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The Effect of Different Set-Repetition Protocols on Squat Technique In Resistance Trained Individuals

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The Effect of Different Set-Repetition Protocols on Squat Technique in Resistance
Trained Individuals.

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The Effect of Different Set-Repetition Protocols on Squat Technique in Resistance Trained Individuals.

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ABSTRACT

The effect of different set-repetition protocols on squat technique in resistance trained individuals.

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Purpose: The purpose of this investigation is to determine whether or not the increase in repetitions within a set will change the technique of the exercise, and how repetition number in a set affects exercise technique in resistance trained individuals in three different set-repetition protocols equated by total volume.

Methods: 10 men (24.3 ± 2.8 yrs; 179.7 ± 5.7 cm; 85.5 ± 12.5 kg) and 10 women (23.9 ± 2.4 yrs; 166.2 ± 9.1 cm; 66.8 ± 8.4 kg) were the subjects of this study. Each subject completed 5 visits. The first visit was a one-repetition maximum (1-RM) test of the squat. The second visit was a familiarization visit. The last three visits were testing visits assigned in a balanced and randomized order. The three visits consisted of either 1 set of 30 repetitions, 3 sets of 10 repetitions, or 10 sets of 3 repetitions, all at 60% of the subject's 1-RM. For the protocols with multiple sets, 3 minutes of rest was given between each set. Peak power and peak velocity for each repetition was recorded as well as the hip and knee angles at the bottom of each repetition. A three-way (gender x condition x time) analysis of variance with repeated measures (MANOVA) was used to analyze the data. Significance was set at $p < 0.05$.

Results: Significant differences were observed in all four dependent variables. The 1 set of 30 repetitions protocol showed significant differences in both men and women in power, velocity, and hip angle. Significant differences were observed between all three protocols in the knee angle.

Conclusions: Set-repetition protocols, though their volumes may be equal, are executed differently depending on how the total volume is broken down by sets, repetitions, and rest.

CHAPTER 1

INTRODUCTION

The squat exercise is a standard strength training exercise used for increasing power and strength in the lower extremity and the trunk (Abelbeck, 2002; Sato & Heise, 2012; Sato, Fortenbaugh, & Hydock, 2012). The squat exercise is considered fundamental because “it quickly stimulates overall strength increases in both men and women.” (Chandler & Stone, 1991) The squat exercise also improves the athlete’s ability to “forcefully extend the knees and hips, and can considerably enhance performance in many sports.” (Chandler & Stone, 1991) Anatomically, the squat exercise is the most effective way to train the quadriceps, the gluteals, the adductors, the erector muscles of the spine, the abdominals, and the hamstrings in tandem (Delavier, 2003). All this evidence validates why the squat lift is a commonly utilized exercise in many strength and conditioning training programs across a wide array of sports. Improper execution of the exercise, however, can lead to injury. Also, because the incorrect execution of an exercise causes muscles other than the targeted muscle to be activated or trained, poor technique of an exercise could potentially hinder maximization of performance gains. (Fleck & Kraemer, 2004)

Exercise technique refers to the specific manner in which a particular exercise is properly performed. There are no official standards for “proper technique” or “correct form” in regards to body angles, but several organizations, including the National Strength and Conditioning Association, have developed guidelines for the proper execution of exercises such as the squat (Chandler & Stone, 1991). The general basis for these guidelines is to inform athletes on potential sources or risks of injury while

executing the exercise, and also to aid in maximization of strength, power, and performance gains in the exercise. Because proper technique execution is so crucial to meeting training goals and avoiding injury, it deserves considerable attention aside from being treated as one of several acute program training variables. The current literature base lacks adequate information on the association between technique analyses and performance or its effect on performance measuring variables, and also the magnitude of difference in technique that occurs in comparing different protocols whose volumes are equal.

Statement of Problem

The purpose of this investigation is to determine whether or not the increase in repetitions within a set will change the technique of the exercise, and how repetition number in a set affects exercise technique in resistance trained individuals, as no data exists for different set-repetition schemes that are truly matched for volume.

It is hypothesized that in observing three different set repetition protocols, one set of thirty repetitions, three sets of ten repetitions, and ten sets of three repetitions, differences will exist in hip angles, knee angles, power, and velocity though the load and total volume are equivalent for each protocol. Also, differences in these performance variables between genders are expected to be observed in comparing the three different protocols. The most dramatic changes in hip angles, knee angles, power, and velocity from first repetitions to last repetitions are expected to be observed in the one set of thirty repetition protocol, due to its physically taxing demands and fatigue inducing nature, and because this is the only protocol where the trained subjects are expected to reach volitional fatigue (Shimano et al., 2006).

CHAPTER 2

REVIEW OF LITERATURE

Strength training benefits affect body composition and structure, strength and power capabilities, and neuromuscular function. “Resistance training impacts several body systems, including muscular, endocrine, skeletal, metabolic, immune, neural, and respiratory,” (Kraemer, Duncan, & Volek, 1998) and has the potential to make positive adaptations to the cardiovascular system, skeletal muscle, fiber type, and the metabolic and endocrine systems. More specifically, significant benefits of strength training include increased ligament and tendon strength, increased bone density, development and increased strength in the muscle groups, including the large muscle groups in the back, hips, and legs, increased power and speed of the hips and legs, and “improved neuromuscular efficiency that aids performance in biomechanically similar movements.”(Chandler & Stone, 1991)

The squat exercise is a standard strength training exercise used for increasing power and strength in the lower extremity and the trunk (Abelbeck, 2002; Sato & Heise, 2012; Sato, Fortenbaugh, & Hydock, 2012). The squat exercise is considered a fundamental exercise because “it quickly stimulates overall strength increases in both men and women. Neglecting this exercise retards overall physical development and prevents the athlete from achieving optimal performance.” (Chandler & Stone, 1991) The squat exercise also improves the athlete’s ability to “forcefully extend the knees and hips, and can considerably enhance performance in many sports.” (Chandler & Stone, 1991) Anatomically, the squat exercise is the most effective way to train the quadriceps, the gluteals, the

adductors, the erector muscles of the spine, the abdominals, and the hamstrings in tandem (Delavier, 2003). All this evidence validates why the squat lift is a commonly utilized exercise in many strength and conditioning training programs across a wide array of sports. Improper execution of the exercise, however, hinders maximization of strength and power capabilities, and more importantly can lead to injury.

Variables of Training

Load. Training load is one of the most influential variables in attempting to reach a training goal. Load or intensity dictates motor unit recruitment, which can then be applied to specificity of training, or the desired training goal. Although some discrepancy exists in the literature, in general each training goal correspond to a load range, or percentages of a one-repetition maximum which are most effective in meeting that desired goal, whether it be hypertrophy, strength, power, or muscular endurance. More specifically, hypertrophy has been found to be maximized at 75% 1-RM whereas strength has been found to be maximized at 85-100% 1-RM (B. Crewther, Cronin, & Keogh, 2005; B. T. Crewther, Cronin, & Keogh, 2008; Kraemer et al., 2002). Other research, however, suggests that these loads are not the only way to achieve strength or hypertrophy gains, and that lighter loads (<45% 1-RM) have the ability to induce these gains as well (B. T. Crewther, Cronin, & Keogh, 2008; Holm et al., 2008). These lighter loads are also often used in order to increase speed and power in training (B. T. Crewther, Cronin, & Keogh, 2008; M. Stone et al., 1998).

Repetitions. Volume, load, rest, and order are all different resistance training variables that are maneuvered or adjusted in training programs in order to reach specific goals (Kraemer, Duncan, & Volek, 1998). The number of repetitions in a set is one of the key resistance training variables that can be manipulated in order to reach a specific training goal (Baker & Newton, 2007). The number of repetitions in a set seems to be more impactful than an overall set number as a prescribed training variable, as the load and number of repetitions are what actually create the stress, which is why repetition number is so important in meeting a training goal (M. Stone et al., 1998).

High repetition training protocols are generally utilized to increase endurance in the musculature. As long as high repetition sets are performed safely and correctly, they are an effective way to train if increasing or improving muscular endurance is the goal. An additional benefit to endurance training is maximizing the capabilities of connective tissues. Specifically, it has been found in animal studies that endurance training generally seems to “enhance the size and tensile strength of tendons and ligaments,” (M. H. Stone, 1990) which can potentially be applied to muscular endurance training as well, and possibly serve to reduce the risk of injury at these sites.

