$) with 1RM squat (depth was 90° of knee flexion). This knee angle is considered to be the sticking point in the squat. According to the findings above, an isometric squat performed at 90° and 120° should provide a strong indication of the dynamic 1RM squat.

Dynamic Tests of Maximal Strength

The gold standard for assessing lower body maximal strength is 1RM squat. The 1RM squat has been used in numerous studies to assess strength in untrained, recreationally trained, and highly trained individuals (Campos et al., 2002; Harris et al., 2000; Willougby, 1993; Wilson et al., 1996). The 1RM squat is often used to assess dynamic maximal strength because of its high degree of specificity with training exercises. The addition of force plates in the testing procedure has been used to assess kinetic and kinematic aspects of the squat (Rahmani, Viale, Dalleau, & Lacour, 2001).

While the tests are reliable, the protocols used to assess 1RM squat are highly variable. For example, some studies had the participants perform squats to 90° while others had participants descend until the top of their thigh was parallel to the ground (Blazevich, Gill, & Newton, 2002). Some studies only reference that a 1RM protocol was performed, while others gave a brief outline on the test protocol. There is a considerable amount of research on the rest time between sets in a training program; however, there is no research stating the optimal rest time between attempts at the 1RM determination (Willardson, 2006). Additionally, there is no research stating the appropriate adjustments in weight prior to attempts, between attempts, or after a failed attempt. Further research is needed to formulate a standard 1RM protocol for the squat.

Aside from the variety of protocols used to assess 1RM strength there is an abundance of research to support its use as an assessment of strength changes throughout a training program

(Campos et al., 2002; Harris et al., 2000; Kraemer et al., 2000; Kraemer et al., 2003; Stone et al., 2000; Willougby, 1993; Wilson et al., 1996). This may be due to the high degree of intermuscular task specificity between the movements performed and the 1RM test. A downside, however, is that 1RM tests have a high metabolic cost, they are fatiguing, and require a high level of skill compared to isometric tests. Nonetheless, the 1RM tests are still considered the best assessment of maximal strength and are the tests most commonly used in training studies (Baechle & Earle, 2000).

CHAPTER 3

EFFICACY OF PARTIAL ROM SQUAT IN MAXIMAL STRENGTH TRAINING

Original Investigation

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Abstract

Eighteen well trained males (1RM Squat: 150.57 ± 26.79 kg) were assigned to 2 groups: full ROM training (control) and full ROM with partial ROM training (CP) for the 7-week training intervention. There was a significant time effect ($p<0.05$) for 1RM squat, 1RM partial squat, IPFa 90°, IPFa 120° and impulse at 90ms, 200ms, and 250ms at 90° and 120° of knee flexion. There was a significant interaction for RFD 200ms at 120° and a near significant interaction for 1RM squat scaled ($p=0.07$). There was a trend for CP to improve over control in 1RM squat (+2.3%), 1RM partial squat (+4.1%), IPFa 120° (+5.7%), and impulse scaled at all time points for 90° (+6.3-11.9%) and 120° (3.4-16.8%). Our findings suggest that partial ROM squats in conjunction with full ROM squats may be an effective training modality for improving maximal strength and early force-time curve characteristics in well-trained males.

Introduction

In the strength and conditioning profession, partial lifts have been incorporated into training programs (Clark et al., 2008, Clark et al., 2011; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Stone, Potteiger, & Pierce, 2000). Some of the proposed benefits are improved strength at the terminal ROM of a movement, improve weak portions of a movement, substitute for full ROM exercise during rehabilitation, injury prevention, enhance metabolic adaptations, increase training volume, provide variation in training, and enhance sport performance (Clark et al., 2008, Clark et al., 2011; Massey et al., 2004; Massey et al., 2005; Mookerjee & Ratamess, 1999; Pinto et al., 2012; Zatsiorsky, 1995) . There are only a few studies that directly examine their efficacy in improving maximal strength (Bloomquist et al., 2013; Graves et al., 1989; Graves et al., 1992; Massey et al., 2004; Mookerjee & Ratamess, 1999; Pinto et al., 2012), and the findings of these studies are conflicting.

Graves et al. (1989) had untrained males and females perform leg extensions once per week for 10 weeks and found groups that trained with a partial ROM had greater gains in isometric strength in the trained ROM than in the untrained ROM. The group that trained through a full ROM improved isometric strength equally at all joint angles. Massey et al. (2004) compared full ROM with partial ROM and reported an improved 1RM bench press in both groups after training twice per week for 10 weeks with no significant difference between groups. In contrast, Pinto et al. (2012) compared full ROM vs. partial ROM and found that after 10 weeks of training twice per week, the full ROM group significantly increased 1RM strength on preacher curls over the partial ROM group. Additionally, Pinto reported effect sizes for muscle thickness of 0.57 and 1.09 in the partial and full ROM groups, respectively. Considering the lack of consistency in the design and results of the aforementioned studies, further research is warranted.

Previous research has well documented the specificity of ROM in strength training with adaptations incurred being specific to the ROM trained. Bloomquist et al. (2013) only found significant improvements for the partial group in front thigh muscle CSA at the most proximal sites, whereas the full ROM group improved at all sites. They also found full ROM group significantly increasing 1RM squat over the partial; however, the partial ROM group significantly improved partial 1RM squat over the full. Clark et al. (2011) reported similar findings, where the group training at varying ROM of the bench press improved over full ROM in iso-kinetic bench at 45° per second the terminal portion of the movement, ½ ROM bench press throw peak force and full ROM bench press throw displacement. Additionally, Graves et al. (1989) found isometric strength gains for the full ROM knee extension group were similar throughout the entire ROM at all knee angles tested, whereas strength gains for partial ROM groups were greater in the trained than in the untrained joint angles tested. In fact, post-intervention isometric strength measured at untrained knee angles was similar to the control group that did not train. These results strongly support the specificity of ROM in training adaptations.

Therefore, we hypothesized that both groups would improve from pre to post-intervention on all dynamic and isometric variables measured; however the FP would improve over F at measurements associated with the terminal ROM (1RM partial squat, 120° isometric squat peak force, RFD and impulse scaled at all time points).

Purpose

The purpose of our study was to examine the effects of two different training modalities, full ROM training (control) and full ROM with partial ROM training (CP), on well-trained males during a seven-week training intervention. The study included measurements of 1RM squat, 1RM partial squat, and maximal isometric squat at 90° and 120° of knee flexion.

Methods

Participants

Eighteen well trained college males between the ages of 18 and 28 with at least one year of resistance training experience and ability to squat at least 1.3 x body weight (BW) volunteered for the study. Participants must have completed 80% of the programmed work. (Stone et al., 2000). Descriptive statistics for all participants can be found in Table 3.1. Participants were primarily recruited from the strength and conditioning courses offered at East Tennessee State University. Students were informed of the study at the beginning of the spring semester. Those who volunteered and met the above criteria were selected. Students who volunteered were assigned extra credit for the class. To ensure equal treatment, students who did not volunteer were offered alternative options for receiving extra credit. All participants signed an informed consent and completed a health history questionnaire before taking part in the study. The study was approved by the East Tennessee State University Institutional Review Board.

Table 3.1

Participant Characteristics

	Control	CP
Age (years)	20.77 ± 1.99	20.67 ± 1.87
Height (cm)	176.44 ± 6.25	177.56 ± 8.09
Body Mass (kg)	84.88 ± 10.92	86.06 ± 8.94
Body Fat %	22.14 ± 8.52	20.82 ± 11.96
1RM Squat (kg)	148.93 ± 23.70	152.21 ± 30.94
1RM Partial Squat (kg)	207.90 ± 30.77	223.27 ± 55.57
IPFa 90 (N/body mass$^{0.67}$)	107.51 ± 6.97	114.87 ± 13.60
IPFa 120 (N/body mass$^{0.67}$)	196.71 ± 38.24	210.73 ± 35.13

**data presented in mean ± SD*

Experimental Conditions

The experiment was a counterbalanced design with one control group and one experimental group. The control group performed only full ROM squat exercise, whereas the experimental group performed the full ROM squat with a partial ROM squat. Anthropometrics, 1RM squat and 1RM partial squat were measured during the weeks four and twelve dynamic testing sessions. Isometric squat peak force, RFD and impulse at 50, 90, 200, and 250ms were also assessed at the same time during the isometric testing session.

Testing Procedures

Participants were asked to abstain from all physical activity 24 hr prior to each testing session. They were also instructed to complete a dietary log for the 24 hr prior to the first testing session and to replicate the log for all testing sessions thereafter. Participants reported to the laboratory on day one of weeks four and twelve at pre-designated times. After the protocol was explained anthropometric measurements were obtained. Body composition was measured via skinfolds with Lange calipers (Cambridge Scientific Industries, Cambridge, MD) and the sum of seven skinfolds (Ball, Altena, & Swan, 2004). Participants proceeded to the dynamic warm-up followed by dynamic measurements on day one and isometric measurements on day two. Tests were performed as follows: day one- 1RM squat and partial squat at 100° of knee flexion, day two- isometric squat at 90° and 120° of knee flexion. Participants rested 72-96 hr between testing sessions. Isometric measures of peak force, RFD, and impulse were determined by uniplanar force plates collecting at 1000Hz (0.91 m x 0.91 m; Rice Lake Weighing Systems, Rice Lake, WI, USA), data were smoothed using a moving average of 11 data points (all data points equally weighted) and analyzed with Labview software (ver. 2010, National Instruments, Austin, TX, USA). Because of diurnal variations in maximal strength, participants were tested at the same time of the day for both test days (Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988).

Dynamic Strength Assessment. The 1RM squat was chosen to determine dynamic maximal strength because it was the primary exercise performed during the training program. Partial squat at 100° was chosen because it is above the typical “sticking point” allowing for supra-maximal loads to be lifted during training (Zatsiorsky, 1995). The 1RM protocols involved a progressive increase in load and decrease in repetitions per set, modified from McGuigan et al. (2006). The protocol consisted of five repetitions at 30% of the 1RM followed by 2 min rest (1RM was estimated from previous training), 5 repetitions at 50% followed by 2 min rest, 3 repetitions at 70% followed by 3 min rest, and 1 repetition at 90% followed by 3 min rest. Attempts were selected with the goal of reaching their max in three attempts. Participants were given 4 min of rest between each attempt.

The 1RM partial squat began 3-5 minutes after the 1RM squat. The warm-up protocol for the partial squat began with three repetitions at squat 1RM followed by 3 min rest, and 1 repetition at 120% followed by 3 min rest. Attempts were selected with the goal of reaching their max in 3 attempts. Participants were given 3-4 minutes rest between attempts. In all tests, verbal encouragement was given to obtain a maximal effort.

Testing criteria for the squat was determined using USAPL rules (USAPL & IPF Administrators, 2001). Back squat depth was determined as the top of the leg at the hip joint arriving below the knee. For the partial squat, the bar was set on the safety pins at the height corresponding to 100° of knee flexion as determined during familiarization sessions. The participant performed the concentric portion of the squat to a full lockout position then lowered the bar back down to the safety pins. This was done to avoid injury from trying to move supra-maximal loads from the rack to the starting position. Figure 3.1 shows an example of squat and partial squat position used for the study.

Figure 3.1. Squat and Partial Squat Positions

Isometric Strength Assessment. For isometric squat, participants performed two warm-up attempts at 50% and 75% maximal effort followed by 2 min rest. After the rest period, at least two maximal efforts were performed with at least 3 min rest between. Isometric squat testing was performed at 90° and 120° of knee flexion (Blazevich, Gill, & Newton, 2002). Knee flexion and bar height were recorded to ensure the same position in subsequent testing sessions. The bar was placed across the back in the same position used in training and placed against two metal stops to prevent upward movement (Figure 3.2). The tester instructed participants to push "as fast and as hard as possible" (Holtermann et al. 2007). The tester shouted 'push' and participants pushed maximally into the ground until peak force was reached when the tester shouted 'stop' to end the test. As with dynamic testing, verbal encouragement was be given to obtain a maximal effort.

Figure 3.2. Isometric Squat Positions (90° and 120°)

Training Protocol

Both conditions followed a block-periodized model in order to control for volume and intensity fluctuation (Stone et al., 2007). All participants trained for three weeks in a strength-endurance phase. During this phase, all participants were familiarized with partial lifts and isometric tests to minimize the influence of learning during testing. The strength-endurance phase was followed by pre-testing (week 4), strength phase 1 (weeks 5-7), de-load (week 8), strength phase 2 (weeks 9-11) and post-testing (week 12). During the intervention, work performed was estimated for each participant using the following equation (Clark et al., 2008):

$$\textit{Work (kg} {}^{\bullet} \textit{m) = Mass of the external load (kg) x Displacement (m) x Repetitions}$$

Displacement for squat and partial-squat was measured manually each week during the study. Test-retest reliability for squat displacement possessed an ICC of 0.97.

