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Muscle activation in the loaded free barbell squat: a brief review.

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ABSTRACT

The purpose of this article was to review a series of studies (n=18) where muscle activation in the free barbell back squat was measured and discussed. The loaded barbell squat is widely used and central to many strength training programmes. It is a functional and safe exercise that is obviously transferable to many movements in sport and life. Hence a large and growing body of research has been published on various aspects of the squat. Training studies have measured the impact of barbell squat loading schemes on selected training adaptations including maximal strength and power changes in the squat. Squat exercise training adaptations and their impact on a variety of performance parameters, in particular countermovement jump, acceleration and running speed have also been reported. The purpose of this review is to examine studies that reported muscle activation measured by electromyography (EMG) in the free barbell back squat. Muscle activation of the lower limb resulting from variations of squat depth, foot placement and training status and training intensity have been reported. There have also been studies on the impact of squatting with or without a weight belt on trunk muscle activation. More recently a number of researchers have reported the effect of instability on trunk muscle activation and squat performance. Muscle activation of the prime movers in the squat exercise increases with increases in the external load. Many common variations, such as stance width, hip rotation and front squat do not significantly effect muscle activation.

Key words: resistance training, strength tests, athletic performance

INTRODUCTION

The squat exercise has a long history in fitness training, exercise for rehabilitation and strength training for performance in sport. It is a functional movement which is performed loaded or unloaded by flexing and extending the hip, knee and ankle joints in a manner similar to many movements which occur in daily activity and sport. The squat exercise is regarded as a closed kinetic chain exercise where the force is expressed through the end (length) of the limb while it is fixed to the ground (11).

Variations of the loaded barbell squat are widely used in the physical preparation programmes for athletes in many sports. The primary reasons for this are the functional nature of the squat exercise movement, the ability to overload the muscles during this exercise and the relative safety (9) of the squat when performed in a squat rack or cage. As a consequence, this exercise and a selection of variants have been subjected to research. For example, training studies have measured the impact of barbell squat loading schemes (14) on selected training adaptations including maximal strength (30) and power changes in the squat (29,31,14,18,2). Squat exercise training adaptations and their impact on a variety of performance parameters, in particular countermovement jump, acceleration and running speed (7,34) have also been reported. Kinematic, kinetic and electromyography (EMG) studies have reported muscle activation of the lower limb resulting from variations of squat depth (5), foot placement (24,10,25) and training status and training intensity (26). There have also been studies (36) on the impact of squatting with or without a weight belt on trunk muscle activation. More recently a number of researchers have reported the effect of instability on trunk muscle activation and squat performance (20,21,23,2,3,33,13,27)

The barbell squat was established as a key exercise in the physical preparation of athletes prior to the growing body of scientific evidence describing muscle activation in variations of this exercise. The organic manner in which this research has been conducted and published necessitates a review of the findings as they relate to athletic training and therefore inform practice. Due to; 1) the narrow topic area, muscle activation in the free barbell back squat, 2) the wide range of methodologies used in the studies, and 3) the spread of muscle sites reported a systematic, narrative review method was deemed appropriate. Furthermore, the direction of future research in this area will be more focussed and consolidated.

The purpose of this article is to review the studies (n=18) that investigated the muscle activation during the free barbell back squat and applied variations of this exercise as used in the physical training of athletes for performance. The review does include data from studies that reported muscle activation in the leg extension, leg press, front squat and Smith Machine squat, only where these exercises have been compared to the free barbell back squat.

A PubMed search of the academic literature was performed using the following terms: 'free barbell back squat', 'loaded back squat', 'back squat', 'electromyography', 'EMG', and 'muscle activation', limited to English papers and human subjects. Literature was also sourced from links to related articles, hand searches and the bibliographies of academic papers. The searches retrieved 18 full papers, where muscle activation in the loaded free barbell back squat was reported.