Mohamad et al. studied differences in kinematic and kinetic variables in comparing a low-load high velocity protocol to a high-load low velocity protocol that were matched for volume (Mohamad, Cronin, & Nosaka, 2012). Although the findings of this study reported that several of the variables were significantly higher in the low-load high velocity protocol, including eccentric and concentric time under tension, peak force, peak power, average power, and work, the volumes were not necessarily “equal.” The low-load high velocity protocol consisted of 6 sets of 12 repetitions at 35% 1-RM and the

high-load low velocity protocol consisted of 3 sets of 12 repetitions at 70% 1-RM, but although these seem to be equal in a mathematical sense, doubling the number of sets is not equivalent to halving the load, due to the differences in motor units that different loads recruit (HENNEMAN, SOMJEN, & CARPENTER, 1965). Therefore, it is difficult to accept the report of this study that the high repetition, low-load high velocity protocol is “equal if not [a] better training stimulus than the high-load low velocity training protocol.” (Mohamad, Cronin, & Nosaka, 2012)

A negative aspect of high repetition sets is that they generally tend to elicit fatigue. For this reason, high repetition sets require particular attention in maintaining technique in these fatigued states so as to not sustain injury. Studies have found that sets of high-repetitions have a negative effect on power output when the high repetition set or sets are performed prior to the power performance measures, due to the fatigue-inducing effects of the high repetitions (Baker & Newton, 2007). Similarly, previous research has shown that, “impaired postural control can originate from the disturbance of the motor pathway by excessive repetitions of submaximal muscular contractions.” (Bizid et al., 2009; Paillard, Maitre, Chaubet, & Borel, 2010; Yaggie & McGregor, 2002) Baker et al. found that training with high repetition sets at light loads is beneficial for learning proper technique and for warming-up, and training with high repetition sets at higher loads can potentially increase power endurance, however it is important to note that power levels drop significantly after the first 5 or 6 repetitions at these higher loads (Baker & Newton, 2007).

Rest Periods. Rest periods or intervals are an important component of a training program prescription. Rest periods are used to allow for the recovery of muscle tissues,

and are also used as an element of metabolic training. Differences in rest intervals affect intensity levels, which in turn determines what energy system is being utilized. Both the intensity and metabolic energy system being employed are generally prescribed according to the specific needs of the sport that the athlete is training for, and the rest periods are used to mimic the manner or demands of the sport. Rest intervals can be manipulated within a set to dictate tempo, or can be manipulated between sets. Not only can manipulating rest intervals be used for metabolic or recovery reasons, but altering rest periods can also be used as a way to maximize certain aspects of performance. For example, a study observing different repetition schemes in the bench press found that both the highest amount of successful repetitions executed as well as the highest power outputs were completed when there was no rest allowed at the bottom of the repetitions (Pryor, Sforzo, & King, 2011). Similarly, another study comparing rest within sets to rest intervals between sets only found that the protocol with rest intervals between sets only produced lower peak power and peak velocity levels, suggesting that “Providing inter-repetition rest during a traditional set of six repetitions can attenuate decreases in power and velocity of movement through the set.” (Hansen, Cronin, & Newton, 2011)

Manipulating rest intervals between sets can help in improving performance as well. Evangelista et al. found that in comparing two set-repetition protocols, one with a one minute rest in between sets, and one with a three minute rest in between sets, the protocol with the longer rest interval between sets produced a larger total volume when the subjects were asked to continue until reaching voluntary fatigue (Evangelista, Pereira, Hackney, & Machado, 2011). There were no differences in creatine kinase activity or muscle soreness, between these two protocols, however, which suggests that the differences in

volume able to be completed does not “present any additional challenge to recovery in untrained subjects.” (Evangelista, Pereira, Hackney, & Machado, 2011)

Physiological responses to variable manipulation: Fatigue, Power, and Velocity

The effects of acute program variable manipulation can be directly identified through observation of changes in power, velocity, or force produced. Measuring power, velocity, and force is useful due to the fact that these measurements give nominal, objective data to a subjective topic such as technique. Additionally, these objective measurements are beneficial to strength & conditioning coaches in the execution of their training programs because the changes in technique that may be identified could be possible indicators of fatigue. Identifying the presence of fatigue as early as possible can facilitate in the prevention of sustaining injury during training.

Fatigue. A common component to definitions of fatigue is the appearance of a decline in force production of the muscle (Sanchez-Medina & Gonzalez-Badillo, 2011). Observing changes in force is useful in identifying a fatigued-state of the muscle, or even more so in quantifying the relative amount of fatigue. More specifically, measuring force, which also incorporates a velocity component, can therefore be used to identify or attempt to quantify the appearance or presence of fatigue. A study by Sanchez-Medina et al. looking at the correlation of decreases in velocity to metabolic responses found “an almost perfect correlation between decreases in mean propulsive velocity loss over three sets and postexercise peak lactate [was found] for both squat and bench press exercises.” (Sanchez-Medina & Gonzalez-Badillo, 2011) Because this study showed biological markers of

fatigue correlating highly with decreases in velocity measurements, it can be assumed that the observation of this type of change in velocity would be an indicator of fatigue.

Power. Similarly to force and velocity, power measurements in relation to technique can be used both as measurements of performance, and also can be used as an indicator of the presence of fatigue. Power is especially important because several athletes train specifically to increase power capabilities in order to improve performance in their sport. Specifically regarding technique, Kipp et al. found that maximal power at the knee joint, hip joint, and ankle joint was different depending on the percentage of one-repetition maximum the athlete was lifting in the power clean. Alternately said, maximal power was not reached at the same load for all three joints, but rather each joint had a specific load at which power was maximal (Kipp, Harris, & Sabick, 2011). This finding is important because it shows that from a technique standpoint, prescriptions for load must take into account the power capabilities of each individual joint, and that training to maximize power at a specific joint may hinder the power capabilities at another joint.

Another study evaluating differences in power between two protocols executed at different speeds found that the protocol executed at a self-selected volitional speed produced significantly higher power outputs in both 60% and 80% of one-repetition maximum in both the bench press and the squat exercises compared to a very slow tempo dictated protocol (Hatfield et al., 2006).

Velocity. As mentioned previously, lighter training loads are used if improving speed is the desired training goal. Improving speed is also pertinent if increasing power is the goal, because velocity is a component of power. Previous research suggests that, “the

velocity component of power may be the most difficult to shift in training,” (Hansen K., 2009) suggesting that velocity capabilities may be more quickly maximized due to physiological or genetic capabilities.

Program Variables and Technique

Increases in power and strength as well as injury risk are partially dependent upon the technique or form used to execute the squat. Technique, similar to load and volume, is a mechanical stimulus for muscular adaptation, whether it be size, strength, or power (B. T. Crewther, Cronin, & Keogh, 2008). The literature examining the effects of training protocols on technique analyses of resistance training is limited. Technique should be regarded at the highest importance in relation to other acute program variables such as volume, load, rest, and order, because it is the determining crossroad by which either the training goal is met or an injury, either acute or chronic, is sustained. In other words, if correct technique is executed, training goals can be reached, whether it be strength, power, hypertrophy, or muscular endurance, as well as gains in power and velocity, whereas if incorrect technique is executed, injury can be resultant. Technique is distinctive from other acute program variables, in a sense, because it is a more dependant variable on the other acute program variables, which are more independent (load, volume, rest and order). Alternately said, maintaining proper technique in the execution of a lift is dependent upon the athlete’s physical ability to handle the combination of volume, load, rest, and order that is prescribed. These concepts are illustrated in Figure 2.1 below.