Strength-Endurance Phase. All participants performed three weeks of high volume training prior to the training intervention. The goal of the strength-endurance phase was to equilibrate the training program for all participants and to minimize residual effects from previous training (Fry et al., 2000). For example, Harris et al. (2000) had collegiate football players perform four weeks of high volume training prior to the training intervention. Considering the training status of our sample, participants only trained high volume for three weeks. Load used for squats was based off estimated 1RM (Baechle & Earle, 2000). There was a 10-15% difference in load between heavy and light days. Twice per week, the participants were familiarized with partial and isometric squat to prepare for testing. The safety pin heights and bar displacements for squat and partial squats were recorded for subsequent training and testing sessions. The training protocol, including exercises, sets, reps, load (%1RM), are detailed in Appendix C.

Strength Phase I. Following week 4, testing participants were assigned to either condition based on absolute and relative strength to control for strength and training differences between groups. During Strength Phase 1, the loads for the squat and partial squat were calculated using %1RM. Both conditions trained with heavy and light days in order to manage fatigue and avoid training to failure (Stone et al., 2000). Rest periods of three to five minutes were given in between sets and between exercises. Details of this phase can be viewed in Appendix C.

De-Load. Following strength phase 1, there was a programmed de-load during week 8. A de-load is a planned decrease in the volume-load of a training program usually inserted between training blocks. The primary purpose was to dissipate fatigue from previous training and allow for the ‘realization’ of strength gains made during the previous training period (Stone et al., 2007). According to the fitness-fatigue paradigm, fatigue from training and other variables ‘masks’ gains in fitness. Thus, fitness is not realized until the training load is reduced and fatigue dissipates. Fatigue declines more rapidly than fitness; however, each fitness ability has a different rate of decline. Maximal strength has a low rate of decline (Fry et al., 2000); therefore it is unlikely that a one week de-load caused a net loss in fitness (maximal strength). On the contrary, the de-load week may have allowed for supercompensation and subsequently enhanced maximal strength. Because the three weeks of strength training caused an accumulation of stressors the insertion of a de-load week allowed for fatigue to dissipate and fitness to be realized in the next training cycle: Strength Phase 2. Load for squat and partial squat were calculated using %1RM. Details of the de-load week can be viewed in Appendix C.

Strength Phase II. Following the de-load, participants began the final block of training. This phase further emphasized training with loads >85% 1RM in order to recruit higher threshold motor units and increase rate coding. Both of these variables tend to improve neuromuscular control with heavier loads, directly contributing to 1RM strength. Details of this phase can be viewed in Appendix C. The following week, participants completed the study with post-testing.

Statistical Analysis

The force-time curve data analyzed for this study were computed directly using Labview software. The average of two attempts on the isometric squat at 90° and 120° were used for analysis. Anthropometric, dynamic and isometric testing data for each group were reported with mean and standard deviation. A 2x2 repeated measures ANOVA was used to compare the differences between training groups for dependent variables. A paired sample t-test and one-way ANOVA were calculated to determine within and between group differences for all dependent variables. SPSS software was used to perform all statistical analysis, (IMB Co., NY, USA).

Results

Participants and Anthropometric Data

Two participants dropped out of the study prior to the training intervention and one participant in the control was not able to complete post-testing due to knee pain. Thus, eighteen participants were included in the final data analysis. There was no significant difference ($p<0.05$) between groups during pre and post testing for any of the anthropometric variables. A time effect was found for body fat percentage. Both groups improved body composition from pre to post testing. Body fat percentage decreased from 22.14 ± 8.52 to 19.86 ± 8.9% and 20.82 ± 11.96 to 19.68 ± 11.39% in the control and CP groups, respectively. Descriptive statistics, homogeneity of variances, repeated measures and paired t-tests for all anthropometric variables can be seen in Appendix D.

Dynamic Strength Assessment

1RM Squat. No group by time interaction was found for 1RM squat or 1RM squat allometrically scaled. However, 1RM squat scaled was near significant ($p=0.073$). A significant time by 1RM squat and 1RM squat scaled interaction ($p<0.001$) was found. The mean values for 1RM squat in control increased from 148.93 ± 23.71 to 156.58 ± 23.86 kg (+5.1%) and in the CP from 152.21 ± 30.94 to 163.55 ± 29.45 kg (+7.4%). The mean values for 1RM squat scaled in control increased from 7.69 ± 0.65 to 8.10 ± 0.66 $\text{kg}^{\cdot}((\text{body mass}^{0.67})^{-1})$ (+5.3%) and in the CP from 7.80 ± 1.35 to 8.40 ± 1.34 $\text{kg}^{\cdot}((\text{body mass}^{0.67})^{-1})$ (+7.7%). Mean values with percent change for 1RM squat and 1RM squat scaled for each group can be seen in Appendix E.

1RM Partial Squat. No group by time interaction was found for 1RM partial squat or 1RM partial squat scaled. A significant time interaction ($p<0.001$) was found for both 1RM partial squat and 1RM partial squat scaled. The mean values for 1RM partial squat in control increased from 207.90 ± 30.76 to 229.16 ± 48.79 kg (+10.2%) and in the CP from 223.27 ± 55.57 to 255.30 ± 60.49 kg (+14.3%). The mean values for 1RM partial squat scaled in control increased from 10.77 ± 1.24 to 11.87 ± 2.08 kg·((body mass$^{0.67}$)$^{-1}$) (+10.2%) and in the CP from 11.45 ± 2.52 to 13.11 ± 2.81 kg·((body mass$^{0.67}$)$^{-1}$) (+14.5%). Mean values with percent change for 1RM partial squat and 1RM partial squat scaled for each group can be seen in Appendix E.

Isometric Strength Assessment

Isometric Squat Peak Force Scaled. No group by time interaction was found for IPFa at 90° or 120° of knee flexion. A significant time by IPFa 90° and IPFa 120° interaction was found. The mean values for IPFa 90° in control increased from 107.51 ± 6.96 to 113.16 ± 8.51 N·((body mass$^{0.67}$)$^{-1}$) (+5.3%) and in the CP from 114.85 ± 13.60 to 116.32 ± 12.81 N·((body mass$^{0.67}$)$^{-1}$) (+1.3%). Paired t-test results indicated that the increase for CP from pre-training was not statistically significant ($p=0.47$). The mean values for IPFa 120° in Control increased from 196.72 ± 38.24 to 201.45 ± 39.47 N·((body mass$^{0.67}$)$^{-1}$) (+2.4%) and in the CP from 210.74 ± 35.13 to 227.74 ± 31.66 N·((body mass$^{0.67}$)$^{-1}$) (+8.1%). Paired t-test results indicated that the increase for control from pre-training was not statistically significant ($p=0.32$). Test-retest reliability using ICC for IPFa 90° and 120° was 0.97 and 0.98, respectively. It is important to note that homogeneity of variance assumption for IPFa 90° was not met ($p=0.02$) indicating that although reliability of the test-retest exists, the magnitude of variances between groups were present for IPFa 90°. Mean values with percent change for IPFa 90° and IPFa 120° for each group can be seen in Appendix E.

Isometric Squat Impulse Scaled. No group by time interaction was found for impulse at 90° or 120° of knee flexion for any time measured (50, 90, 200, 250ms). A significant time interaction was found at all tests for both knee angles except for 50ms at 120° (p=0.06). Paired t-tests showed significant increases from pre-training in CP for all time points at 90° and 120°, but for Control only at 250ms 120° (p-values for impulse can be found in Appendix D). The mean values for impulse at 200ms for 90° in Control increased from 13.96 ± 1.49 to 14.77 ± 1.58 $N \cdot ((\text{body mass}^{0.67})^{-1})$ (+5.8%) and in the CP from 14.11 ± 2.41 to 15.99 ± 2.56 $N \cdot ((\text{body mass}^{0.67})^{-1})$ (+13.3%). Paired t-test results indicated that the increase for CP from pre-training was not significant. The mean values for impulse 200ms 120° in Control increased from 20.21 ± 5.14 to 22.10 ± 4.79 $N \cdot ((\text{body mass}^{0.67})^{-1})$ (+9.3%) and in the CP from 20.07 ± 3.95 to 22.75 ± 5.37 $N \cdot ((\text{body mass}^{0.67})^{-1})$ (+13.3%). Test-retest reliability was determined to be ICC >0.92 for all time points measured. It is important to note that homogeneity of variance for impulse 200, 250ms at 90° was not met (p=0.04, 0.02 respectively) indicating that although reliability of the test-retest exists, the magnitude of variances between groups were present for impulse 200, 250ms at 90°. Mean values with percent change for impulse 200ms at 90° and impulse 200ms at 120° for each group can be seen in Appendix E.

Isometric Squat Rate of Force Development. A significant group by time interaction for RFD 200ms at 120° of knee flexion was found. No significant time by knee angle interaction was found for any time points (200, 250ms) at either knee angle. The mean values for RFD 200ms at 90° in Control increased from 3414.10 ± 950.10 to 3580.9 ± 749.13 $N \cdot s^{-1}$ (+4.9%) and decreased in the CP from 3814.80 ± 854.05 to 3579.82 ± 1106.35 $N \cdot s^{-1}$ (-6.2%). The mean values for 200ms at 120° in Control increased from 5861.67± 2853.13 to 6910.70 ± 2956.08 $N \cdot s^{-1}$ (+7.9%) and decreased in the CP from 6930.23 ± 2243.61 to 6612.30 ± 1458.01 $N \cdot s^{-1}$ (-4.6%).

Paired t-test results indicated that the increase for Control from pre-training was not significant. Test-retest reliability for all time points at 90° possessed an ICC ranging from 0.74 - 0.9 and 200, 250ms at 120° ranging from 0.76 - 0.94. RFD 50 and 90ms at 120° were excluded due to low test-retest reliability (ICC<0.7). Mean values with percent change for RFD 200ms at 90° and 120° for each group can be seen in Appendix E.

Estimated Work. A one-way ANOVA showed no difference between groups for total work. The mean values for estimated work in Control group was 30842.70 ± 5972.043 kg˙m and in CP group 30484.382 ± 5589.329 kg˙m. In order to be included in the data analysis, participants were required to complete >80% or more of the programmed work. Mean values for total work for each group can be seen in Appendix E.

Results without Subject #17

Subject 17 was an outlier for all dynamic strength assessment variables because his pre-training scores were greater than two standard deviation from the mean. As a result, coefficient of variation (CV) for the CP group was inflated for all dynamic strength assessment variables. For example, CV for pre-training 1RM squat decreased from 20.33% to 15.41% when subject 17 was removed, whereas CV in the control group for pre-training 1RM squat was 15.92%.

Additionally, because the standard deviation was higher for all dynamic strength variables, effect size calculated using the formula suggested by Rhea (2004): $(\text{Mean}_{\text{post}} - \text{Mean}_{\text{pre}})/\text{Standard Deviation}_{\text{pre}}$, was drastically lower when subject 17 was included. Effect size increased by 0.11 to 0.37 for all dynamic strength variables when subject 17 was removed. However, homogeneity of variances for pre-training IPFa at 90°, impulse at 200, and 250ms at

90° were still significant when subject 17 was removed. Descriptive data, homogeneity of variances, and paired t-tests for all dependent variables are included in Appendix D.

Results for 1RM Squat over 12 Weeks

At the beginning of the study, participants were required to test 1RM squat to determine if they were eligible (T_0). If the participant was able to squat at least 1.3 x body weight and had at least one year of resistance training experience on squat they were considered eligible for the study. Participants were not assigned to the control and CP group until after Pre-intervention testing. One participant was excluded from the analysis due to a minor injury prior to the intervention that did not allow him to train for 1 week of the strength-endurance phase (n=17).

No group by time interaction for 1RM squat and 1RM squat scaled was found. As expected, there was a main effect for time. The mean values for 1RM squat in control increased from 132.68 ± 22.55 to 147.13 ± 24.68 kg (10.9%) to 154.33 ± 24.46 kg (+4.9%) and in the CP from 140.87 ± 26.24 to 152.21 ± 30.94 kg (+8.0%) to 163.55 ± 29.45 kg (7.5%). The mean values for the allometrically scaled 1RM squat in control increased from 6.95 ± 0.87 to 7.67 ± 0.69 kg (+10.4%) to 8.06 ± 0.70 kg (+5.1%) and in the CP from 7.25 ± 1.18 to 7.80 ± 1.35 kg (+7.6%) to 8.40 ± 1.34 kg (+7.8%). The percent increase in 1RM squat from T_0 to post-intervention was 16.3% and 16.1% for control and CP respectively. The percent increase in the allometrically scaled 1RM squat T_0 to post-intervention was 16.1% and 16.0% for control and CP respectively. Mean values with percent change for 1RM squat and 1RM squat scaled for each group can be seen in Appendix E.

Discussion

The purpose of this study was to examine the effects of two different training modalities, full ROM training (control) and full ROM with partial ROM training (CP), on well- trained males during a seven-week training intervention. Work was equated between groups in order to control for training load. The main findings for dynamic strength were a significant improvement in 1RM squat and partial squat in both groups with a 2.3% greater improvement in the CP group. For isometric strength, the control group significantly improved IPFa at 90° and the CP group significantly improved IPFa at 120°. There were no significant differences between groups at pre- or posttests for any variable measured.