MUSCLE SITES ANALYSED

In all the studies reviewed EMG activity in muscles of the lower limb were measured and reported more than twice as often (56/80) as muscles of the trunk (24/80) (Table 1.). Interest in hamstring and quadriceps activation was the highest than any other muscle group reported; biceps femoris and vastus medialis activation were each reported in 12 of the 18 studies. This reflects the fact that these muscles are traditionally the primary muscles of interest in loaded squat training, hence the interest in factors and variables that may influence muscle activation and therefore training efficacy of the squat exercise.

More recently a number of investigators (27,23,13,3,33,2) have reported trunk muscle activation (TMA) for the loaded squat exercise under different conditions. The trunk muscles reported most frequently are the rectus abdominus (6/18), external oblique (4/18) and various aspects of the erector spinae (8/18). In all the studies reviewed, the measurement of the activation of the muscles of the trunk is used to assess the impact of stability versus instability in the squat.

NORMALIZATION PROCEDURES

One of the challenges with EMG analysis is that the amplitude of the data is highly variable and influenced by a number of factors. Measurements can differ across muscle sites and intra-subject day-to-day fluctuations also contribute to the variability. While it is not the purpose of this article to review EMG normalization procedure, a basic understanding of the process and the procedures used in the studies reviewed justify comment.

One method of accounting for this variation is to normalize the EMG data against a reference value. The most common normalization method is to express the EMG activity under investigation as a percent of the EMG activity during a maximal isometric voluntary contraction (MVIC), usually performed at the start of test session.

The majority of the studies reviewed (36,23,13,33,28,3,12,32,25) used an MVIC procedure to normalize EMG data. In studies with repeated measures within the same individual, mean EMG was reported without normalization (2,27). Recent evidence (1) has been published to support a dynamic method of normalization (i.e. EMG data collected while cycling at 70% peak power) as being more repeatable than MVC. Dankaerts et al (8) also showed that normalization with sub maximal voluntary contractions was more reliable than normalization with MVC when measuring trunk muscle activation. In his recent review Burden (4) states that using a dynamic MVC with the same muscle action is better than an isometric MVC at an arbitrary angle to normalize the EMG for a dynamic test effort.

MUSCLE ACTIVATION AND THE LOADED BACK SQUAT

An inclusion criterion for this review was that the exercise under investigation was the free barbell back squat as this is the most widely practiced version of the loaded squat (12), especially in strength training for athletic performance. Given this popularity it is not surprising that this version of the squat is used in most research where muscle activation is investigated to confirm commonly held coaching theories. A summary of research design and key findings for all reviewed studies is presented on Table 2.

Stance width and hip rotation

It is a long held belief in coaching that by manipulating squat stance width, specific muscle groups in the lower limb can be targeted thereby influencing training adaptation. For example, in track sprint cycling there is a strong belief that stance width in the squat should be equal to the width between the bicycle pedals and that feet should be parallel as they are when pedalling. The two studies (22,24) that measured lower limb muscle activation in three different stance widths for two sub maximal relative squat loads had one common finding; lower limb muscle activation increased as a result of the increase in load. Paoli et al (24) had subjects squat with 0, 30 and 70% 1RM with feet at hip width (greater trochanter width), 150% and 200% of hip width. They reported an increase in activation for all 8 muscles monitored with each increment in load; however the gluteus maximus was the only muscle which had increased activation as stance width increased. These differences were only significant at the lowest loads (0% 1RM) and heaviest load (70% 1RM). McCaw and co-workers (22) also used the 3 stance widths; shoulder width and 75 and 140% of shoulder width and two test loads; 65 and 75% Squat 1RM. On average EMG of the quadriceps (rectus femoris, vastus lateralis and vastus medialis) was 20% higher for the 75% 1RM for all stance widths and phases of the squat compared to the 60% 1RM. Interestingly, stance width did not effect muscle activation of the quadriceps contrary to popular belief. Activation of the adductor longus was 28% greater for the heavier load and was highest during the ascent in the wide stance squat. Similarly, the activation of the gluteus maximus during the ascent was double that compared to the descent.