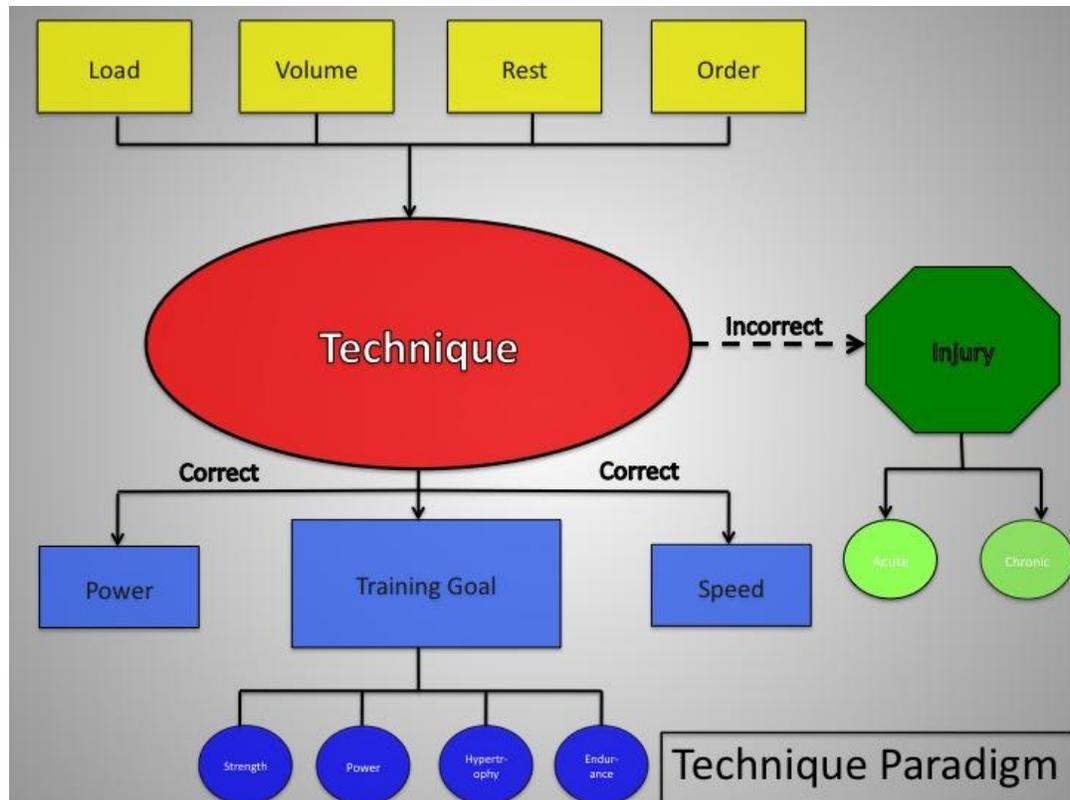


Figure 2.1 As can be seen in the paradigm, technique is the direct pathway from acute program variables to the desired training goal, and is therefore centrally located. With correct technique execution, the training goal can be met, whereas with incorrect technique execution, injury can be sustained.

Technique in the squat is important because one must be able to move in a manner to execute the lift correctly in order to maximize performance gains and to avoid injury. It has been suggested that in order to perform the basic squat movement pattern efficiently, one requires mobility of the ankle, hip and thoracic spine; while requiring stability of the foot, knee, and lumbar spine (Lynn & Noffal, 2011). There exists much discrepancy surrounding the proper execution of the squat exercise, and there is no “right” answer. Squat technique is important, however, because when strength is close to maximization, technique can further increase strength and power gains, and can also minimize the incidence of injury. Additionally, technique and volume, in combination

with intensity, “appear [to be] the major determinants of set kinematics and kinetics.” (B. T. Crewther, Cronin, & Keogh, 2008) Kinematics and kinetics, or the study of motion and the forces applied to a mass, are important in applying resistance training to sport specific movements, or in other words, translating the strength training movements to the sport itself.

The National Strength and Conditioning Association published a position statement in 1991 addressing proper technique execution of the squat exercise. The general guidelines suggest technique factors to both maximize performance as well as decrease incidence of or exposure to injury. The guidelines defining proper technique include:

- “Use approximately a shoulder-width foot stance.
- Descend in a controlled manner. Ascent can be made at a variety of speeds. At faster speeds there should be no compromise in technique.
- Proper breath control is important to support the torso. The breath should be held from the start of the descent until the athlete passes the sticking point on the ascent.
- Avoid bouncing or twisting from the bottom position.
- Maintain a normal lordotic posture with the torso as close to vertical as possible during the entire lift.
- Generally, in typical back or front squats, descend only until the tops of the thighs are parallel to the floor or slightly below. Exceptions can be made for sports that require lower positions.

- Feet should be kept flat on the floor.
- Forward lean on the knee increases shear forces on the knee. Keeping the shin perpendicular may increase shear forces on the back as a result of forward trunk inclination. Although there are exceptions, the shin generally should remain as vertical as possible to reduce shear forces at the knee. Maximal forward movement of the knees should place them no more than slightly in front of the toes. Depending on the type of squat being used, volume and intensity should not be increased at a rate that exceeds the body's ability to adapt to the imposed demands.
- Every effort should be made to maintain a consistent stable pattern of motion for each repetition, in order to load the muscles in a consistent manner and help prevent injury.” (Chandler & Stone, 1991)

Each one of these guidelines is specific to a component of the squat exercise that could potentially elicit injury. Minimizing shear forces to the knee and excessively loading the lower back or hips are of the highest concern which is evident in these guidelines. Still, there is no “right” way to squat, but there are incorrect ways, namely those with the ability to cause injury.

Aspects of Technique

Control. Control is an aspect of technique that is addressed in the guidelines. As stated by Bobbert et al., “control, also called coordination, may be

operationalized as the stimulation of muscles as a function of time, which ultimately determines the resulting movement.” (Bobbert, van der Krogt, van Doorn, & de Ruitter, 2011)

Control in most lifting techniques, specifically the squat exercise, is important because it plays an imperative role in optimization and maximization, and also because it has a great potential to cause injury if it does not receive proper attention (Bobbert, van der Krogt, van Doorn, & de Ruitter, 2011). Bobbert et al. reported that the effort to match control to the musculoskeletal properties of the muscle, whether it was in a fatigued or unfatigued state, resulted in the maximization of total work. Another study analyzing differences in postural control compared voluntary muscular contraction to electrical stimulation. This study presented the idea that because postural control is mainly controlled by slow-twitch Type I fibers, and due to the fact that during voluntary muscle contraction, muscle fibers are recruited in order from small to large in accordance to the size principle, (HENNEMAN, SOMJEN, & CARPENTER, 1965) the Type I fibers that are responsible for maintaining postural control are the first to fatigue. The fatigued state of the Type I fibers make maintaining posture difficult, and because this task is unfeasible for Type II fibers, postural control is lost in high repetition sets (Paillard, Maitre, Chaubet, & Borel, 2010). This combined evidence displays the importance of control as an aspect of technique in the squat, and why it demands attention.

Foot Placement. Foot placement, which is also addressed in the guidelines, is an important technique factor worth attention. Placement of the feet affects the distribution of stress on the muscle groups. “Placement of the user’s feet closer under the body results in greater stress on the quadriceps and more work done by these muscles.

Placement of the feet farther in front of the body generates more stress on, and work done by the glutes and hamstrings.” (Abelbeck, 2002) Differences in lower back loading during a box lifting exercise were observed when foot placement was varied in relation to a box that was marked on the floor (Kingma, Bosch, Bruins, & van Dieen, 2004). “Lifting with the feet beside the box rather than with the feet behind the box reduced the difference in back loading between squat and stoop lifts.” (Kingma, Bosch, Bruins, & van Dieen, 2004) Such positioning can help reduce the risk of lower back injury. Maintaining consistent foot placement while doing the squat lift is important for consistency in training.

Asymmetry. Because the squat lift is a bilateral exercise, asymmetries are sometimes a concern regarding technique in training. Asymmetries may be well tolerated in this particular exercise, however, but consistent technique is required. Hodges et al. found that the free-weight barbell back squat did not negatively impact athletes with bilateral asymmetries, and even improved their bilateral asymmetries when the subjects were in a fatigued state (Hodges, Patrick, & Reiser, 2011). Similarly, a different study on side dominance and its effects on bar end power outputs found that even if an athlete favored or was dominant on one side of his or her body, there were no significant differences in the bar end power outputs between the right and left sides (Lake, Lauder, & Smith, 2011). This evidence suggests that athletes with functional bilateral asymmetries should not be deterred from implementing the free-weight barbell back squat in their training regimen, and that it may even improve any deficiencies that are present.

Injury in Resistance Training and the Squat

With resistance training comes the potential risk of injury. Injuries can be either acute or chronic in resistance training; acute occurring from a single incident and chronic occurring from overuse of a certain muscle or a certain joint. A study observing the epidemiology of weight-training related injuries arriving at Emergency Rooms reported that the most common injuries were sprains or strains, the most common mechanism of injury was dropping weights, and the majority of injuries occurred with the use of free weights (Kerr, Collins, & Comstock, 2010). These injuries seem to be more acute in nature than chronic, and assumingly amongst a more recreational population, due to the fact that the athlete population typically has other resources besides an emergency department to treat or evaluate injury. A study observing power lifters, however, reported that the most commonly injured areas of the body were the shoulders, lower back, and knee (Siewe et al., 2011) which seems more applicable to the squat. Also, Keogh et al. reported that in another injury epidemiology analysis, acute injuries were more prevalent than chronic injuries in competitive power lifters (J. Keogh, Hume, & Pearson, 2006).