Dynamic Strength Assessment

In the current study, mean squat to body mass ratio improved from 1.62 to 1.76 to 1.88 at T_0, preintervention and postintervention testing sessions respectively. This corresponds to a 9.3% increase from T_0 to pre-intervention, a 6.3% increase from pre- to postintervention testing, and a total increase of 16.2% over the 12 weeks (T_0 to postintervention). These findings are similar to training studies that have found increases in 1RM squat ranging from 10-20% over a 9-15 week period (Harris et al., 2000; Hoffman et al., 2009; Peterson, Dodd, Alvar, Rhea, & Fave, 2008).

The findings of this study indicate that there was a 6.3% and 12.4% improvement in overall 1RM squat and partial squat, respectively from pre- to postintervention. Compared to the only other known study examining the squat exercise in partial lift training, Bloomquist et al. (2013) found a ≈15% and 28% increase in overall 1RM squat and partial squat, respectively. The reason for the smaller increases in our findings is likely due to the difference in training status. Their study recruited untrained males (no previous training experience) and our study involved well-trained (>1.3 x body weight squat) males. Another difference was the partial ROM used. They had participants perform partial ROM to 120° of knee flexion, whereas in the present study participants performed partial squats to 100° of knee flexion.

Table 3.2

Overall Changes in Dynamic Variables Pre- to Postintervention

Variables (kg.)	**Pre-Intervention**	**Post-Intervention**
1RM Squat	150.57 ± 26.79	160.06 ± 26.25* (+6.3%)
1RM Squat scaled	7.74 ± 1.03	8.25 ± 1.04* (+6.6%)
1RM Partial Squat	215.58 ± 44.28	242.23 ± 54.99* (+12.4%)
1RM Partial Squat scaled	11.11 ± 1.96	12.49 ± 2.49* (+12.5%)

Values are in means ± standard deviation.
*p<0.05, significantly different from pre-training. N=18

1RM Squat. Although both groups significantly improved in 1RM squat and the allometrically scaled 1RM squat, there was no statistical difference between groups. These findings are in agreement with Massey et al. (2004) who found no difference in 1RM bench between full ROM training and mixed in recreationally males after training twice per week for 10 weeks. Similar to the present study, both groups improved 1RM bench from pre- to posttests. These findings suggest that partial lifts may be an effective training modality for improving maximal strength in conjunction with full ROM training.

The group by time effect was near significance for 1RM squat scaled (p=0.07). There was 2.4% difference in rate of gain in the allometrically scaled 1RM squat between groups (5.3% vs. 7.7%). This difference could be attributed to either greater fatigue in the control group resulting in reduced adaptive potential or superior adaptations in the partial ROM group or both. None of these assumptions can be affirmed from the results because there was not a third group for comparison.

1RM Partial Squat. A major drawback to past training studies on partial lifts is that, all except for one (Bloomquist et al. 2013), do not test 1RM for the partial lift. Similar to the findings for 1RM squat, both groups significantly improved 1RM partial squat from pre-training values with the rate of gain in CP being 4.1% larger than control (14.3% vs. 10.2%). Bloomquist reported a 20% and 36% increase for partial 1RM in the full ROM and partial ROM group, respectively. The increase in the partial ROM group was statistically significantly greater than the full ROM group after 12 weeks of training twice per week. It also important to note that the partial ROM group in their study did not perform full ROM training and consequently only improved full ROM squat by 9% as compared to 20% in the full ROM group. These findings along with the present study suggest that specificity of ROM in training plays a significant role in the adaptation process.

Harris et al. (2000) found similar results in well-trained football players. After only performing 1/4 ROM squats for nine weeks the high power group improved 1RM 1/4 squat, but did not improve 1RM squat, whereas the other two groups, training full ROM squat, improved 1RM squat and 1RM 1/4 squat. The reason there was no improvement in the high power group in this study is likely due to the higher training status of the participants. Thus, from these findings, it is clear that in order to improve 1RM squat in well-trained individuals, full ROM training is indispensable.

Isometric Strength Assessment

Previous research on partial lift training has not investigated force-time characteristics during isometric contractions with the exception of Clark et al. 2012 who measured isometric peak force at ¼ ROM bench press. The proposed benefits of partial ROM training may be more evident during the onset of force production, thus the present study examined impulse, RFD, and allometrically scaled peak force at 50, 90, 200, and 250ms during isometric squat at 90° and 120° of knee flexion.

Similar to findings by Blazevich et al. (2002), a strong, significant correlation was found between IPFa 90° and 1RM Squat (r=0.72); however, the correlation between IPFa 120° and 1RM Squat was not as strong (r=0.45). As previously noted, this suggests that force produced through the "sticking point" is more closely related to 1RM squat strength than force produced in the terminal ROM. However, only the control group significantly improved IPFa 90° even though CP had a 2.3% greater improvement in 1RM squat scaled. One would expect to see a similar trend for IPFa 90°. The larger percent increases in 1RM squat scaled and partial squat scaled in the CP condition may be alternatively explained by greater improvements in impulse at all time measured at 90°.

Isometric Squat Peak Force Scaled. There was no group by time interaction for IPFa 90°. Only the improvement in the control group was significant from pre to post-intervention. The control group improved IPFa at 90° over CP by a 3.9% margin (5.2% vs. 1.3%); however, the control group only improved 1RM squat scaled by 5.1% compared to the 7.4% increase in the CP group. One possible explanation is that the control group had a greater potential for improvement on this measure. The greater overall volume of full ROM squats performed by the control group may also explain the difference between groups for IPFa 90°. The total work performed through full ROM squat was significantly greater than CP (67,996.44 ± 13,166.09 vs. 43,515.76 ± 9,387.71 kg·m). This corresponds well with the specificity of ROM in training adaptations. Practically speaking, this data suggests that higher volumes of full ROM squats improve strength at the sticking region to a slightly greater degree than lower volumes of full ROM squat combined with partial ROM squat during short training phases (≤7 weeks).

Conversely, CP significantly improved IPFa 120°, whereas the control condition did not. The CP improved IPFa 120° by 5.7% over control. A similar trend was seen for 1RM partial squat scaled, with the CP improving 4.3% over control. This again may be related to specificity of the ROM trained. As proposed by Zatsiorsky (1995), Wilson et al. (1996), and Clark et al. (2011), the greater loads used during partial ROM training seemed to have resulted in the ability to produce higher forces at a knee angle similar to the ROM trained. In regards to training applications for strength athletes, this would be advantageous for geared powerlifters who need to produce higher forces at the terminal ROM where they have less support from their gear.

Isometric Squat Impulse Scaled. CP significantly improved impulse at all time points measured for both knee angles, whereas control only improved impulse at 250ms 120° scaled (p=0.049). These findings seem to agree with Clark et al. (2011) who found greater improvements in iso-kinetic bench peak force at 45° per second in the terminal portion of the movement, ½ bench press throw peak force, and full bench press throw displacement in the group that trained with variable ROM over full ROM alone. The 7.5% and 4% greater increase in the CP over control for impulse at 200ms 90° scaled and 120° scaled, respectively, is comparable to the 3.4% and 4.3% greater increase in 1RM squat scaled and 1RM partial squat scaled. Effect size for all impulse time points ranged from 0.63 to 1.04 and 0.08 to 0.57 in the CP and control group, respectively. Within groups, effect size was larger at earlier time points for the CP, and larger at later time points for control. For example, effect size for impulse 50ms 120° scaled was 1.04 vs. 0.08, whereas effect size for impulse 250ms 120° was 0.63 and 0.34, for CP and control respectively. This trend was seen for both knee angles. Effect sizes for all time points can be found in Appendix D. The larger effect sizes at earlier time points may have significant implications for strength-power athletes. This will be discussed further below.

The greater improvements in impulse at earlier time points at 90° may explain why CP improved 1RM squat although there was no significant improvement in IPFa 90°. Increased impulse at all time points could be beneficial for 1RM strength because it may enhance ability to get through the sticking point. Theoretically, if greater forces can be produced through that time window then more weight can be lifted during a maximal attempt. If force produced during this brief time window is not large enough to overcome torque then the repetition will not be completed. While this theoretical conclusion is not fully supported in the literature, future research is needed to understand kinetic characteristics specifically of the sticking region.

The larger effect sizes for impulse at all time points in the CP group also suggests that partial lifts may have significantly improved rate coding, recruitment of high threshold motor units, motor unit synchronization, as well as decreased neural inhibition. All of which are associated with the onset of force production (Aagaard et al., 2000; Semmler & Nordstrom, 1998; Stone et al., 2007). For a sprinter this may mean decreased contact times and greater turnover rate resulting in faster times.

Isometric Squat Rate of Force Development. The only significant group by time interaction found in the present study was for RFD 200ms at 120°. However, there was no significant time interaction found for RFD at any time point. Additionally, paired t-tests results showed RFD 200ms at 120° was near significance in the control group (p=0.06) with a moderate effect size (0.37). No within-group differences were found for RFD at any time point for isometric squat at 90° or 120°. There was a trend for RFD at 200, 250ms at both knee angles to increase in the control and decrease in the CP. This can likely be explained by the changes in the force time curve for each group. A leftward shift in the force time-curve in the CP condition would explain the larger effect sizes for impulse at earlier time points and the decrease in RFD at later time points. RFD, the slope of tangent line to the function, may have begun to level off at later time points (200, 250ms).

Earlier RFD time points (50 and 90ms at 120°) were not as reliable (r<0.7) and therefore not included in the analysis. However, RFD at 50, 90ms at 90° were more acceptable (r>0.83). For these time points there was no significant difference in RFD between pre and post-intervention for either group. Considering the small effect sizes (<0.3) and large coefficients of variation (19.6%-48.7%) for RFD at all time points, impulse seems to be a better representation of changes during the early stages of isometric force production. Thus, partial ROM training in conjunction with full ROM training may be effective because it results in larger improvements in IPFa and impulse at 120° to offset the slight decrease in RFD.

Conclusion

Partial lifts have often been incorporated in periodized resistance training programs aimed at improving maximal strength; however, their efficacy has not been thoroughly investigated. Therefore, the purpose of our study was to expand upon the paucity of research on partial lift training by uniquely comparing a group performing only full ROM training (control) to an equated volume group that performs both full and partial ROM training (CP). The primary finding of our study was a trend for CP to improve over control in 1RM squat (2.3% greater), 1RM partial squat (4.1% greater), IPFa 120° (5.7% greater), and impulse for all time points at 90° (6.3%-13.2% greater) and 120° (3.4%-16.8% greater). These findings demonstrate that partial ROM training can be an effective training modality for improving maximal strength in conjunction with full ROM training. However, further research is needed to ascertain whether combined training is more effective than full ROM training alone for improving maximal strength.

Practical Applications

In relation to athletic performance, previous authors have proposed partial ROM training as an effective training modality for improving strength and power in the terminal ROM. These authors claim that partial ROM training more optimally loads the terminal ROM where joint angles, force-velocity relationship, and movement patterns are more similar to those in sport (Clark et al., 2011; Wilson et al., 1996; Zatsiorsky, 1995). Although the participants in the present study were not collegiate athletes, their strength level is comparable to previous research on athletes (Baker, Wilson, & Carlyon, 1994; Clark et al., 2011; Harris et al., 2000; Hoffman et al., 2009). The findings of the present study suggest that combined training may be more effective than full ROM training alone for improving early force-time curve characteristics. The larger effect sizes for IPFa at 120° (0.48) and impulse at 120° (0.63-1.04) in the CP group have implications for strength-power athletes. For example, the contact time for an elite sprinter is ~90ms, the effect size for impulse at 90ms 120° was 0.93 vs. 0.22 in CP and control, respectively. For an elite sprinter, producing larger forces in that narrow time window may be the difference between finishing first or finishing fourth.

As stated previously, partial ROM training is commonly practiced, particularly amongst geared powerlifters. The larger improvements in peak force and impulse at 120° found in the experimental group suggest that partial ROM squats may be beneficial for geared powerlifters who struggle finishing the lift. The larger improvements in impulse at 90° may also enhance their ability to move through the sticking point. Thus, partial squats can be included in the training program while peaking for a competition to enhance maximal strength in the terminal ROM.

If nothing else, this study supports the use of partial ROM training as an effective means of providing variation in a training program for well-trained lifters. As discussed previously, at higher training levels variation becomes a lager component of the program design. Thus, from a practical standpoint, partial ROM training could be incorporated during a strength-speed mesocycle in preparation for a sprinter's upcoming competition. Future studies on partial ROM training should include analysis of kinetic and kinematic variables during athletic movements (such as countermovement jump, 40m sprint and agility testing), longer training programs, measures of CSA with total work controlled, and different training exercises (bench press and deadlift).