Pereira et al (25) compared squatting to parallel depth while the hip was in neutral position and rotated to 30º and 50º. Ten subjects performed a 10RM parallel squat in the three hip positions and muscle activity of the rectus femoris and the hip adductors (adductor longus and gracilis) was recorded. Muscle activity of the hip adductors was significantly greater with the rotation of the hips from neutral to 30º and from 30º and to 50º only in the last 30º of flexion to parallel and the first 30º of extension or ascent. Hip rotation did not change activation of the rectus femoris, the main extensor muscle in the squat. All muscle activity was significantly greater in the deepest phase (last 30º) of the squat in flexion and extension regardless of hip rotation.

Extreme stance widths of 40% wider than shoulder width (22) or twice the width of the hips (24) result in greater activation of adductors of the thigh and gluteus maximus. High adductor activation is also increased by turning the feet out or rotating the hips (25). The studies by Paoli et al (24) and McCaw et al (22) demonstrate that activation of quadriceps, the agonist, increases as a result of an increase in external load in the squat. Therefore it may be concluded that if the purpose of the squat exercise is to overload the primary movers then the stance, width of feet and hip rotation, should be dictated by the technical demands of executing the squat safely and to the appropriate or selected depth. These guidelines will vary according to individual physical mechanics and are covered by strength coaching principles. Central to this is ensuring that the vertical travel of the load in the sagital plane remains in the line of gravity. In applied terms this means that from a side view (sagital plane) the vertical path of the bar during the squat is kept close to a perpendicular line emanating from the middle of the foot throughout the range of movement.

There is also evidence (25) that regardless of foot position, activation is highest in the last phase of the descent to parallel and the first phase of the ascent. This means partial or quarter squats will result in reduced muscle activation of the prime movers and therefore arguably produce an inferior training effect in comparison to parallel or full squats. While the loads used in these studies are representative of those used in athletic strength training, it is also common to train at higher relative loads where it would be unlikely that the widest stance widths in these studies would be practical or safe.

Squat depth

A range of squat depths are used practically, however it is generally believed that a squat depth to parallel is the most effective for improving athletic performance (6). This belief is supported by a study (5) where the activation of muscles of the quadriceps, hamstrings and buttocks for squats to three depths; partial, parallel and full with knee angles of 135, 90 and 45^{o} respectively were measured[4].

Caterisano et al (5) used a load of between 100 and 125% body weight, due to the difficulty of standardising the load across the 3 depths, and found that activation of the gluteus maximus increased with the increase in squat depth. Gluteus maximus accounted for 35% mean integrated EMG of the four thigh muscles (biceps femoris, vastus medialis and vastus lateralis) measured in the full squat compared to 17% in the partial squat. A limitation of this study was the selection of the test load as this would have represented very different relative loads for the squat at each depth. For example, a load that may have been a moderately high load for the full squat would have been a light load for the partial squat in the same individual.

Given the findings in the studies looking at stance width (24,22) where an increase in absolute load resulted in increased activation, one would expect that if Caterisano et al (5) had managed to test using a relatively equivalent load for each squat depth, they may well have found a difference in the activation for each depth of squat. A possible solution would be to determine a 1RM for the squat for each depth and then test muscle activation at the same relative sub maximal percentage for each depth.

Wretenberg et al (35) measured the activation of the vastus lateralis, rectus femoris and the long head of biceps femoris in powerlifters (n=6) and weightlifters (n=8) with a combined average 1RM of 200 kg for the full squat. All subjects performed both parallel squats and full squats with the bar in the high position for the weightlifters and low position for the powerlfiters. Mean peak muscle activation for all muscles was higher in the powerlifters for both squat depths, although this was only significant for the rectus femoris. Wretenberg at al (35) found no difference in muscle activation across the two depths of the squat.