There is conflicting evidence in the literature suggesting whether or not the squat exercise poses an injury risk. As mentioned previously, improper technique can lead to knee joint instability, injury, and fatigue-related problems (Chandler & Stone, 1991). If injury is sustained during execution of the squat exercise, some aspect of poor technique is likely to be the cause. Common injuries sustained during the squat exercise typically affect the lower back, hips, and knees. The NSCA position statement reports that, “injuries attributed to the squat may result not from the exercise itself, but from improper

technique, pre-existing structural abnormalities, other physical activities, fatigue or excessive training.” (Chandler & Stone, 1991)

Knee. Specifically in relation to the knee, there is literature that supports and also negates injury caused directly by the squat exercise. Weakness in the hips has been suggested as a possible cause of conditions at the knee (Lynn & Noffal, 2011). The only research to suggest that the squat exercise causes joint instability at the knee was done by Klein et al. who reported findings that the deep squat exercise permanently stretched the ligaments of the knee. A review paper on technique and safety in resistance exercises reported that there was greater tension at the knee in the full squat compared to the parallel squat, which could be a potential cause of patellofemoral syndrome (Colado & Garcia-Masso, 2009).

As mentioned previously, control is an important aspect of technique in the squat, and is also a large potential source of injury. The mismatch of control to musculoskeletal properties that Bobbert et al. studied in relation to force maximization also had an analysis of potential injury. In this study, the fatigued state of the plantarflexor muscles caused a hyperextension of the knee joint at takeoff. Although previous research has reported that forced hyperextension at the knee joint can lead to soft tissue damage, (Fornalski, McGarry, Csintalan, Fithian, & Lee, 2008) Bobbert et al. reported that the mismatch of control to musculoskeletal properties at takeoff is an unlikely source of injury due to the fact that none of the subjects reported any discomfort at the knee. The study did report, however, that their findings could not rule out the possibility of potential injury during landing or when large contact forces were involved (Bobbert, van der Krogt, van Doorn, & de

Ruiter, 2011). For this reason, it must be stated that the lack of the ability to control in a fatigued state does have the potential to cause damage to the soft tissues of the knee.

A review paper on biomechanics of the knee during the squat exercise, on the other hand, concluded that the squat exercise, when executed with proper technique “does not compromise knee stability, and may enhance stability if performed correctly.”

(Escamilla, 2001) The NSCA position statement on the squat exercise also states that the squat exercise does not diminish knee joint stability when done properly (Chandler & Stone, 1991). Chandler et al. also found that the full squat exercise does not cause permanent stretching of the knee ligaments, and did not decrease knee stability in either the half squat or full squat exercise (Chandler, Wilson, & Stone, 1989). Additionally, the NSCA position statement affirms that “squats, when performed correctly and with appropriate supervision, are not only safe, but may be a significant deterrent to knee injuries.”

(Chandler & Stone, 1991) Another study adds “the full-range motion of the squat is the best protection against knee injury.” (O'Shea, JP, Wegner, J., 1981)

As is evident by the above statements, there is far more research published in the literature to support the idea that the squat exercise does not negatively impact the knee and may deter knee injury, as long as proper technique is executed, than the idea that the squat exercise is detrimental to knee function, or is an injury provoking exercise.

Sex. It has also been shown that females experience injury at the knee joint more commonly than men (Lynn & Noffal, 2011). There are several different possible causes of these discrepancies which include a difference in muscle activation or structural differences. A five-year evaluation of anterior cruciate ligament injuries in NCAA

collegiate basketball and soccer players found that incidence of injury in both female sports was significantly higher than their male counterparts. Possible causes of this difference were listed to be either “intrinsic (joint laxity, limb alignment, notch dimensions, and ligament size) or extrinsic (body movement, muscular strength, shoe-surface interface, and skill level).” (Arendt & Dick, 1995)

As is evident by all the previous research presented here, several different aspects of technique in the squat, such as load, rest intervals, and power and velocity outputs, have previously been studied and analyzed. Although these different aspects have been analyzed, however, there exists a deficit in how these different components either collectively impact changes in technique execution or can be used to identify changes in technique execution. More specifically to the current study being presented, lacking in the literature base is analyses of how different set-repetition schemes affect technique, or to what degree technique is affected, when load and volume are kept constant. Using two-dimensional motion analysis software to evaluate technique, this study seeks to utilize technological advances to enhance analysis. Bridging the gap between analyzing individual specific components which constitute technique and rather observing changes in technique as a whole will serve beneficial to the literature because of the significant impact technique execution has on reaching a specific and desired training goal.

References

1. Abelbeck, K. G. (2002). Biomechanical model and evaluation of a linear motion squat type exercise. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 16*(4), 516-524.
2. Arendt, E., & Dick, R. (1995). Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *The American Journal of Sports Medicine, 23*(6), 694-701.
3. Baker, D. G., & Newton, R. U. (2007). Change in power output across a high-repetition set of bench throws and jump squats in highly trained athletes. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 21*(4), 1007-1011.
4. Bizid, R., Margnes, E., Francois, Y., Jully, J. L., Gonzalez, G., Dupui, P., et al. (2009). Effects of knee and ankle muscle fatigue on postural control in the unipedal stance. *European Journal of Applied Physiology, 106*(3), 375-380.
5. Bobbert, M. F., van der Krogt, M. M., van Doorn, H., & de Ruitter, C. J. (2011). Effects of fatigue of plantarflexors on control and performance in vertical jumping. *Medicine and Science in Sports and Exercise, 43*(4), 673-684.
6. Chandler, T. J., & Stone, M. H. (1991). The squat exercise in athletic conditioning: A position statement and review of the literature. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 13*(5), 51-52, 53, 54, 55, 56, 57, 58.
7. Chandler, T. J., Wilson, G. D., & Stone, M. H. (1989). The effect of the squat exercise on knee stability. *Medicine and Science in Sports and Exercise, 21*(3), 299-303.

8. Clark, D. R., Lambert, M. I., & Hunter, A. M. (2012). Muscle activation in the loaded free barbell squat: A brief review. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 26(4), 1169-1178.
9. Colado, J. C., & Garcia-Masso, X. (2009). Technique and safety aspects of resistance exercises: A systematic review of the literature. *The Physician and Sportsmedicine*, 37(2), 104-111.
10. Cormie, P., McGuigan, M. R., & Newton, R. U. (2010). Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. *Medicine and Science in Sports and Exercise*, 42(9), 1731-1744.
11. Crewther, B., Cronin, J., & Keogh, J. (2005). Possible stimuli for strength and power adaptation: Acute mechanical responses. *Sports Medicine (Auckland, N.Z.)*, 35(11), 967-989.
12. Crewther, B. T., Cronin, J., & Keogh, J. W. (2008). The contribution of volume, technique, and load to single-repetition and total-repetition kinematics and kinetics in response to three loading schemes. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 22(6), 1908-1915.
13. Delavier, F. (2003). *Women's strength training anatomy*. Champaign, IL: Human Kinetics.
14. Escamilla, R. F. (2001). Knee biomechanics of the dynamic squat exercise. *Medicine and Science in Sports and Exercise*, 33(1), 127-141.
15. Evangelista, R., Pereira, R., Hackney, A. C., & Machado, M. (2011). Rest interval between resistance exercise sets: Length affects volume but not creatine kinase

- activity or muscle soreness. *International Journal of Sports Physiology and Performance*, 6(1), 118-127.
16. Fleck, S. J., & Kraemer, W. J. (2004). *Designing resistance training programs*. Champaign, IL: Human Kinetics.
 17. Fornalski, S., McGarry, M. H., Csintalan, R. P., Fithian, D. C., & Lee, T. Q. (2008). Biomechanical and anatomical assessment after knee hyperextension injury. *The American Journal of Sports Medicine*, 36(1), 80-84.
 18. Hansen K., C. J. (2009). Training loads for the development of lower body muscular power during squatting movements. *Strength and Conditioning Journal*, 31(3), 17-33.
 19. Hansen, K. T., Cronin, J. B., & Newton, M. J. (2011). The effect of cluster loading on force, velocity, and power during ballistic jump squat training. *International Journal of Sports Physiology and Performance*,
 20. Hatfield, D. L., Kraemer, W. J., Spiering, B. A., Hakkinen, K., Volek, J. S., Shimano, T., et al. (2006). The impact of velocity of movement on performance factors in resistance exercise. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 20(4), 760-766.
 21. HENNEMAN, E., SOMJEN, G., & CARPENTER, D. O. (1965). Functional significance of cell size in spinal motoneurons. *Journal of Neurophysiology*, 28, 560-580.
 22. Hodges, S. J., Patrick, R. J., & Reiser, R. F., 2nd. (2011). Effects of fatigue on bilateral ground reaction force asymmetries during the squat exercise. *Journal of*

Strength and Conditioning Research / National Strength & Conditioning Association, 25(11), 3107-3117.