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CHAPTER 4

CONCLUSION

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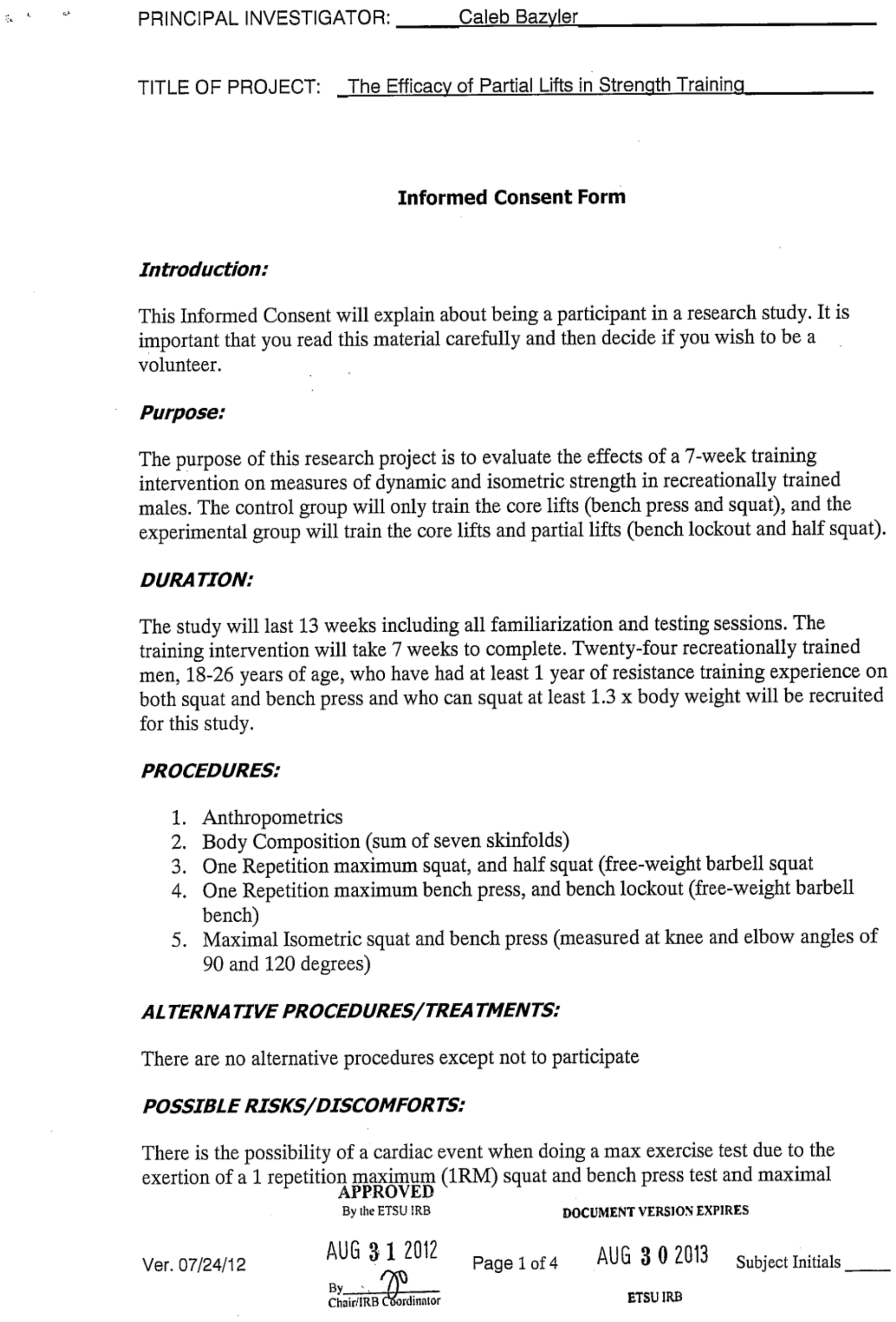
APPENDICES

Appendix A: Informed Consent Documents



PRINCIPAL INVESTIGATOR: Caleb Bazyler

TITLE OF PROJECT: The Efficacy of Partial Lifts in Strength Training

Informed Consent Form

Introduction:

This Informed Consent will explain about being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

Purpose:

The purpose of this research project is to evaluate the effects of a 7-week training intervention on measures of dynamic and isometric strength in recreationally trained males. The control group will only train the core lifts (bench press and squat), and the experimental group will train the core lifts and partial lifts (bench lockout and half squat).

DURATION:

The study will last 13 weeks including all familiarization and testing sessions. The training intervention will take 7 weeks to complete. Twenty-four recreationally trained men, 18-26 years of age, who have had at least 1 year of resistance training experience on both squat and bench press and who can squat at least 1.3 x body weight will be recruited for this study.

PROCEDURES:

1. Anthropometrics
2. Body Composition (sum of seven skinfolds)
3. One Repetition maximum squat, and half squat (free-weight barbell squat
4. One Repetition maximum bench press, and bench lockout (free-weight barbell bench)
5. Maximal Isometric squat and bench press (measured at knee and elbow angles of 90 and 120 degrees)

ALTERNATIVE PROCEDURES/TREATMENTS:

There are no alternative procedures except not to participate

POSSIBLE RISKS/DISCOMFORTS:

There is the possibility of a cardiac event when doing a max exercise test due to the exertion of a 1 repetition maximum (1RM) squat and bench press test and maximal

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Ver. 07/24/12 Page 1 of 4 Subject Initials _____ isometric squat and bench press. There is also a possibility of a cardiac event during or after training sessions. These changes could include abnormal blood pressure, fainting, disorders of heart rhythm, and very rare instances of heart attack. There is the possibility of muscle strains, tears and joint pain from the maximal tests and training sessions. There is the possibility of muscle soreness following the testing and training sessions due to a lack of familiarity. The testing sessions involve progressive stages of increasing effort and at any time the participant may terminate the test for any reason. Participant must complete a medical history questionnaire before participating in the study. If the participant has high blood pressure (greater than 140/90 mmHg), heart disease, has ever had a stroke, smoke, family history of heart attack or stroke, has any contraindications to exercise testing, neurological disorders, or orthopedic limitations then the participant cannot participate in this study.

The risks will be minimized by using trained technicians and by teaching the participant proper technique in performing the lifts and how to use the power racks and other exercise equipment. There is minimal risk involved in the training session since the participant will not perform any repetitions to complete exhaustion or failure. To reduce the risk of muscular strains and tears and joint pain the participant will be told to perform the lifts as instructed, and safety pins and/or spotters will be used to assist them in case they fail during a repetition.

POSSIBLE BENEFITS:

Benefits from this study include dynamic and isometric testing by certified strength and conditioning specialists (NSCA-CSCS), free training program designed by specialists, free muscular strength and body composition assessment, and learning principles involved in the training process.

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. ETSU makes no commitment to pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6055.

FINANCIAL COSTS:

There are no financial costs to you.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. You may quit by calling or e-mailing Caleb Bazyler, whose phone number is 305-205-4462, and whose e-mail is bazyler@goldmail.etsu.edu or Dr. Kimitake Sato, (423) 439-5138, SATOK1@mail.etsu.edu.

CONTACT FOR QUESTIONS:

If you have any questions, problems or research-related injury or medical problems at any time, you may call or e-mail Caleb Bazyler at 305-205-4462, bazyler@goldmail.etsu.edu or Dr. Kimitake Sato at (423) 439-5138, SATOK1@mail.etsu.edu. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY:

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in a locked file cabinet in the kinesiology lab for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the ETSU/VA IRB or ETSU IRB, and the Kinesiology, Leisure and Sport Science department will have access to the study records. Your (medical) records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the

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ETSU IRB

PRINCIPAL INVESTIGATOR: Caleb Bazyler

TITLE OF PROJECT: The Efficacy of Partial Lifts in Strength Training

chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

SIGNATURE OF PARTICIPANT	DATE
PRINTED NAME OF PARTICIPANT	DATE
SIGNATURE OF INVESTIGATOR	DATE
SIGNATURE OF WITNESS (if applicable)	DATE

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Appendix B: Health History Questionnaire

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes/No

2. Do you feel pain in your chest when you do physical exertion?

Yes/No

3. In the past month, have you had chest pain when you were not doing physical activity?

Yes/No

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes/No

5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

Yes/No

6. Is your doctor currently prescribing drugs (for example, water pills) for a blood pressure or heart condition?

Yes/No

7. Do you know of any other reason why you should not do physical activity?

Yes/No

If yes, please explain:

8. Please list all medications that you are currently taking. Please include vitamins or supplements.

9. Have you been lifting consistently for the past year (perform squat and bench press at least once/week)

Yes/No

10. Do you squat at least 1.3 x body weight

Yes/No

11. Have you ever been diagnosed with any of the health conditions below (check those applicable):

_ heart disease
_ heart surgery
_ high cholesterol
_ diabetes
_ heart attack
_ congenital heart disease
_ high blood pressure
_ stroke
_ premature death

12. Do any of your immediate family/grandparents have a history of (check those applicable):

_ heart disease
_ heart surgery
_ high cholesterol
_ diabetes
_ heart attack
_ congenital heart disease
_ high blood pressure
_ stroke
_ premature death

If yes, please note relationship and age ______________________

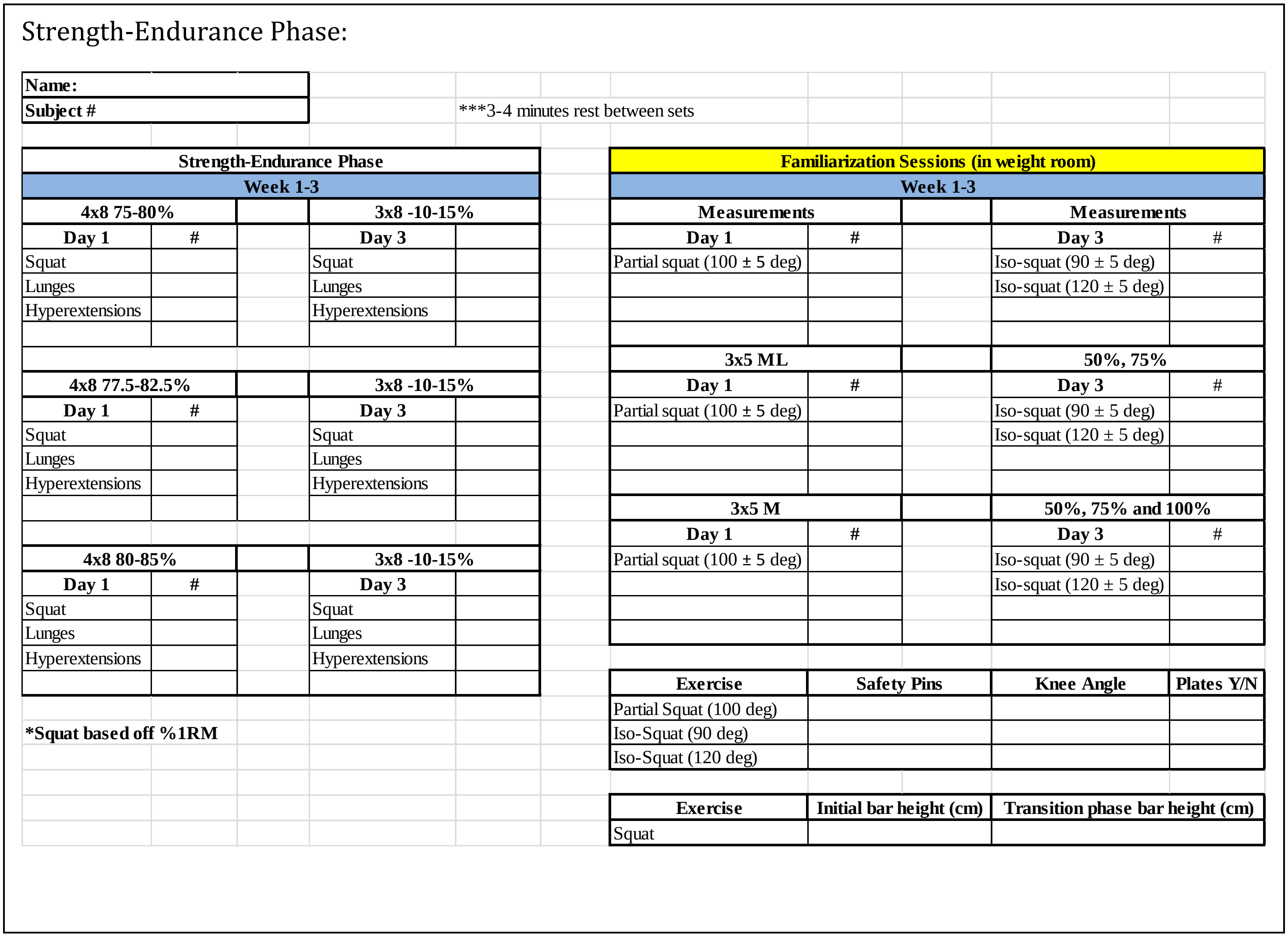
____

____

13. Has there been a death in the family via heart attack, heart disease, or stroke?

Yes/No

Appendix C: Training Mesocycles



Strength-Endurance Phase:

Name:	
Subject #	

***3-4 minutes rest between sets

Strength-Endurance Phase				
Week 1-3				
4x8 75-80%			**3x8 -10-15%**	
Day 1	**#**		**Day 3**	
Squat			Squat	
Lunges			Lunges	
Hyperextensions			Hyperextensions	
4x8 77.5-82.5%			**3x8 -10-15%**	
Day 1	**#**		**Day 3**	
Squat			Squat	
Lunges			Lunges	
Hyperextensions			Hyperextensions	
4x8 80-85%			**3x8 -10-15%**	
Day 1	**#**		**Day 3**	
Squat			Squat	
Lunges			Lunges	
Hyperextensions			Hyperextensions	