The authors suggested that this was due to their greater body mass and absolute mass lifted in testing for the powerlifters. While the average body mass of the powerlifters was 5.7 kg greater than the weightlifters, the powerlifters average full squat 1RM was 100 kg greater than for the weightlifters. This meant that average test load of 65% of the 1RM represented 123% percent of the body mass the weightlifters compared to 190% for the powerlifters. The average test load for the powerlifters was 65 kg heavier than that used for the weightlifters while the body mass difference was only 5.7 kg in favour of the powerlifters. Hence, the greater overall activation found in the powerlifters is probably explained entirely by the greater absolute loads lifted by them compared to the weightlifters, rather than the difference in body mass. However, if we ignore the comparison between powerlifters and weightlifters the pooled data indicate that at a relative submaximal load there was no difference in muscle activation of the muscles of the upper leg, including the prime movers, between squatting to parallel or full depth.

The real question in applied strength training for performance in sport is whether loaded squats performed to different depths at the same relative load result in different muscle activation and therefore different training stimuli. By using the same absolute load Caterisano et al (5) failed to answer this question, however their results did give some indication that greater depth increases activity of the gluteus maximus. In the study of Wretenberg et al (35) there was no difference in activation between parallel and full squats for well trained subjects at a sub maximal load. Pereira (25), however, divided the eccentric and concentric movements into 30^{o} segments and found that activation was highest for the deepest segment of both phases in a 10RM parallel squat. This suggests that depth of squat does impact on muscle activation. The results of the study by Wretenberg et al (35) suggest that absolute load lifted per kilogram body mass impacts on activation regardless of the depth of the squat. Both these studies focussed exclusively on the muscles of the thighs; it would be of significant interest to assess the impact of squat depth on TMA.

Weight belt

The use of a supportive abdominal belt or weight belt is common in heavy lifting in weight training and in manual handling tasks. Zink et al (36) conducted a study to measure the impact of squatting at a high relative load (90% 1RM) with or without a weight belt on join kinematics and muscle activity of the following muscles; vastus lateralis, biceps femoris, abductor magnus, gluteus maximus and erector spinae. There were no significant differences for mean EMG and time to peak EMG for any of the muscles in the concentric or eccentric phase of a parallel squat at 90% 1RM with a weight belt compared to no weight belt. Squatting with a weight belt, however, was significantly faster, for the total movement, and for each phase separately, than when performed without a weight belt.

It appears that when stability is enhanced by the use of a weight belt, squat performance in terms of the velocity of movement and bar kinematics is improved. The authors of this research concede that while this may possibly represent an opportunity for the development of more work and power, at the same time this may undermine the training effect resulting from slower and more stable training.

External load

The loads used for the free barbell squat tests in the studies reviewed ranged from 0-90% of 1RM and included loads determined as a percentage of body mass and according the repetition maximum method (Table 2.). Wretenberg et al (35) conducted a study to assess the effect of squatting with the high bar position compared to a low bar and whether this was different for full squats compared to the parallel squat. He used highly trained subjects that performed squats at 65% of their full squat 1RM. The loads reported were representative of the sub maximal loads commonly used in strength training for the development of dynamic athlete performance. Two research groups used near maximal loads of

90% of 1RM. Zink et al (36) used parallel squats at this intensity to assess the impact of a weight belt versus no weight belt on muscle activation. Nuzzo at al (23) used a range of loads; 50, 70 and 90% of 1RM in the squat and deadlift to assess muscle activation in comparison to 3 stability ball exercises.

A methodological challenge facing investigators comparing two or more variations of the squat is how to determine a relatively equal test load for each variation to ensure that dependant variable is the variation of the squat and not the load. Wretenberg et al (35) and Caterisano et al (5) failed to account for this in their studies comparing squats at different depths. The former used a load of 65% of the 1RM for the full squat for both test depths; full and parallel squat. Caterisano (5) overcame this by selecting a test load which the subjects could complete for the three squat depths with correct technique. If we assume that squats performed to different depths each represent a different physical challenge, then the test load for each depth should be based on the same sub maximal relative percentage calculated from the maximal ability for each depth. Wilk (32), Pereira (25) and Schwanbeck (27) overcame this challenge by using 12, 10 and 8 repetition maximum respectively, for each of the test variations. This is achieved by determining the maximal load that the subject can complete for the given number of repetitions, and in Schwanbeck's (27) study this was determined for the free bar back squat and the Smith machine back squat. Possibly the most accurate theoretical method is to determine the 1RM for each of the squat variations and then calculate the sub maximal test load for each as a percentage of the maximum (1RM). Gullett et al (12), in a biomechanical comparison for the front and back squats, tested 1RM for each of these exercises and McBride (21) determined both stable and unstable squat 1RM.