23. Holm, L., Reitelseder, S., Pedersen, T. G., Doessing, S., Petersen, S. G., Flyvbjerg, A., et al. (2008). Changes in muscle size and MHC composition in response to resistance exercise with heavy and light loading intensity. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 105(5), 1454-1461.
24. Keogh, J., Hume, P. A., & Pearson, S. (2006). Retrospective injury epidemiology of one hundred one competitive oecania power lifters: The effects of age, body mass, competitive standard, and gender. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 20(3), 672-681.
25. Kerr, Z. Y., Collins, C. L., & Comstock, R. D. (2010). Epidemiology of weight training-related injuries presenting to united states emergency departments, 1990 to 2007. *The American Journal of Sports Medicine*, 38(4), 765-771.
26. Kingma, I., Bosch, T., Bruins, L., & van Dieen, J. H. (2004). Foot positioning instruction, initial vertical load position and lifting technique: Effects on low back loading. *Ergonomics*, 47(13), 1365-1385.
27. Kipp, K., Harris, C., & Sabick, M. B. (2011). Lower extremity biomechanics during weightlifting exercise vary across joint and load. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 25(5), 1229-1234.
28. Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., Feigenbaum, M. S., et al. (2002). American college of sports medicine position stand. progression

- models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, 34(2), 364-380.
29. Kraemer, W. J., Duncan, N. D., & Volek, J. S. (1998). Resistance training and elite athletes: Adaptations and program considerations. *The Journal of Orthopaedic and Sports Physical Therapy*, 28(2), 110-119.
30. Kraemer, W. J., Gordon, S. E., Fleck, S. J., Marchitelli, L. J., Mello, R., Dziados, J. E., et al. (1991). Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *International Journal of Sports Medicine*, 12(2), 228-235.
31. Lake, J. P., Lauder, M. A., & Smith, N. A. (2011). Does side dominance affect the symmetry of barbell end kinematics during lower-body resistance exercise? *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 25(3), 872-878.
32. Lynn, S. K., & Noffal, G. J. (2011). Lower extremity biomechanics during a regular and counter-balanced squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*,
33. Mohamad, N. I., Cronin, J. B., & Nosaka, K. K. (2012). Difference in kinematics and kinetics between high- and low-velocity resistance loading equated by volume: Implications for hypertrophy training. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 26(1), 269-275.
34. O'Shea, JP, Wegner, J. (1981). Power weight training and the female athlete. *Physician and Sportsmedicine*, 9(6), 109-120.

35. Paillard, T., Maitre, J., Chaubet, V., & Borel, L. (2010). Stimulated and voluntary fatiguing contractions of quadriceps femoris differently disturb postural control. *Neuroscience Letters*, 477(1), 48-51.
36. Pereira, G. R., Leporace, G., Chagas, D. V., Furtado, L. F., Praxedes, J., & Batista, L. A. (2010). Influence of hip external rotation on hip adductor and rectus femoris myoelectric activity during a dynamic parallel squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 24(10), 2749-2754.
37. Pryor, R. R., Sforzo, G. A., & King, D. L. (2011). Optimizing power output by varying repetition tempo. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 25(11), 3029-3034.
38. Sanchez-Medina, L., & Gonzalez-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise*, 43(9), 1725-1734.
39. Sato, K., Fortenbaugh, D., & Hydock, D. S. (2012). Kinematic changes using weightlifting shoes on barbell back squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 26(1), 28-33.
40. Sato, K., & Heise, G. D. (2012). Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*,
41. Shimano, T., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., et al. (2006). Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and

- untrained men. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 20(4), 819-823.
42. Siewe, J., Rudat, J., Rollinghoff, M., Schlegel, U. J., Eysel, P., & Michael, J. W. (2011). Injuries and overuse syndromes in powerlifting. *International Journal of Sports Medicine*, 32(9), 703-711.
43. Smilios, I., Hakkinen, K., & Tokmakidis, S. P. (2010). Power output and electromyographic activity during and after a moderate load muscular endurance session. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 24(8), 2122-2131.
44. Stone, M., Plisk, S., Stone, M., Schilling, B., O'Bryant, H., & Pierce, K. (1998). Athletic performance development: Volume load - 1 set vs multiple sets, training velocity and training variation. *Strength and Conditioning Journal*, 20, 22-31.
45. Stone, M. H. (1990). Muscle conditioning and muscle injuries. *Medicine and Science in Sports and Exercise*, 22(4), 457-462.
46. Yaggie, J. A., & McGregor, S. J. (2002). Effects of isokinetic ankle fatigue on the maintenance of balance and postural limits. *Archives of Physical Medicine and Rehabilitation*, 83(2), 224-228.

CHAPTER 3

METHODS

Experimental Approach to the Problem

The testing protocol consisted of five testing visits. The first visit was a one-repetition maximum test for the squat. The second visit was a familiarization that consisted of a practice trial of the one set of thirty repetition protocol. The last three visits were actual testing visits assigned in a balanced, randomized order, which were either one set of thirty repetitions, three sets of ten repetitions, or ten sets of three repetitions all at sixty percent of the subject's tested one repetition maximum. The visits that consisted of more than one set included a three minute rest period between each set.

Subjects

Twenty subjects (10 males and 10 females) between the ages of 18-35 were recruited for this research study. Each subject was required to have at least six months of lower body resistance training experience, specifically with experience in the squat exercise. Subjects were also required to be squatting on a regular and consistent basis at the time of recruitment. All the subjects were medically cleared to participate by the medical monitor. A summary of anthropometric measurements as well as the ratio of one repetition maximum in the squat exercise to body weight (Cormie, McGuigan, & Newton, 2010) is provided in Table 3.1.

	n=	Age (yr)	Height (cm)	Weight (kg)	Wt/BW
		24.3 ±			
Men	10	2.8	179.7 ± 5.7	85.5 ± 12.5	1.7 ± 0.2
		23.9 ±			
Women	10	2.4	166.2 ± 9.1	66.754 ± 8.4	1.3 ± 0.3
All		24.1 ±			
Subjects	20	2.5	172.9 ± 10.2	76.1 ± 14.1	1.5 ± 0.3

Warm-Up

Each subject completed a standardized warm-up protocol prior to each of the five visits. The warm-up consisted of 5 minutes on a cycle ergometer at a resistance level of 5 and a speed of 60 rpms followed by a series of dynamic stretches including body weight squats, forward and lateral lunges, knee hugs, quadriceps stretches and a straight leg march.

1-Repetition Maximum (1-RM) Test

The subject's first visit consisted of anthropometric height and weight measurements followed by a one-repetition maximum test (1-RM). Each 1RM test followed the same protocol. After completing the standardized warm-up protocol, a warm up set consisting of 8-10 repetitions at a weight of fifty percent of the subject's predicted 1-RM was performed. This and each successive set was followed by a 3 minute rest period. A second warm-up set of 80% predicted 1-RM was then performed. These two warm up sets were followed by a first attempt of one repetition at a weight that the subject was believed to be able to complete. After each successful lift, the weight was

increased and another lift was attempted. 1-RM was considered the most amount of weight the subject could lift one time with appropriate technique. 1-RM was reached within 5 attempts for all subjects. (Kraemer et al., 1991)

Familiarization

The familiarization visit began with the standardized warm-up. Next, the subject was asked to perform 2-3 squats without any added load on the bar to determine the subject's foot placement for all of the following visits. The subject's foot placement was marked by pieces of tape with the subject's identification number placed on the floor mat medial, lateral, and anterior to the toes.