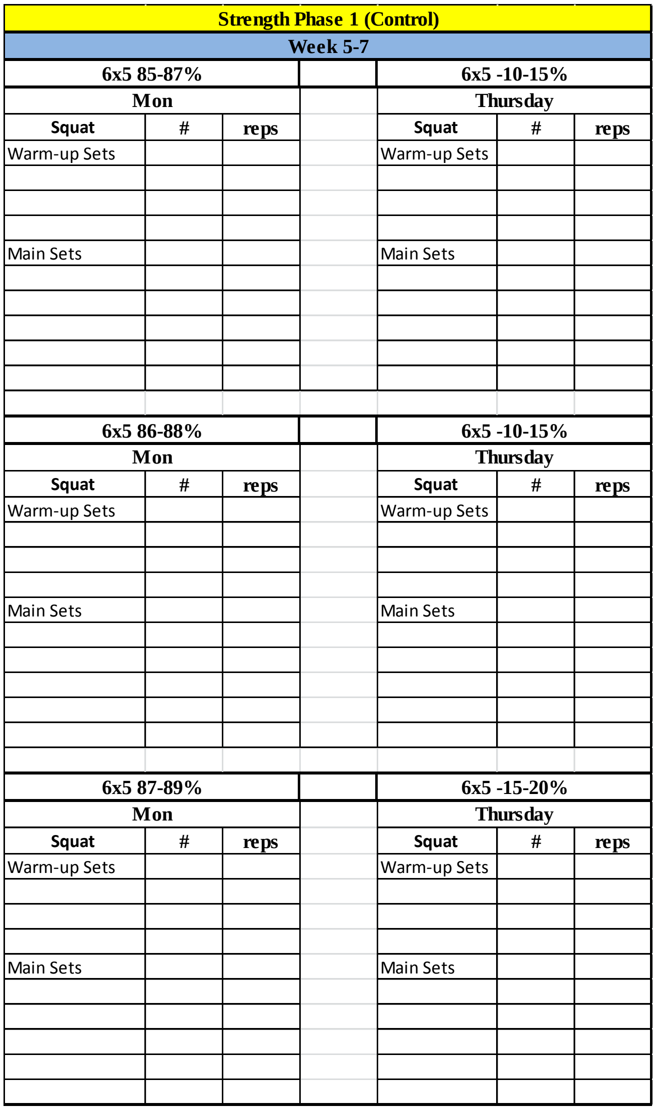
***Squat based off %1RM**

Familiarization Sessions (in weight room)				
Week 1-3				
Measurements			**Measurements**	
Day 1	**#**		**Day 3**	**#**
Partial squat (100 ± 5 deg)			Iso-squat (90 ± 5 deg)	
			Iso-squat (120 ± 5 deg)	
3x5 ML			**50%, 75%**	
Day 1	**#**		**Day 3**	**#**
Partial squat (100 ± 5 deg)			Iso-squat (90 ± 5 deg)	
			Iso-squat (120 ± 5 deg)	
3x5 M			**50%, 75% and 100%**	
Day 1	**#**		**Day 3**	**#**
Partial squat (100 ± 5 deg)			Iso-squat (90 ± 5 deg)	
			Iso-squat (120 ± 5 deg)	

Exercise	**Safety Pins**	**Knee Angle**	**Plates Y/N**
Partial Squat (100 deg)			
Iso-Squat (90 deg)			
Iso-Squat (120 deg)			

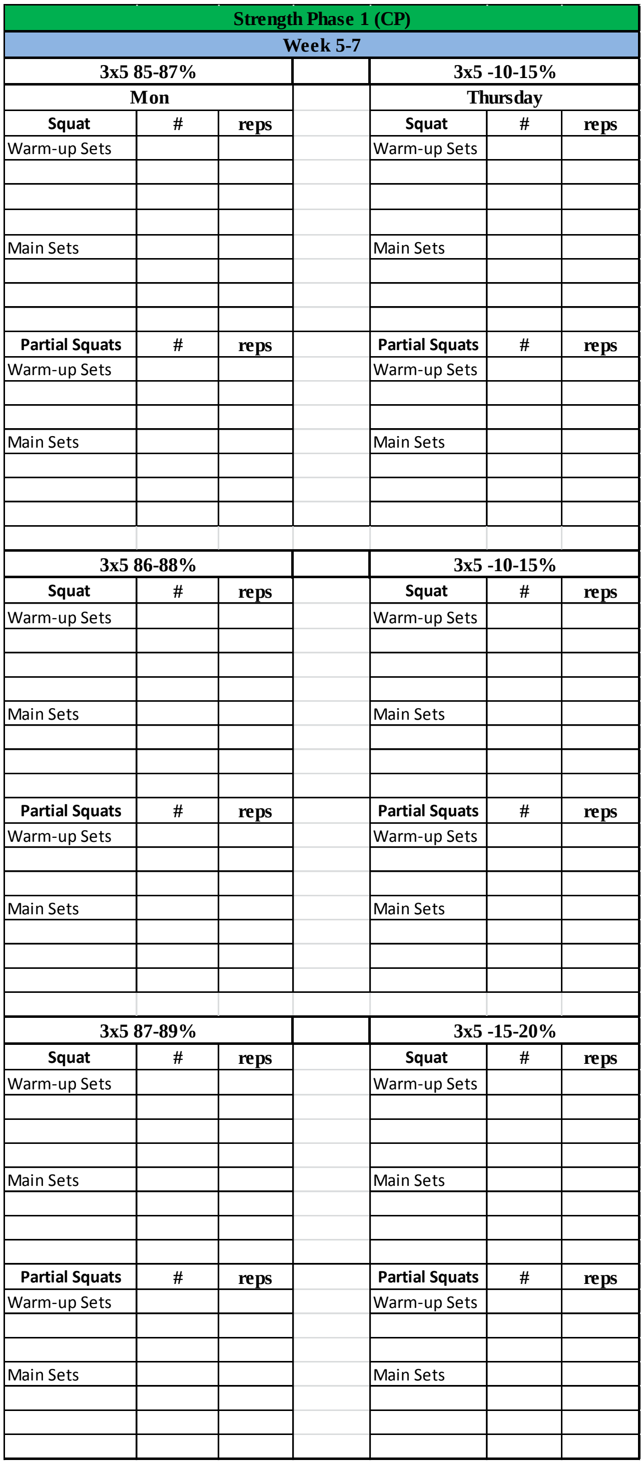
Exercise	**Initial bar height (cm)**	**Transition phase bar height (cm)**
Squat		

Strength Phase 1 (Control):



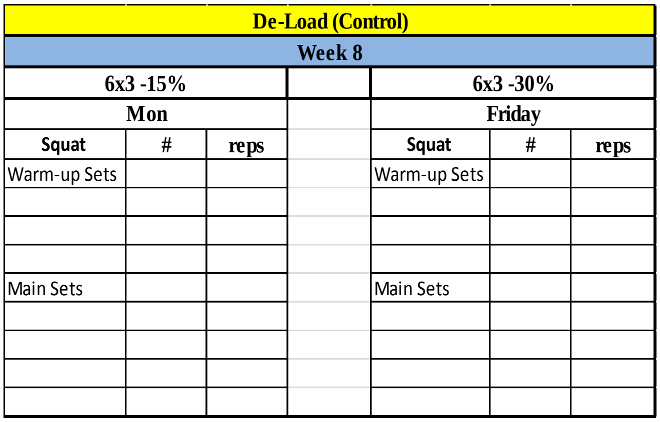
Strength Phase 1 (Control)						
Week 5-7						
6x5 85-87%				**6x5 -10-15%**		
Mon				**Thursday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
6x5 86-88%				**6x5 -10-15%**		
Mon				**Thursday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
6x5 87-89%				**6x5 -15-20%**		
Mon				**Thursday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		

Strength Phase 1 (CP):



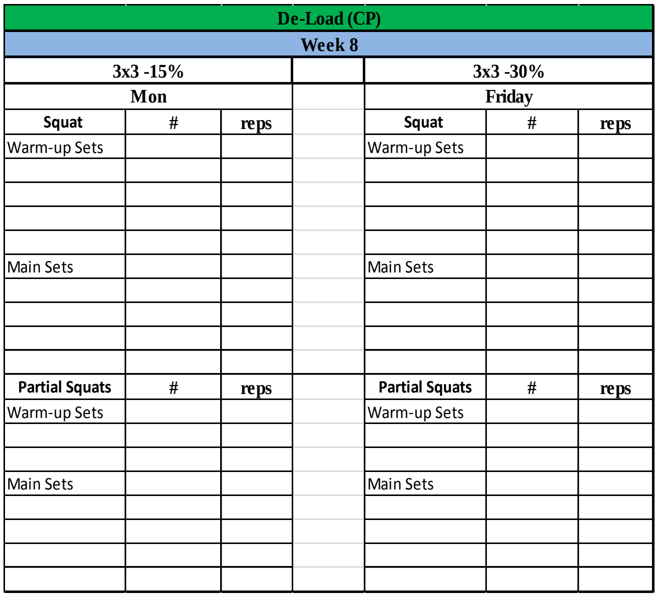
Strength Phase 1 (CP)						
Week 5-7						
3x5 85-87%				**3x5 -10-15%**		
Mon				**Thursday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
3x5 86-88%				**3x5 -10-15%**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
3x5 87-89%				**3x5 -15-20%**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		

De-Load (Control):



De-Load (Control)						
Week 8						
6x3 -15%				**6x3 -30%**		
Mon				**Friday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		

De-Load (CP):



De-Load (CP)						
Week 8						
3x3 -15%				**3x3 -30%**		
Mon				**Friday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		

Strength Phase 2 (Control):

Strength Phase 2 (Control)						
Week 9-11						
7x3 88-90%				**7x3 -10-15%**		
Mon				**Friday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
7x3 89-91%				**7x3 -10-15%**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
7x3 90-92%				**7x3 -15-20%**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		

Strength Phase 2 (CP):

Strength Phase 2 (CP)						
Week 9-11						
3x3 88-90%				**3x3 -10-15%**		
Mon				**Thursday**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
3x3 89-91%				**3x3 -10-15%**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
3x3 90-92%				**3x3 -15-20%**		
Squat	**#**	**reps**		**Squat**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		
Partial Squats	**#**	**reps**		**Partial Squats**	**#**	**reps**
Warm-up Sets				Warm-up Sets		
Main Sets				Main Sets		

Appendix D: Statistical Analysis for All Dependent Variables

Repeated Measures

Variable	Time	Condition by Time	Condition
Mass			
Height			
Age			
Percent Fat	*		
Skinfold thickness	*		
Lean Body Mass	*		
IPFa 90deg	*		
RFD200ms 90deg			
RFD250ms 90deg			
Impulse50ms 90deg scaled	*		
Impulse90ms 90deg scaled	*		
Impulse200ms 90deg scaled	*		
Impulse250ms 90deg scaled	*		
IPFa 120deg	*		
RFD200ms 120deg		*	
RFD250ms 120deg			
Impulse50ms 120deg scaled			
Impulse90ms 120deg scaled	*		
Impulse200ms 120deg scaled	*		
Impulse250ms 120deg scaled	*		
1RM Squat	**		
1RM Partial Squat	**		
1RM Squat scaled	**		
1RM Partial Squat scaled	**		

* denotes p<.05

** denotes p<.001

no change in any variable when subject #17 is removed

Descriptive Statistics, T-tests and Effect Sizes

Variable	Group	Pre-intervention			Post-intervention			p	Cohen's d
		Mean	SD	COV	Mean	SD	COV		
Percent Fat (%)	Control	22.14	8.52	38.49	19.86	8.90	44.84	0.027	0.27
	CP	20.82	11.96	57.45	19.68	11.39	57.86	0.046	0.10
Skinfold thickness (mm)	Control	135.00	32.46	24.05	126.06	34.30	27.21	0.023	0.28
	CP	128.67	43.62	33.90	124.44	41.94	33.70	0.055	0.10
LBM (kg)	Control	65.54	6.22	9.50	67.33	7.18	10.66	0.017	0.29
	CP	67.51	8.09	11.99	68.38	8.11	11.85	0.038	0.11
Mass (kg)	Control	84.88	10.92	12.86	84.66	10.69	12.63	0.516	0.02
	CP	86.06	8.94	10.39	85.79	8.62	10.05	0.537	0.03
Height (cm)	Control	176.44	6.25	3.54	176.22	6.40	3.63	0.169	0.04
	CP	177.56	8.09	4.56	177.44	7.89	4.45	0.681	0.01
Age (years)	Control	20.78	1.99	9.56	20.78	1.99	9.56		
	CP	20.67	1.87	9.05	20.67	1.87	9.05		