There is an indication that increments in load for the same squat variation impacts on muscle activation (24,22,35). Therefore, the test loads should be relatively equal if the research question is whether muscle activation is effected by a specific squat variation.

Instability

While the squat is an established method of developing strength through the whole body, evidence that it is an effective method of developing core stability or trunk strength is relatively new (23,13).The concept of using instability as part of the protocol, whether it be for fitness for health, conditioning for sport, or exercise for rehabilitation, is based on the principle of core stability (19,15). Initially the recommendations for core stability training were to isolate the contraction of the deep stabilizing muscles of the trunk (16,17). The use of unstable training surfaces was introduced in the belief that this would increase the challenge placed on these stabilizing muscles. As a consequence a number of studies (20,21,33,2) have been conducted to assess the impact of instability during the squat on muscle activation. There have also been studies comparing muscle activation in the squat performed on a stable surface and selected unstable trunk exercises (23,13). For example, Anderson and Behm (2) reported greater muscle activation in the key muscles of the thigh and trunk when performing squats on two balance discs compared to in a Smith machine. Hamlyn and co-workers (13) compared the TMA during squats and deadlifts at 80% of 1RM to 2 trunk strengthening exercises performed on an unstable surface. The results showed that first, the squat produced significantly greater activation of the lower sacral erector spinae than the other three exercises and second, the deadlift resulted in greater activation of the upper lumbar erector spinae. Nuzzo et al (23) showed that trunk muscle activation in squats and deadlifts was greater than or equal to that found in three stability ball exercises in male subjects with an average squat 1RM to body mass ratio of 1.78[21]. The latter two groups (23,13) concluded that upright free weight training on a stable base, was effective in challenging and developing trunk stability through effective TMA. Finally, McBride et al (20,21) assessed the impact of instability on force and muscle activity (vastus lateralis, biceps femoris and erector spinae) in both isometric(20) and dynamic squats (21). They found that instability in an isometric squat significantly impaired force and power capabilities without an advantage for muscle activity. Unstable squat 1RM (83 kg) was significantly lower (44 kg) than the stable squat 1RM (128 kg) and muscle activity at the same relative loads was equal or less in the unstable trial compared to the stable squat. McBride (20,21) concluded that stable squats were more effective in producing force, power and muscle activation, including TMA, than unstable squats.

Anderson and Behm (2) assessed the parallel squat under three conditions of stability; in a Smith machine, with a free bar and with a free bar standing on balance discs. Three loads were tested for each condition; body mass, 29.5 kg and 60% of body mass. They found that muscle activation in the muscles of the legs and the trunk stabilizers was highest during the most unstable squat with the free bar on the balance discs. They also report an increase in activation with the increase in load for all muscles apart from the hamstrings and abdominal stabilizers. Furthermore, they showed that EMG activity was highest during the concentric movement compared to the eccentric phase for all squat variations in the following muscles; soleus, vastus lateralis, biceps femoris, upper lumbar erector spinae and abdominal stabilizers. Duration of activity of the abdominal stabilizers during the transition between descent and ascent was significantly higher for the unstable squat.

While the purpose of many of the studies referred above was not primarily to measure and describe TMA in the loaded squat, they all showed that this exercise is an effective method of challenging the trunk stabilizers. There is also evidence that the introduction of instability impairs force and power production in the squat without necessarily increasing TMA.

Acute fatigue

Strength training in the practical setting is usually performed with a certain amount of acute muscular fatigue and as such the effect of this on muscle activation is of interest. Smilios et al (28) measured the power output and EMG activity during a moderate load muscular endurance session (4 sets of 20 repetitions at 50% 1RM). They measured power output and EMG in a set of 4 repetitions at a light load (40% 1RM) and heavy load (80% 1RM) immediately before and after the endurance sets and again at 30 minutes after this. The subjects, who were resistance trained males with an average squat 1RM of 129 kg, performed the parallel back squat. Power output was significantly reduced in set 3 and 4 of the muscular endurance protocol while EMG activity increased from set to set for the quadriceps but not the biceps femoris muscles.