The familiarization visit was then completed with a practice trial of the one set of thirty repetition protocol at 60% of the subject's tested 1RM. As it was assumed and then confirmed by each subject prior to starting the study that subjects were unfamiliar with training at one set of thirty repetitions at 60% of the subject's 1RM, subjects completed this protocol prior to the actual testing visit as to expose or familiarize them to this type of high intensity workout. A linear transducer (*Tendo Sport Machines, Slovak Republic*) unit was attached to the bar during the familiarization visit so that the subject could feel any differences it might add, but no values from the unit were collected during this visit.

The subjects were instructed to squat to parallel at minimum during the familiarization visit but could squat past parallel if that was how he or she trained. Subjects were not given instructions or coaching in regards to squat depth for the remaining of the testing visits after the familiarization visit as this would influence the technique variables being measured. A minimum squat depth was not dictated for the

testing visits because the depth of the squat was not expected to alter muscle activation (Clark, Lambert, & Hunter, 2012).

Testing Protocol

The final three visits were assigned to the subjects in a balanced, randomized order. Subjects were required not to exercise 48 hours prior to each testing visit, and were also required to consume the same diet 24 hours prior to each testing visit. Subjects were unaware of which testing protocol he or she would be performing that day until he or she arrived for the visit. The three testing protocols were either one set of thirty repetitions (1x30), three sets of ten repetitions (3x10), or ten sets of thirty repetitions (10x3), all at 60% of the subject's tested 1RM of the squat. The linear transducer unit was attached to the bar for all testing protocols. Peak power and peak velocity values of each repetition was recorded off of the linear transducer.

Each subject first completed the standardized warm up. Three stickers, designed to provide a color contrast that was easily detected by the analysis software, were then placed on the subject's lateral malleolus, lateral to the patella, and lateral to the anterior superior iliac spine. A sticker was also placed on the end of the bar. All testing visits were recorded on a camcorder (*Canon VIXIA HF R20 Camcorder, Lake Success, NY*) which was placed perpendicular to the subject.

Rest. For the 3x10 and 10x3 protocols, three minutes rest was taken in between each set, and the subject could not take a longer or shorter rest period. For the 1x30 protocol, because there was only one set, there was no rest interval assigned. The subject was required to complete thirty repetitions to the best of his or her ability. The subject

could pause within the set but was not allowed to rack the bar until thirty repetitions were completed.

2-Dimensional Analyses

The video recordings of each testing visit were later analyzed using the Dartfish (*Dartfish Video Solutions Version 6.0, Fribourg, Switzerland*) 2-dimensional motion analysis software program. Hip and knee angle measurements were taken by placing markers over the stickers that were on the subject. For the purpose of this study, “hip angle” is defined as the angle of flexion at the hip joint which has possible contributions from the trunk, hip and thigh flexing (illustrated in Figure 3.1). The vertex of the hip angle was set at the sticker marking lateral to the anterior superior iliac spine, and the rays were set to end: 1. on the bar, 2. lateral to the patella. Also for the purpose of this study, “knee angle” is defined as the angle of flexion at the knee joint due to flexion of the thigh. The vertex of the knee angle was set at the sticker marking lateral to the patella and the rays were set to end: 1. Lateral to the anterior superior iliac spine, 2. Lateral malleolus. Angle measurements were recorded for each repetition of each testing protocol at the “bottom” of each repetition. The “bottom” of each repetition was determined to be the last frame at the bottom of the subject’s squat before upward movement began (Sato, Fortenbaugh, & Hydock, 2012). Figure 3.1 provided below is an example of how the motion analysis software was used to measure angles.



Figure 3.1 Dartfish software was used to draw trajectory lines connecting the stickers on the subject's body and on the bar, and the angles between the lines were recorded at the bottom of each repetition before the first frame of upward movement.

Statistical Analyses

All values are presented as means and standard error (SE). The data sets met the assumptions for linear statistics. A priori power analysis determined an individual group size of $n=18$ (9 males and 9 females) would be adequate to defend the 0.05 alpha level of significance with a Cohen probability of at least 0.50 for each dependent variable.

Therefore, a total of $n=20$ (10 males and 10 females) were tested to ensure fulfillment of the minimal statistical requirements to defend the proposed significance level. Data was analyzed using a three-way (gender by condition by time) analysis of variance with repeated measures (MANOVA). When necessary, a Fisher LSD post hoc test was used to determine pair-wise differences between the means. Significance for this study was set at $p < 0.05$. All statistics were calculated with SPSS 17 statistical software.

CHAPTER 4

RESULTS

The statistical findings reported below were determined by using a three-way (gender by condition by time) analysis of variance with repeated measures (MANOVA). The three conditions as defined by the statistical model were the three training protocols (one set of 30 repetitions, three sets of 10 repetitions, and ten sets of 3 repetitions,) and time was defined in a pre to post fashion, where pre was the first three repetitions in any given training protocol, and post was the last three repetitions in that same protocol. All subjects with the exception of one were able to finish all training protocols. For this subject, the data for last three repetitions for that protocol were determined using repetitions 25 through 27. The four dependent variables that were observed were: 1. Power 2. Velocity 3. Hip Angle 4. Knee Angle.

Power

The MANOVA showed a significant three-way interaction ($p \leq 0.001$) between gender by condition by time in the power variable. Secondly, There was a significant overall gender effect ($p < 0.001$). The power values in the males decreased significantly from pre to post in the 1x30 protocol ($p < 0.001$), but the females had no significant differences in power either within conditions (pre to post) or between conditions. These findings are presented below in Figure 4.1.

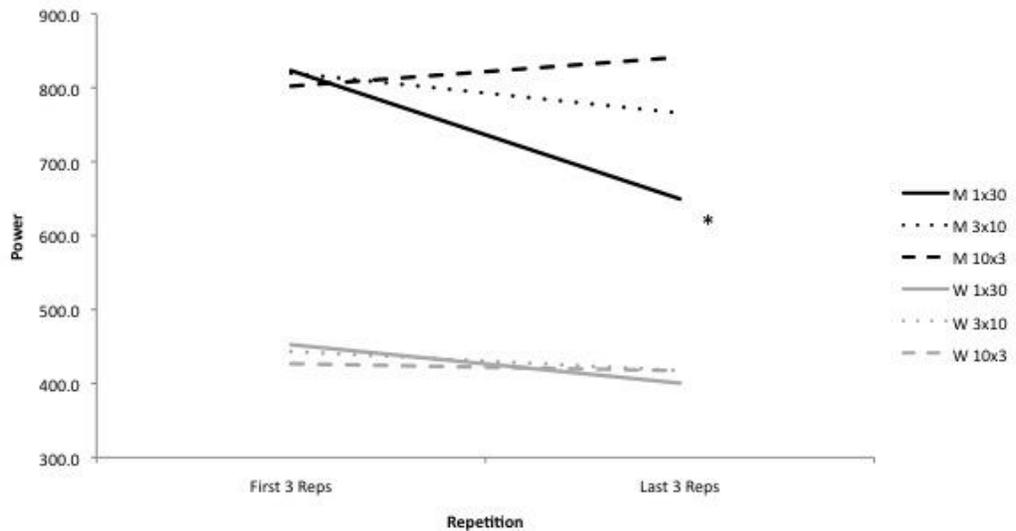


Figure 4.1 Mean power values as a function of repetition number. *Significant difference between the first three repetitions and the last three repetitions in that protocol where $p \leq 0.05$.

Velocity

The MANOVA showed a significant three-way interaction ($p \leq 0.010$) between gender by condition by time in the velocity variable. The velocity values decreased significantly in the males for the 1x30 protocol, and in the females in both the one set of thirty repetition protocol ($p = 0.01$) as well as in the three sets of ten repetition protocol ($p = 0.047$). No overall significant differences between genders existed in the velocity variable. These findings are presented below in Figure 4.2.