Descriptive Statistics, T-tests and Effect Sizes

Variable	Group	Pre-intervention			Post-intervention			p	Cohen's d
		Mean	SD	COV	Mean	SD	COV		
IPFa 90 N.((body mass^0.67)-1)	Control	107.51	6.97	6.48	113.16	8.52	7.53	0.008	0.81
	CP	114.87	13.60	11.84	116.32	12.80	11.01	0.474	0.11
RFD200ms 90deg (N.s-1)	Control	3414.09	950.07	27.83	3580.90	749.12	20.92	0.578	0.18
	CP	3814.81	854.04	22.39	3579.81	1106.35	30.91	0.532	0.28
RFD250ms 90deg (N.s-1)	Control	3136.56	818.02	26.08	3183.18	676.75	21.26	0.823	0.06
	CP	3439.56	630.74	18.34	3157.77	865.69	27.41	0.357	0.45
Impulse50ms 90deg scaled N.((body mass^0.67)-1)	Control	2.76	0.41	14.98	2.88	0.36	12.62	0.138	0.30
	CP	2.70	0.49	18.05	3.20	0.51	16.01	0.006	1.03
Impulse90ms 90deg scaled N.((body mass^0.67)-1)	Control	5.26	0.74	14.08	5.50	0.65	11.75	0.104	0.33
	CP	5.27	0.98	18.53	6.16	0.99	16.08	0.004	0.91
Impulse200ms 90deg scaled N.((body mass^0.67)-1)	Control	13.97	1.48	10.62	14.76	1.58	10.73	0.069	0.53
	CP	14.11	2.42	17.16	15.99	2.55	15.93	0.003	0.78
Impulse250ms 90deg scaled N.((body mass^0.67)-1)	Control	18.53	1.76	9.51	19.54	1.94	9.93	0.066	0.57
	CP	18.76	2.92	15.59	20.97	3.26	15.55	0.003	0.76
IPFa 120 N.((body mass^0.67)-1)	Control	196.71	38.24	19.44	201.47	39.46	19.58	0.317	0.12
	CP	210.73	35.13	16.67	227.73	31.65	13.90	0.020	0.48
RFD200ms 120deg (N.s-1)	Control	5861.67	2853.13	48.67	6910.69	2956.09	42.78	0.062	0.37
	CP	6930.23	2243.60	32.37	6612.29	1458.03	22.05	0.401	0.14
RFD250ms 120deg (N.s-1)	Control	5377.22	2267.18	42.16	5631.87	2005.41	35.61	0.555	0.11
	CP	6051.89	1638.27	27.07	5861.72	1036.57	17.68	0.562	0.12
Impulse50ms 120deg scaled N.((body mass^0.67)-1)	Control	3.74	0.85	22.59	3.81	0.62	16.36	0.754	0.08
	CP	3.51	0.60	17.00	4.13	1.03	24.94	0.045	1.04
Impulse90ms 120deg scaled N.((body mass^0.67)-1)	Control	7.34	1.79	24.39	7.73	1.40	18.07	0.334	0.22
	CP	6.99	1.30	18.66	8.20	2.08	25.41	0.027	0.93
Impulse200ms 120deg scaled N.((body mass^0.67)-1)	Control	20.22	5.12	25.32	22.09	4.78	21.66	0.058	0.36
	CP	20.07	3.93	19.61	22.76	5.36	23.54	0.015	0.68
Impulse250ms 120deg scaled N.((body mass^0.67)-1)	Control	27.04	6.53	24.15	29.24	6.32	21.60	0.049	0.34
	CP	27.08	4.97	18.37	30.20	6.75	22.35	0.017	0.63

Descriptive Statistics, T-tests and Effect Sizes

Variable	Group	Pre-intervention			Post-intervention			p	Cohen's d
		Mean	SD	COV	Mean	SD	COV		
1RM Squat (kg)	Control	148.93	23.70	15.92	156.58	23.86	15.24	0.006	0.32
	CP	152.21	30.94	20.33	163.54	29.45	18.01	0.000	0.37
1RM Partial Squat (kg)	Control	207.90	30.77	14.80	229.16	48.79	21.29	0.045	0.69
	CP	223.27	55.57	24.89	255.30	60.49	23.69	0.001	0.58
1RM Squat scaled kg.((body mass^0.67)-1)	Control	7.69	0.65	8.41	8.10	0.66	8.19	0.003	0.64
	CP	7.80	1.35	17.35	8.40	1.34	15.89	0.000	0.45
1RM Partial Squat scaled kg.((body mass^0.67)-1)	Control	10.77	1.24	11.52	11.87	2.09	17.57	0.036	0.89
	CP	11.45	2.52	22.02	13.11	2.82	21.47	0.001	0.66
WorkSquat (kg.m)	Control				67996.44	13166.09	19.36	0.000	
	CP				43515.76	9387.71	21.57		
WorkTotal (kg.m)	Control				67996.44	13166.09	19.36	0.897	
	CP				67206.48	12322.35	18.34		

Descriptive Statistics, T-tests and Effect Sizes without subject # 17

Variable	Group	Pre-intervention			Post-intervention			p	Cohen's d
		Mean	SD	COV	Mean	SD	COV		
Percent Fat (%)	Control	22.14	8.52	38.49	19.86	8.90	44.83		
	CP	17.58	7.45	42.39	16.65	7.34	44.05	0.102	0.12
Skinfold thickness (mm)	Control	135.00	32.46	24.05	126.06	34.30	27.21		
	CP	117.50	29.86	25.42	113.81	29.11	25.58	0.115	0.12
LBM (kg)	Control	65.54	6.22	9.50	67.33	7.18	10.66		
	CP	69.46	5.96	8.58	70.25	6.27	8.92	0.082	0.13
Mass (kg)	Control	84.88	10.92	12.86	84.66	10.69	12.63		
	CP	84.64	8.41	9.93	84.60	8.39	9.91	0.926	0.00
Height (cm)	Control	176.44	6.25	3.54	176.22	6.40	3.63		
	CP	179.13	7.04	3.93	179.00	6.80	3.80	0.685	0.02
Age (years)	Control	20.78	1.99	9.56	20.78	1.99	9.56		
	CP	20.88	1.89	9.03	20.88	1.89	9.03		

Descriptive Statistics, T-tests and Effect Sizes without subject # 17

Variable	Group	Pre-intervention			Post-intervention			p	Cohen's d
		Mean	SD	COV	Mean	SD	COV		
IPFa 90 N.((body mass^0.67)-1)	Control	107.51	6.97	6.48	113.16	8.52	7.53		
	CP	112.76	12.88	11.42	114.43	12.26	10.71	0.471	0.13
RFD200ms 90deg (N.s-1)	Control	3414.09	950.07	27.83	3580.90	749.12	20.92		
	CP	3897.76	873.38	22.41	3576.51	1182.69	33.07	0.444	0.37
RFD250ms 90deg (N.s-1)	Control	3136.56	818.02	26.08	3183.18	676.75	21.26		
	CP	3429.66	673.54	19.64	3114.40	914.95	29.38	0.364	0.47
Impulse50ms 90deg scaled N.((body mass^0.67)-1)	Control	2.76	0.41	14.98	2.88	0.36	12.62		
	CP	2.71	0.52	19.15	3.24	0.53	16.51	0.010	1.01
Impulse90ms 90deg scaled N.((body mass^0.67)-1)	Control	5.26	0.74	14.08	5.50	0.65	11.75		
	CP	5.33	1.03	19.28	6.25	1.01	16.23	0.007	0.65
Impulse200ms 90deg scaled N.((body mass^0.67)-1)	Control	13.97	1.48	10.62	14.76	1.58	10.73		
	CP	14.33	2.50	17.42	16.21	2.63	16.20	0.006	0.50
Impulse250ms 90deg scaled N.((body mass^0.67)-1)	Control	18.53	1.76	9.51	19.54	1.94	9.93		
	CP	19.01	3.01	15.86	21.23	3.39	15.95	0.012	0.66
IPFa 120 N.((body mass^0.67)-1)	Control	196.71	38.24	19.44	201.47	39.46	19.58		
	CP	206.91	35.50	17.16	225.39	32.99	14.64	0.024	0.52
RFD200ms 120deg (N.s-1)	Control	5861.67	2853.13	48.67	6910.69	2956.09	42.78		
	CP	7024.29	2379.47	33.87	6615.04	1558.67	23.56	0.332	0.17
RFD250ms 120deg (N.s-1)	Control	5377.22	2267.18	42.16	5631.87	2005.41	35.61		
	CP	6113.60	1740.16	28.46	5841.48	1106.23	18.94	0.455	0.16
Impulse50ms 120deg scaled N.((body mass^0.67)-1)	Control	3.74	0.85	22.59	3.81	0.62	16.36		
	CP	3.54	0.63	17.87	4.24	1.05	24.78	0.043	1.11
Impulse90ms 120deg scaled N.((body mass^0.67)-1)	Control	7.34	1.79	24.39	7.73	1.40	18.07		
	CP	7.05	1.38	19.58	8.43	2.11	25.02	0.020	0.83
Impulse200ms 120deg scaled N.((body mass^0.67)-1)	Control	20.22	5.12	25.32	22.09	4.78	21.66		
	CP	20.34	4.12	20.24	23.33	5.43	23.27	0.016	0.52
Impulse250ms 120deg scaled N.((body mass^0.67)-1)	Control	27.04	6.53	24.15	29.24	6.32	21.60		
	CP	27.45	5.18	18.88	30.90	6.86	22.19	0.034	0.45

Descriptive Statistics, T-tests and Effect Sizes without subject # 17

Variable	Group	Pre-intervention			Post-intervention			p	Cohen's d
		Mean	SD	COV	Mean	SD	COV		
1RM Squat (kg)	Control	148.93	23.70	15.92	156.58	23.86	15.24		
	CP	144.58	22.28	15.41	156.49	21.89	13.99	0.000	0.53
1RM Partial Squat (kg)	Control	207.90	30.77	14.80	229.16	48.79	21.29		
	CP	207.80	32.69	15.73	238.74	36.88	15.45	0.004	0.95
1RM Squat scaled kg.((body mass^0.67)-1)	Control	7.69	0.65	8.41	8.10	0.66	8.19		
	CP	7.52	1.12	14.96	8.14	1.14	14.04	0.000	0.55
1RM Partial Squat scaled kg.((body mass^0.67)-1)	Control	10.77	1.24	11.52	11.87	2.09	17.57		
	CP	10.83	1.83	16.86	12.43	2.06	16.56	0.004	0.88

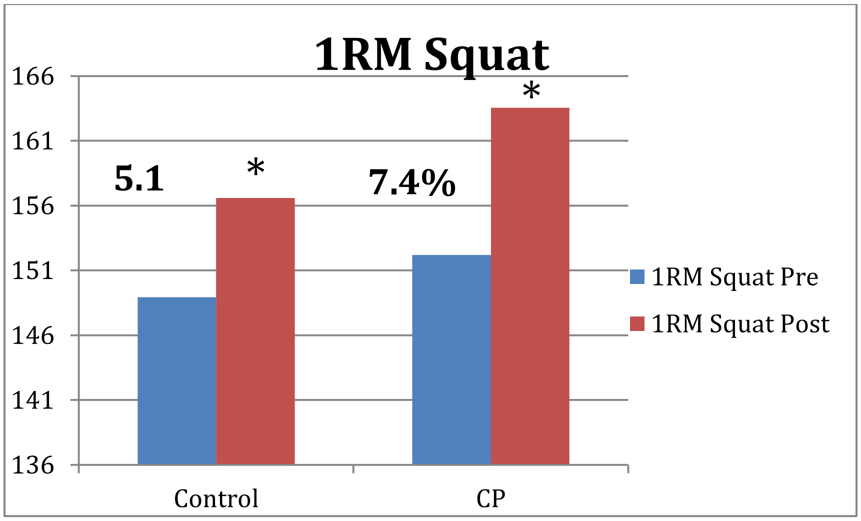
Homogeneity of Variances

Variable	Pre-intervention		Post-intervention	
	Levene Statistic	p	Levene Statistic	p
Percent Fat	0.275	0.607	0.382	0.545
Skinfold thickness	0.156	0.698	0.230	0.638
LBM	0.964	0.341	0.300	0.592
Mass	0.602	0.449	0.819	0.379
Height	0.823	0.378	0.668	0.426
Age	0.009	0.924	0.009	0.924
IPFa 90	7.210	*0.016	1.346	0.263
RFD200ms 90	0.208	0.654	1.334	0.265
RFD250ms 90deg	0.065	0.802	0.818	0.379
Impulse50ms 90 scaled	0.673	0.424	0.893	0.359
Impulse90ms 90 scaled	1.732	0.207	1.122	0.305
Impulse200ms 90 scaled	5.153	*0.037	1.315	0.268
Impulse250ms 90 scaled	6.239	*0.024	1.453	0.246
IPFa 120	0.027	0.873	0.161	0.694
RFD200ms 120	0.277	0.606	1.858	0.192
RFD250ms 120	1.252	0.280	2.170	0.160
Impulse50ms 120 scaled	2.052	0.171	1.571	0.228
Impulse90ms 120 scaled	1.368	0.259	0.826	0.377
Impulse200ms 120 scaled	0.826	0.377	0.044	0.836
Impulse250ms 120 scaled	0.917	0.353	0.019	0.892
1RM Squat	0.173	0.683	0.086	0.773
1RM Partial Squat	1.646	0.218	0.013	0.911
1RM Squat scaled	4.275	0.055	4.056	0.061
1RM Partial Squat scaled	2.876	0.109	0.967	0.340
WorkSquat			0.012	0.914
WorkTotal			0.012	0.914