Average power immediately after the endurance work was reduced by 14 and 21% for the power tests at 40 and 80% 1RM. These improved but remained 8 and 14% lower for the two power test loads respectively after 30 minutes recovery. Average EMG activity at 3 and 30 minutes post endurance effort was decreased by 12 and 14% for the 40% 1RM power tests and 6 and 10% for the 80% 1RM power tests. Biceps femoris EMG activity did not change in the 40 and 80% 1RM power tests performed at 3 and 30 minutes after the endurance protocol.

The authors hypothesise that the increase in EMG activity of the agonists during the endurance sets, despite the loss of power across the sets, was due to a increase central drive to maintain work though increased motor unit recruitment (28).

Front versus back squat

A number of variations of the loaded barbell squat are used in programmes for the development of athletes. The two most common versions are; the back squat where the bar is carried across the back of the shoulders, and the front squat with the bar across the front of the shoulders. There is a belief that this technical difference produces a different physical challenge and therefore training effect. This would be reflected by a difference in activation of the primary muscles across these two squats.

Subjects performed two trials of 3 repetitions for each squat variation; front and back squat at 70% of the 1RM (12). The 1RM scores were determined for each squat on two separate prior occasions. During the investigative efforts EMG activity for the following muscles was recorded; rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendonosus, erector spinae. These authors found no difference in muscle activity across the two squat variations; however they did show that average muscle activity was significantly higher during the ascent than the descent for the six muscles that were monitored.

Using a test load of 70% of 1RM for each of the two squat variations meant that the absolute load lifted was 61.8 ±18.6 kg for the back squat and 45.8 ±14.1 kg for the front squats. Muscle activity was not found to be different for the front squat compared to the back squat at 70% 1RM. The common belief in coaching is that these two exercises offer different physical challenges primarily due to the difference in the position of the load in relation to the line of gravity throughout the movement. It is possible the submaximal load used in this experiment failed to elicit this difference; however this is surprising given the low level of squat training exposure reported for subjects in this study.

Free bar versus Smith machine squat

Schwanbeck et al (27) compared a free bar squat to a squat performed in a Smith machine to assess muscle activity in the legs (tibialis anterior, gastrocnemius, vastus lateralis vastus medialis, biceps femoris), and in the trunk (lumber erector spinae and rectus abdominus). The test load for each exercise was determined as an 8 repetition maximum (8RM) as this load represented a common method of determining training intensity for athletic conditioning. This method resulted in the test loads being 14-23 kg heavier for all subjects for the Smith machine squat than the free bar squat.

Despite this, the free bar squat elicited 43% higher average activity for all muscle groups than the Smith machine squat. Closer inspection of individual muscles shows that only three leg muscles had significantly higher activation in the free bar squat, gastrocnemius (34%), biceps femoris (26%) and vastus medialis (49%) compared to the Smith machine squat. The muscles of the trunk followed this trend but failed to reach significance. The authors claim that this was due the low number of subjects (n=6) in the study.

Squat versus leg extension and leg press

Wilk et al (32) compared the muscle activity of the quadriceps and hamstrings in three exercises; the squat, the leg press and the leg extension. They found that the highest activation occurred in the closed kinetic chain squat compared to both the leg press and leg extension and that this was significant for the vastus lateralis, medial and lateral hamstrings. The maximal activation of the quadriceps presented at a knee angle between 88-102º during the concentric phase. For the hamstrings the peak activation occurred between 60-74º knee flexion also during the concentric movement. This confirms the belief that squatting with a free external load represents a greater neural challenge to the prime movers than exercises that isolate the limb as in the leg press and leg extension exercises. It has been suggested that this may be due to the increased demand to stabilize the free bar load in the squat, however this would not necessarily present as increased EMG of the prime movers but rather the stabilizing muscles. The higher activation in the free bar squat may well be due to the fact that the load is lifted vertically against gravity compared to during the machine leg exercises where the load is applied via levers.