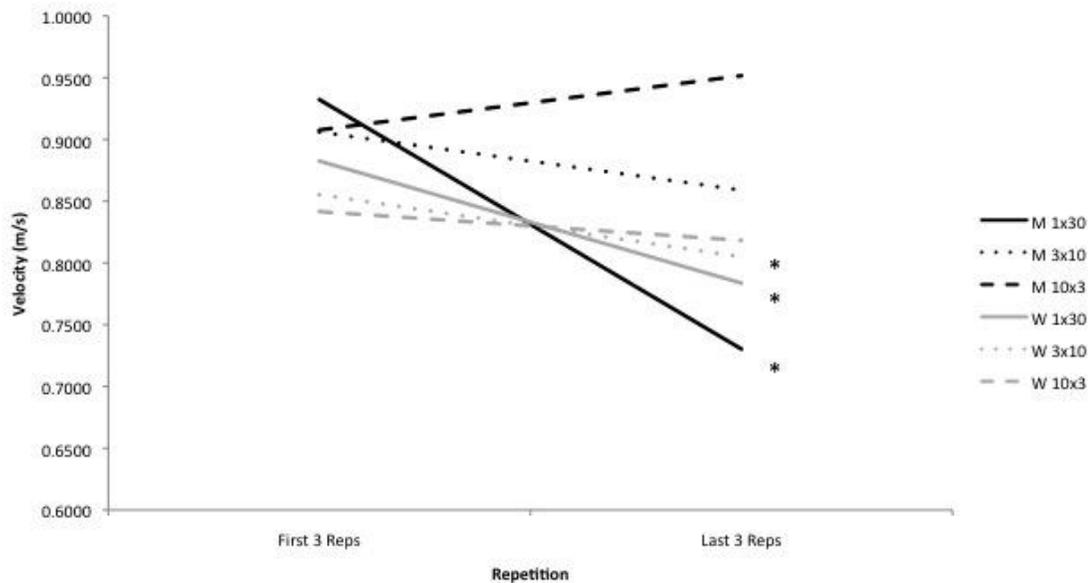


Figure 4.2 Mean bar velocity values as a function of repetition number. *Significant difference between the first three repetitions and the last three repetitions in that protocol where $p \leq 0.05$.

Hip Angle

The MANOVA showed a significant two-way interaction ($p = 0.026$) for condition by time in the hip variable. There was a main overall effect for gender ($p = 0.023$) where men had greater hip angles than women in all conditions and time points. Secondly, there was a significant overall time effect in comparing the mean of the first three repetitions to the mean of the last three repetitions ($p = 0.044$) in all conditions. Thirdly, in the 3x10 repetitions protocol, there were significant differences between the mean of the hip angles in the first three repetitions compared to the mean of the last three repetitions ($p < 0.01$) in both men and women. These findings are presented below in Figure 4.3.

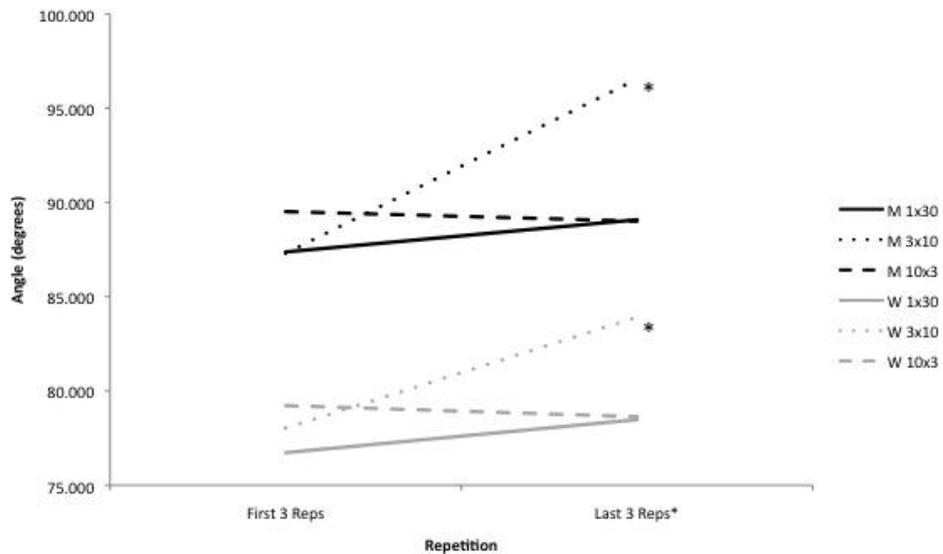


Figure 4.3 Mean hip flexion angles as a function of repetition number. *Significant difference between the first three repetitions and the last three repetitions in that protocol where $p \leq 0.05$.

Knee Angle

The MANOVA showed significant differences between conditions in the knee angle variable ($p = 0.020$), but no significant differences existed between genders or between pre and post times. Both the 3x10 protocol ($p = 0.001$) and the 10x3 protocol ($p = 0.019$) differed significantly from the one set of thirty repetition protocol in the knee angle variable. These findings are presented below in Figure 4.4.

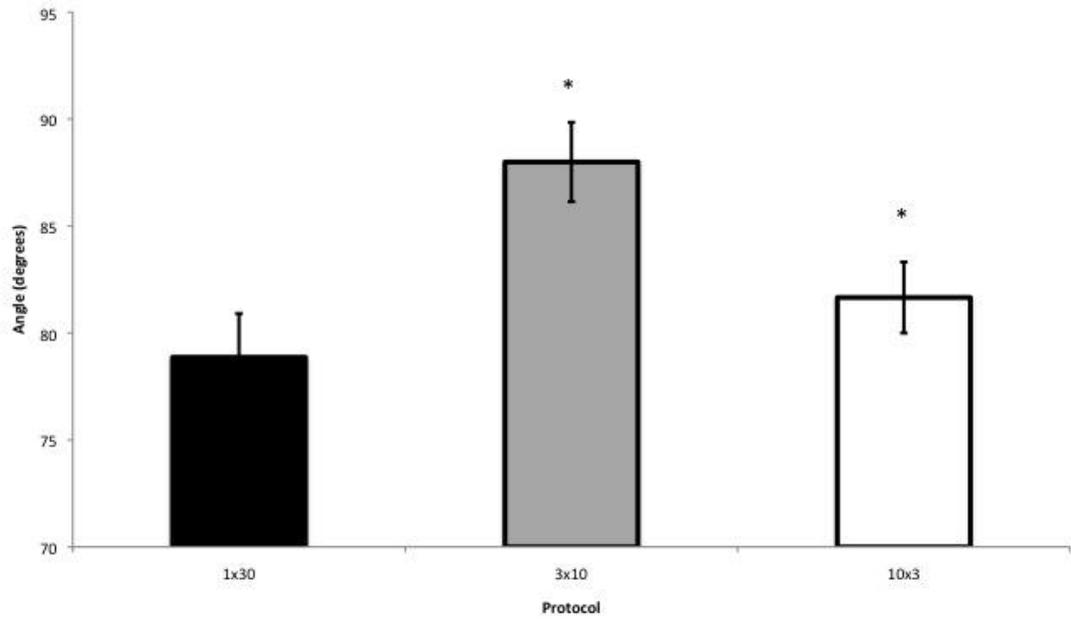


Figure 4.4 Mean knee flexion angles for each protocol. *Significant difference from the 1x30 protocol where $p \leq 0.05$.

DISCUSSION

The goal of this study was to examine differences in technique variables between three different set-repetition protocols, and to observe whether differences in technique existed between genders. Significant differences between the three testing protocols were found in all four dependent variables: power, velocity, hip angles, and knee angles, as well as between genders where $p \leq 0.05$. The one exception to this was the results of the knee variable where no gender differences were present and therefore the null hypothesis was accepted.

The results of the power variable supported both hypotheses. Firstly, there was a significant decrease in the first three repetitions compared to the last three repetitions in the 1x30 repetition protocol for the men. Secondly, there was an overall gender effect in the power variable, with power values for the men significantly higher than those of the women for all repetitions in all protocols. Both of these results are supported by previously published evidence in the literature. Baker et al. reported that training with high repetition sets at higher loads can potentially increase power endurance, though power levels drop significantly after the first 5 or 6 repetitions at these higher loads. (Baker & Newton, 2007) This serves as an explanation as to why power values dropped in the 1x30 protocol.

In the women, there were no statistically significant differences between protocols or from first repetitions to last repetitions for power values, which may be attributed to the fact that the one-repetition maximum value to body mass ratio was significantly lower in women than men ($p = 0.004$), where men were squatting a much higher load relative to

their body mass than the women were. The absolute differences between genders in the power variable is due to the fact that the men were squatting with a significantly higher load on their back than the women, as peak power of the bar takes into account the load on the bar when using the linear transducer.