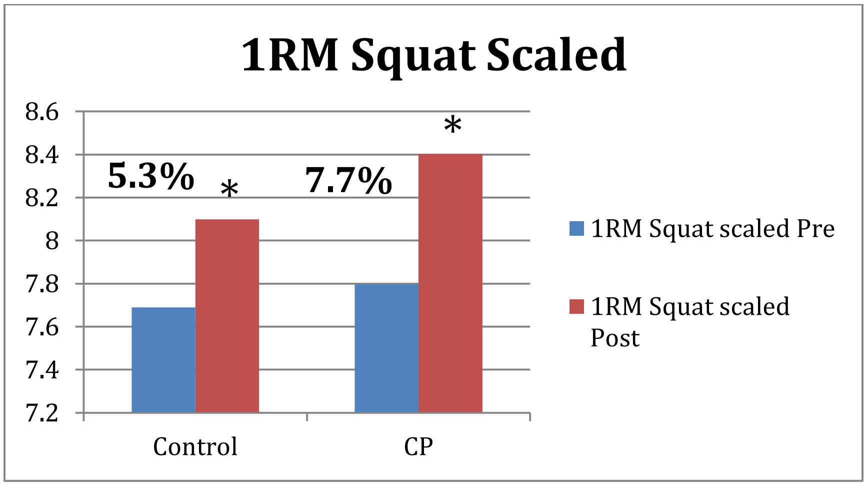
Homogeneity of Variances without Subject #17

Variable	Pre-intervention		Post-intervention	
	Levene Statistic	p	Levene Statistic	p
Percent Fat	0.737	0.404	0.501	0.490
Skinfold thickness	0.651	0.432	0.547	0.471
LBM	0.006	0.941	0.011	0.918
Mass	1.167	0.297	1.193	0.292
Height	0.276	0.607	0.181	0.676
Age	0.051	0.825	0.051	0.825
IPFa 90	6.250	*0.025	1.337	0.266
RFD200ms 90	0.224	0.643	2.667	0.123
RFD250ms 90deg	0.000	0.993	1.424	0.251
Impulse50ms 90 scaled	1.278	0.276	1.249	0.281
Impulse90ms 90 scaled	2.225	0.157	1.360	0.262
Impulse200ms 90 scaled	5.217	*0.037	1.239	0.142
Impulse250ms 90 scaled	6.409	*0.023	1.451	0.283
IPFa 120	0.030	0.864	0.079	0.782
RFD200ms 120	0.119	0.734	1.300	0.272
RFD250ms 120	0.738	0.404	1.589	0.227
Impulse50ms 120 scaled	1.499	0.240	1.744	0.206
Impulse90ms 120 scaled	0.977	0.339	0.976	0.339
Impulse200ms 120 scaled	0.693	0.418	0.049	0.829
Impulse250ms 120 scaled	0.803	0.384	0.008	0.929
1RM Squat	0.311	0.586	0.367	0.554
1RM Partial Squat	0.078	0.784	0.813	0.382
1RM Squat scaled	1.154	0.300	1.622	0.222
1RM Partial Squat scaled	2.108	0.167	0.065	0.802
WorkSquat			2.234	0.156
WorkTotal			0.393	0.540

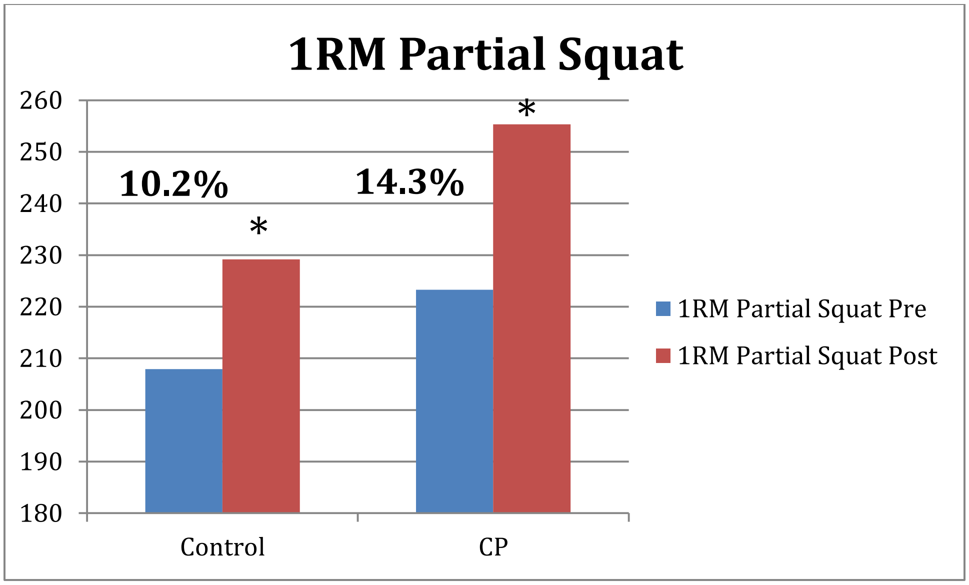
Appendix E: Graphs of Dependent Variables



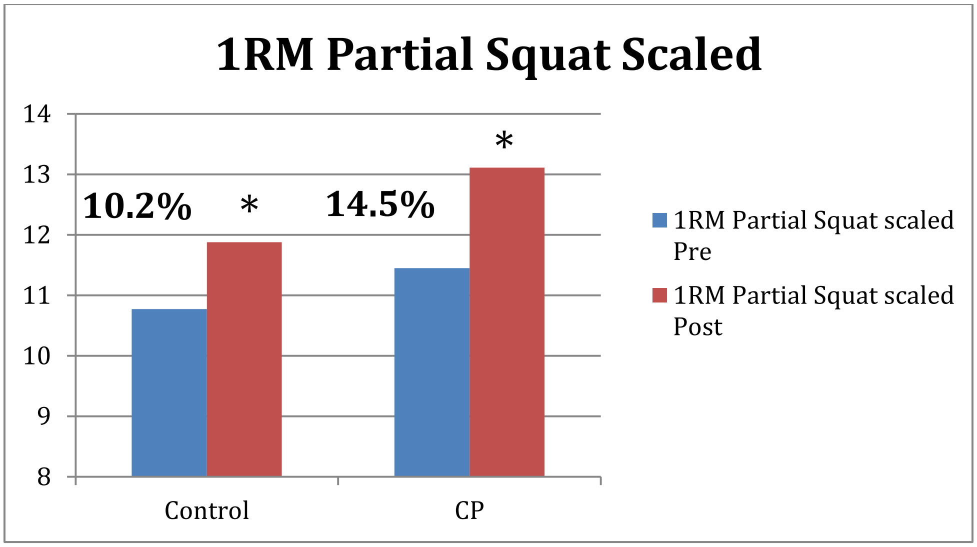
Comparison of mean pre to post 1RM squat between groups. Control=core lift. CP=core and partial lift. 1RM squat strength increased significantly in both groups compared to pre-training measures (p<0.001). *p<0.001, significantly different from pre-training.



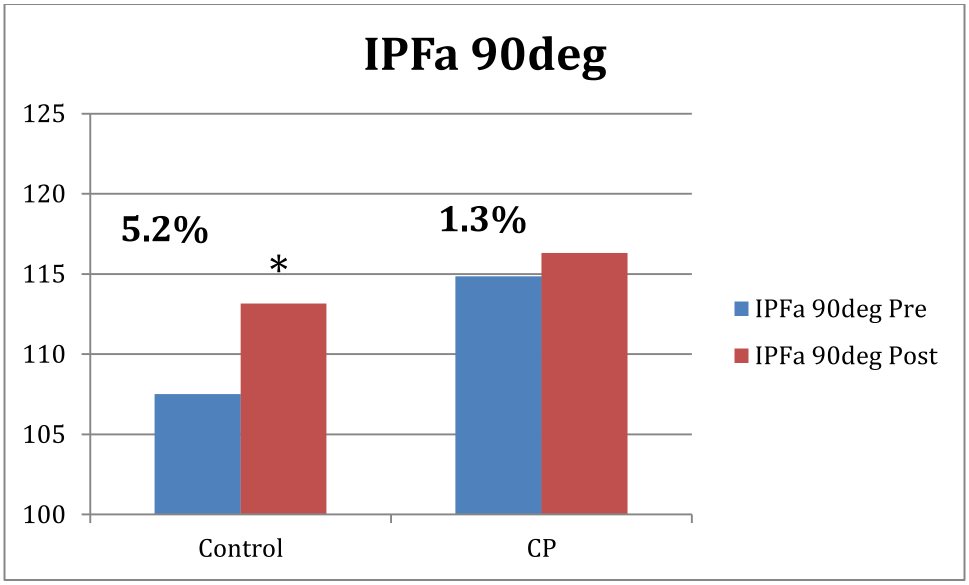
Comparison of mean pre to post 1RM squat scaled between groups. Control=core lift. CP=core and partial lift. 1RM squat scaled increased significantly in both groups compared to pre-training measures (p<0.001). *p<0.001, significantly different from pre-training.



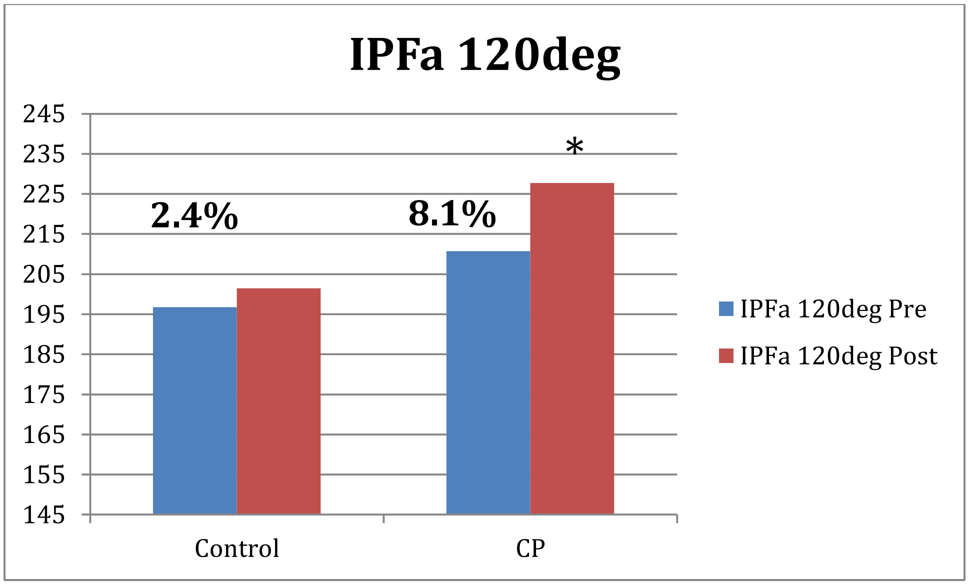
Comparison of mean pre to post 1RM partial squat between groups. Control=core lift. CP=core and partial lift. 1RM partial squat increased significantly in both groups compared to pre-training measures ($p<0.001$). *$p<0.001$, significantly different from pre-training.



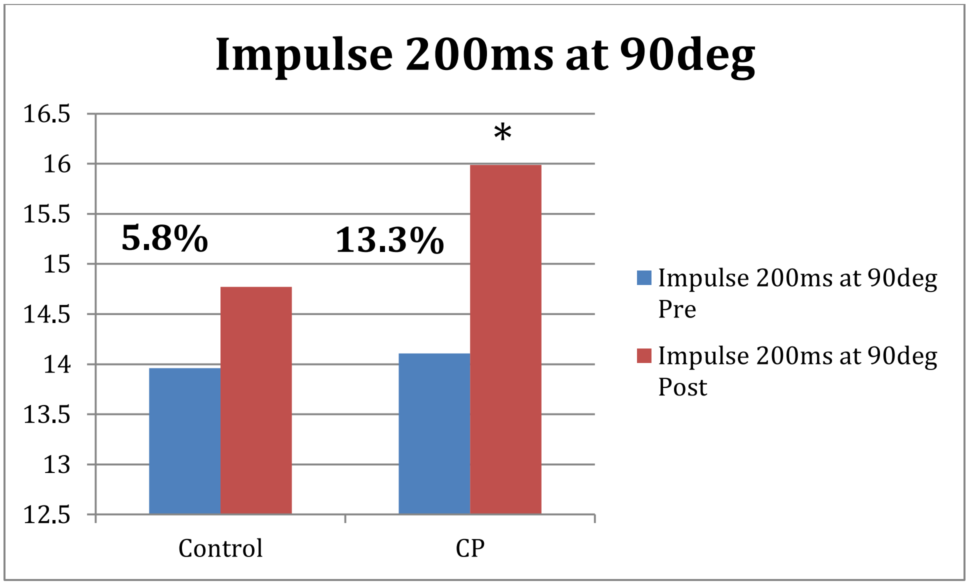
Comparison of mean pre to post 1RM partial squat scaled between groups. Control=core lift. CP=core and partial lift. 1RM partial squat scaled increased significantly in both groups compared to pre-training measures ($p<0.001$). *$p<0.001$, significantly different from pre-training.