TRAINING STATUS AND MUSCLE ACTIVATION IN THE SQUAT

All the studies reviewed so far have compared muscle activation for variations of the back squat in a range of subjects including those untrained, moderately trained and well trained in the back squat and of both genders (Table 1.). Pick and Becque (26) reported muscle activation of two primary movers in the squat; vastus lateralis and vastus medialis for a back squat set to failure at 85% 1RM in trained (1RM = 184 kg) and untrained male subjects (1RM = 120 kg).

They found that the trained subjects (10 ± 0.9 repetitions) completed significantly more repetitions at 85% 1RM than the untrained group (7 ± 0.7 repetitions) and therefore demonstrated greater relative submaximal lifting capacity. Muscle activity was recorded during 1RM testing and EMG during the repetitions to failure was reported as a percentage 1RM EMG. This was higher in both the 1RM test and the repetitions to failure for the trained compared the untrained group for both the individual muscles and combined data. Of particular importance was that this difference was significant towards the end of the test, at 80 and 100% of repetitions to failure.

The study is characterised by the high relative back squat 1RM of 1.6 of body mass reported for an untrained group and the fairly marked difference in body mass between the two groups; the untrained group (74.8 kg) was 15.1 kg lighter than the trained subjects (89.9 kg). This meant that the test load difference on average was 54 kg heavier for the trained group than the untrained group. It appears that the difference in absolute load may explain the difference in the EMG measured during both the 1RM test and repetitions to failure.

SUMMARY

- Increasing stance width and hip rotation increase activation of the adductors and gluteus maximus and not the primary movers of the squat exercise.

- Muscle activation is not different in squats to varying depths at moderate loads. Within a parallel squat it appears that activation is greatest in the last phase of the descent and the first phase of the ascent.
- Activation of the muscles of the legs and trunk increase as a consequence of increases in absolute external load.
- It is important to use equal, relative sub maximal test loads calculated from a maximum for each specific squat if the aim is to measure the differences in activation between two types of squat or squat variation such as depth of squat.
- Muscle activity is not influenced by the use of a weight belt.
- Squatting on an unstable base increases the activation of the leg and trunk muscle but it impairs force and power production in this exercise.
- The squat at moderate external loads is a more effective method of activating the trunk stabilizers compared to other instability trunk exercises.
- Acute fatigue in a sub maximal squatting task results in increased muscle activation corresponding to a loss of power across the task. Power and EMG is reduced for up to 30 minutes in a low and high load power test.
- Muscle activation in muscles of the leg, thigh and trunk is the same in the front and back squat at 70% of 1RM.
- Free bar squat elicits higher overall EMG than squats in a Smith Machine, leg press and leg extension.
- Highest activation occurs in the concentric phase of the squat.

- In sets to failure at 85% 1RM trained subjects completed significantly more squat repetitions than untrained subjects and produced higher muscle activation in both the 1RM test and the set of repetitions to failure.

PRACTICAL APPLICATIONS

The free barbell back squat is superior to more supported squats performed in a Smith machine and closed kinetic chain leg exercises in activating the prime movers. There is also evidence that the level of activation of the agonist muscles is increased with the increase in absolute external load. It is also clear that the many technical alterations to the squat, including stance width, hip rotation and the use of a weight belt do not enhance the activation of the prime movers. At moderate loads even fairly significant alterations, as found in the front squat, do not alter the activation of the prime movers compared to the back squat. The data suggests that increases in load are largely responsible for increased activation. Also the concentric phase produces the highest activation and within the eccentric phase, the last third of the descent to parallel elicits the highest activation. Therefore, if the aim is to increase the strength of the known prime movers, the technique should ensure effective completion of the squat to parallel at the desired load.

At loads of greater than 50% of 1RM the back squat to parallel is an effective method of developing trunk activation and therefore arguably trunk stability. The application of the loaded squat for the development of trunk and core stability is an area for future research.

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