The results of the power variable were valuable and are very pertinent and applicable to training because the load, being 60% of each subject's one-repetition maximum, is a load that is often used in training for power. A review paper by Hansen et al. stated that, "in general, percent changes and effect sizes of peak power measures were greater following moderate load training compared to heavy load training." (Hansen K., 2009) With 60% of 1-RM falling into the "moderate load training" category, the question becomes which of the three training protocols observed in this study was most beneficial in improving power. The results of this study suggest that the protocols that did not have a significant decrease in power from beginning to end, the 3x10 protocol and the 10x3 protocol, are beneficial in training for power because it was able to be produced and maintained throughout. The 1x30 protocol however, seems unsuitable for training for power because the significant decrement in power values throughout the protocol reflects an inability to produce or maintain power, and more broadly an inability to maintain technique. It must be noted, however, that Hansen et al. reference training over certain periods of time, whereas this was an acute study. Other published research, however, states that, "acute fatigue in submaximal squatting task results in increased muscle activation corresponding to a loss of power across the task," (Clark, Lambert, & Hunter, 2012; Smilios, Hakkinen, & Tokmakidis, 2010) which likely serves as the explanation to this loss of power.

The results of the velocity variable supported the hypothesis that differences would exist from the first three repetitions to the last three repetitions in the 1x30 protocol in both the men and women, and so the null hypothesis was rejected. These results are supported by previous research in the literature by Sanchez et al. who stated that, “the magnitude of velocity loss experienced during resistance training gradually increases as the number of performed repetitions in a set approaches the maximum number predicted.” (Sanchez-Medina & Gonzalez-Badillo, 2011)

The results of this study are pertinent if improving velocity or speed, or even power is the primary training goal. Velocity should not be seen as a variable separate from power as velocity is a component of power. Hansen et al. stated that, “the velocity component of power may be the most difficult to shift in training,” (Hansen K., 2009) because none of the studies in the review showed more than a “small” magnitude in effect size in regards to velocity changes over a certain training period. The results of this study did show changes in velocity, especially in the women, who had significant differences between first three repetitions and last three repetitions in two out of the three protocols, but who had no significant differences in power from pre to post in any of the three protocols. It is difficult to say, however, whether or not these changes within a set-repetition scheme have an effect on improving velocity in training over time.

It is noteworthy though, that acutely, especially in women, power can be maintained even if velocity decreases, suggesting an increase in force during the progression of a given set-repetition scheme. A logical explanation for this increase in force, which has been previously suggested in the literature, is due to “an increased central drive to maintain work through increased motor unit recruitment.” (Smilios, Hakkinen, & Tokmakidis, 2010)

The results of the hip angle variable were supported by both hypotheses: the null hypotheses were rejected that no differences existed between conditions and also between genders. The results of the hip variable did not, however, support the hypothesis that the greatest change from first three repetitions to last three repetitions would occur in the 1x30 protocol, being that it in fact occurred in the 3x10 protocol in both men and women. There were no significant differences in either the 1x30 protocol or the 10x3 protocol for both men and women.

The results of the hip angle variable in the present study are contributory to the literature as well. The hip angle measurements taken were a combination of trunk flexion, hip flexion, and thigh flexion. Previous research has shown that activation of the muscles of the trunk, namely the rectus abdominis, external obliques, and the erector spinae, are used to determine the amount of stability or lack thereof during the execution of the squat exercise. (Clark, Lambert, & Hunter, 2012) The findings of this study, however, showed an inability to maintain hip angle in the 3x10 protocol, but no significant decreases in power in this protocol. Also, there were no significant decreases in velocity in the men in this protocol, however, there was a significant decrease in velocity in the women in this protocol. This evidence shows that it is likely that power and possibly velocity can be produced or maintained even if instability increases with the progression of a set or sets.

The results of the hip angle variable, as mentioned previously, have potential contributions from the muscles at the hip in addition to those of the trunk. Previous research looking at hip adductor activation in the squat in different angles of hip rotation has suggested that the range of motion in the squat exercise is not large enough to increase strength of the hip adductor muscles, even with hip external rotation. So

although hip adductor muscles specifically may not influence the hip angle measurements that were observed in this study, it is important to note that in the aforementioned previous hip muscle activation study, “all muscle activity was significantly greater in the deepest phase of the squat in flexion and extension regardless of hip rotation,” (Clark, Lambert, & Hunter, 2012; G. R. Pereira et al., 2010), which is where the values for hip angle measurement were taken in this current study. It is likely, therefore, that the muscles at the hip, though probably not the hip adductor muscles, contributed to the hip angle measurements that were recorded at the deepest part of each repetition of the squat.

The results of the knee angle variable were supported by one of the two hypotheses. Although no significant differences occurred between genders at the knee, there were significant differences between the three conditions or protocols. There were no significant differences between first three repetitions and last three repetitions in any of the three protocols as well.

The results of the knee angle variable were notable because they did not parallel the results of the hip angle variable, which saw significant differences between genders as well as between first three repetitions and last three repetitions in one of the three protocols. From a technique standpoint, this suggests that flexion at the knee may not indicate instability or the appearance of fatigue as trunk flexion does. Because the 3x10 protocol and the 10x3 protocol were both significantly different from the 1x30 protocol for hip angle measurements, it is logical to assume that squat depth is affected by the number of repetitions within a set, because both the load as well as total volume were equal between the three protocols. The results of the knee flexion angle did parallel the hip angle in that the 3x10 protocol produced the largest angles of flexion. Further

research is needed, however, to understand these differences in technique variables within the execution of a set-repetition scheme.

Practical Applications

The findings of this study are beneficial to strength and conditioning professionals because it distinguishes different training protocols of equal volume by measures of technique and performance. Training volumes can be broken down in an infinite number of ways, and paying proper attention to the athlete's ability to maintain technique and successfully execute a given training volume in relation to a specific training goal should be a determinant of how that volume is prescribed. The athlete's ability to maintain both proper technique as well as a high execution level of performance is not necessarily based on the prescribed overall total volume, but by how that volume is broken down by sets, repetitions, and rest intervals, and should also take into account the athlete's gender. Therefore, in designing a set-repetition scheme at a given load, the athlete's ability to maintain proper technique should be taken into consideration and should be regarded at high importance in relation to the other acute program variables influencing the program design.

References

1. Abelbeck, K. G. (2002). Biomechanical model and evaluation of a linear motion squat type exercise. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 16(4), 516-524.
2. Baker, D. G., & Newton, R. U. (2007). Change in power output across a high-repetition set of bench throws and jump squats in highly trained athletes. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 21(4), 1007-1011.
3. Chandler, T. J., & Stone, M. H. (1991). The squat exercise in athletic conditioning: A position statement and review of the literature. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 13(5), 51-52, 53, 54, 55, 56, 57, 58.
4. Clark, D. R., Lambert, M. I., & Hunter, A. M. (2012). Muscle activation in the loaded free barbell squat: A brief review. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 26(4), 1169-1178.
5. Cormie, P., McGuigan, M. R., & Newton, R. U. (2010). Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. *Medicine and Science in Sports and Exercise*, 42(9), 1731-1744.
6. Delavier, F. (2003). *Women's strength training anatomy*. Champaign, IL: Human Kinetics.
7. Fleck, S. J., & Kraemer, W. J. (2004). *Designing resistance training programs*. Champaign, IL: Human Kinetics.

8. Hansen K., C. J. (2009). Training loads for the development of lower body muscular power during squatting movements. *Strength and Conditioning Journal*, 31(3), 17-33.
9. Kraemer, W. J., Gordon, S. E., Fleck, S. J., Marchitelli, L. J., Mello, R., Dziados, J. E., et al. (1991). Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *International Journal of Sports Medicine*, 12(2), 228-235.
10. Pereira, G. R., Leporace, G., Chagas, D. V., Furtado, L. F., Praxedes, J., & Batista, L. A. (2010). Influence of hip external rotation on hip adductor and rectus femoris myoelectric activity during a dynamic parallel squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 24(10), 2749-2754.
11. Sanchez-Medina, L., & Gonzalez-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise*, 43(9), 1725-1734.
12. Sato, K., Fortenbaugh, D., & Hydock, D. S. (2012). Kinematic changes using weightlifting shoes on barbell back squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 26(1), 28-33.
13. Sato, K., & Heise, G. D. (2012). Influence of weight distribution asymmetry on the biomechanics of a barbell back squat. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*,
14. Shimano, T., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., et al. (2006). Relationship between the number of repetitions and selected

percentages of one repetition maximum in free weight exercises in trained and untrained men. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 20(4), 819-823.

15. Smilios, I., Hakkinen, K., & Tokmakidis, S. P. (2010). Power output and electromyographic activity during and after a moderate load muscular endurance session. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 24(8), 2122-2131.