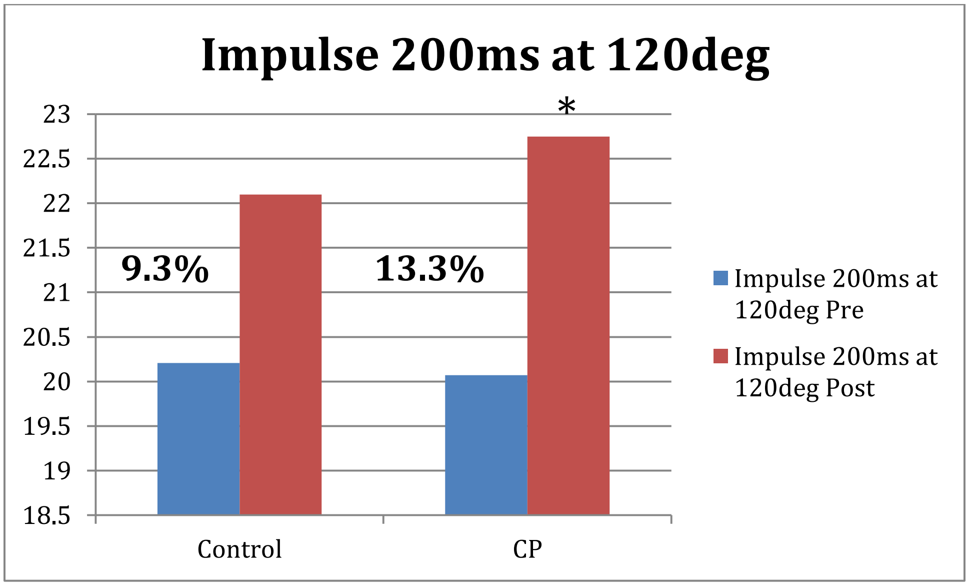
Comparison of mean pre to post IPFa 90° between groups. Control=core lift. CP=core and partial lift. IPFa 90° increased significantly in Control group only compared to pre-training measures (p<0.05). *p<0.05, significantly different from pre-training.



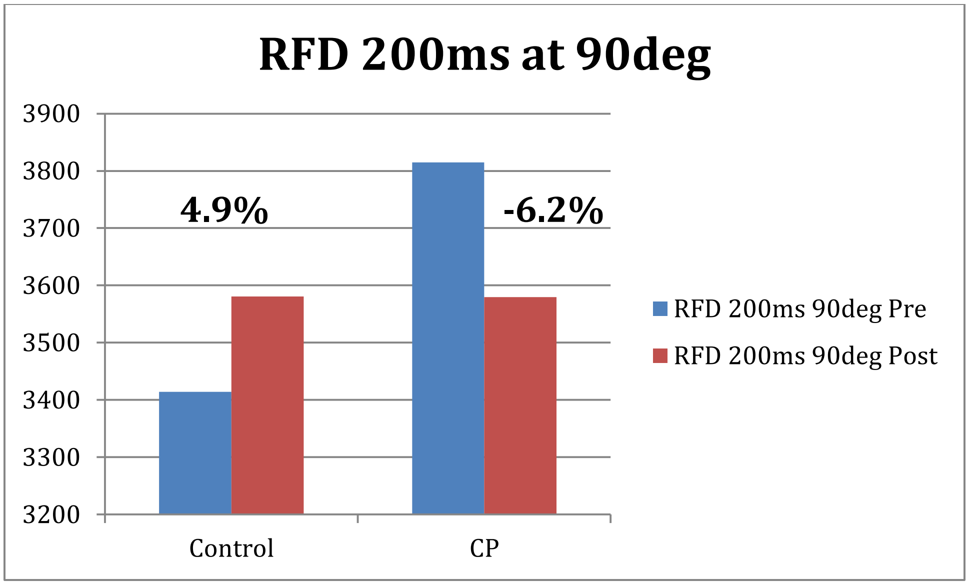
Comparison of mean pre to post IPFa 120° between groups. Control=core lift. CP=core and partial lift. IPFa 120° increased significantly in CP group only compared to pre-training measures (p<0.05). *p<0.05, significantly different from pre-training.



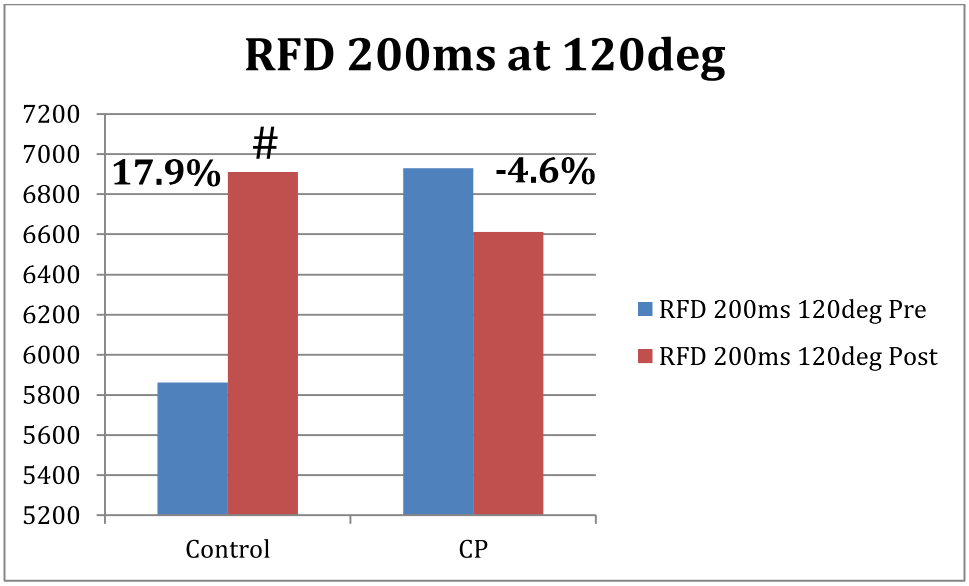
Comparison of mean pre to post Impulse 200ms 90° between groups. Control=core lift. CP=core and partial lift. Impulse 200ms 90° increased significantly in CP group only compared to pre-training measures ($p<0.05$). *$p<0.05$, significantly different from pre-training.



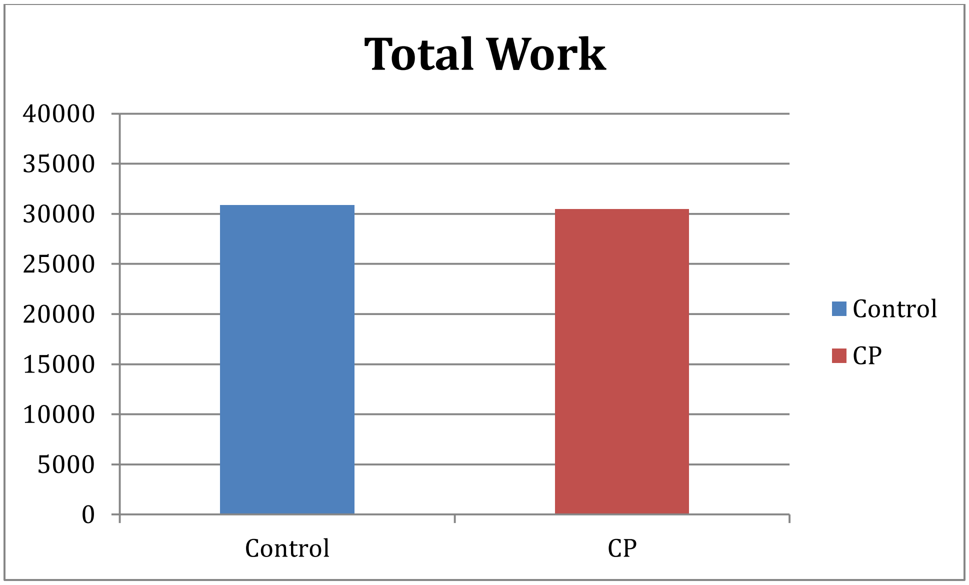
Comparison of mean pre to post Impulse 200ms 120° between groups. Control=core lift. CP=core and partial lift. Impulse 200ms 120° increased significantly in CP group only compared to pre-training measures ($p<0.05$). *$p<0.05$, significantly different from pre-training.



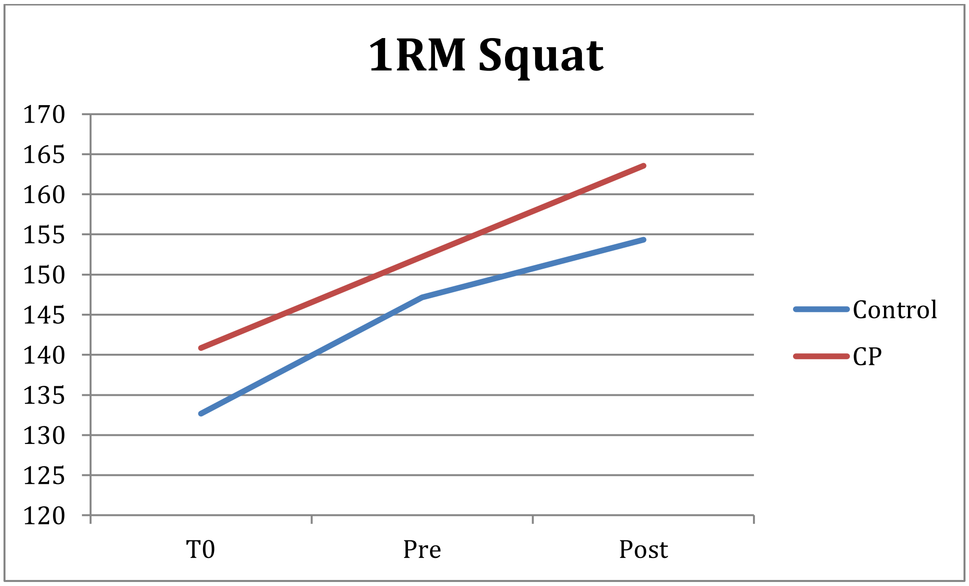
Comparison of mean pre to post RFD 200ms 90° between groups. Control=core lift. CP=core and partial lift. There was no interaction. The Control group increased RFD 200ms 90° 4.9% and CP decreased 6.2% from pre- to post-training.



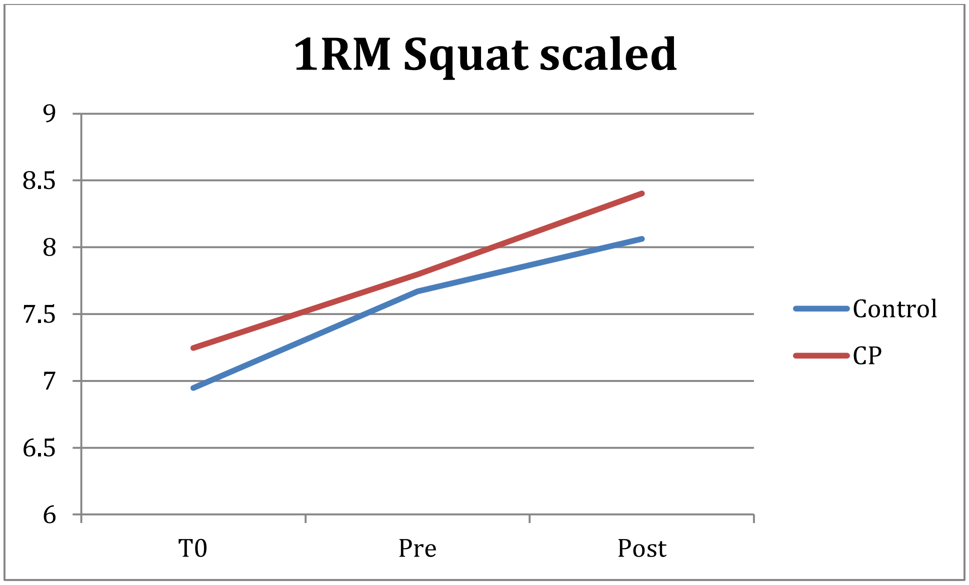
Comparison of mean pre to post RFD 200ms 120° between groups. Control=core lift. CP=core and partial lift. There was a group by time interaction for RFD 200ms 120° in the Control group ($p<0.05$). #$p<0.05$, significantly different rate of gain from pre to post compared to CP.



Comparison of mean total work between groups. Control=core lift. CP=core and partial lift. There was no significant difference between groups for total work completed (p>0.05).



Comparison of mean T_0 to pre to post 1RM squat between groups. Control=core lift. CP=core and partial lift. 1RM squat increased significantly in both groups from T_0 to pre-intervention and from pre to post-intervention measures (p<0.001). *p<0.001, significantly different from pre-training. #p<0.001, significantly different from T_0.



Comparison of mean T_0 to pre to post 1RM squat scaled between groups. Control=core lift. CP=core and partial lift. 1RM squat scaled increased significantly in both groups from T_0 to pre-intervention and from pre to post-intervention measures ($p<0.001$). *$p<0.001$, significantly different from pre-training. #$p<0.001$, significantly different from T_0.

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